Climate Systems

National Environmental Science Program

Physical Climate Risk Assessment in Business and Finance

A handbook for climate scientists

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Executive Summary

This handbook has been developed to support climate scientists as they navigate the growing intersection between climate science and the business and finance sectors. As climate-related financial disclosures become mandatory for large organisations in Australia, the demand for credible, science-informed physical climate risk assessments is increasing rapidly. These requirements will also influence smaller organisations through procurement, insurance, lending, and supply-chain expectations, making an understanding of climate risk relevant across the entire economy.

For climate scientists, this shift creates a significant opportunity to contribute expertise where it is urgently needed. Businesses and financial institutions are now expected to assess how future climate conditions (such as heat extremes, storms, fire weather, flooding, or sea-level rise) may affect assets, operations, and strategic decision-making. Yet many organisations are still developing the capability to interpret climate information and connect it meaningfully to financial risk. The language, assumptions, and analytical approaches used in finance often differ markedly from those used in climate science, which can make collaboration challenging without shared reference points.

This handbook aims to provide such reference points. It offers an introduction to the concepts, frameworks, and terminology that underpin risk assessment in business and finance and compares them to corresponding thinking in climate science. Risk in business context has a long-established history but is adapting quickly as climate risk becomes a mainstream consideration. Understanding the space sufficiently to contribute to the development of physical risk assessment approaches requires engaging with ideas that may be unfamiliar or used differently in scientific contexts.

Physical climate risk assessment is, by nature, interdisciplinary. It requires linking climate drivers and hazards to exposure, vulnerability, adaptation potential, and ultimately financial consequences. No single field can do this alone. Climate scientists bring essential insight into extremes, uncertainty, regional processes, long-term scenarios, and the limitations and appropriate uses of climate projections. These contributions are critical to ensuring assessments are scientifically grounded, transparent, and fit for purpose.

We encourage you to keep this handbook close at hand. It is designed as a practical, companionable guide to help you navigate a world where climate science and financial decision-making increasingly converge. By engaging with these concepts, climate scientists can help shape stronger, more credible approaches to physical climate risk, supporting better decisions for organisations and for society as a whole.

Aims

This report aims to help climate scientists who are interested in engaging with physical climate risk assessment (PCRA) in finance spaces, including in the finance sector, the broader business sector, and in finance-related parts of government. We focus particularly on climate related financial disclosures (CRFD), which are currently being phased-in across many jurisdictions globally, and present an opportunity for climate scientists and experts to engage with decision-making in new and potentially very impactful ways.

PCRA is a highly complex and inherently interdisciplinary process (Ranger et al., 2022), with many potential pitfalls due to different perspectives across disciplines/professions. With this report, we hope to give scientists a head start in understanding the PCRA space, as well as the aims, values, and worldviews of the finance professionals and other people from related disciplines they may be collaborating with.

We believe PCRA is a frame that could lead the business sector to clearer understandings of how climate change is likely to impact their operations, and hopefully spurring them to action. We hope that this report gives climate scientists an advantage in conveying their knowledge, by helping to build an understanding of the methods, language, and ways of thinking common in finance spaces. We also hope to help scientists avoid potential pitfalls by providing insight into some of the complexities of climate-related financial risk assessment and the interdisciplinary collaboration required to do it well.

What's in this document

This explainer is a bit unusual. As climate scientists, we are accustomed to providing information to industry audiences, and a wealth of information exists to help finance and corporate professionals interpret climate data. But information flow is never one-way, and understanding your audience and collaborators is critical.

Accordingly, this explainer aims to provide a concise but reasonably comprehensive overview of business and finance sector concerns and understandings, and how they interact with those of climate scientists. Some key issues are captured in Fig. 1, which is designed to give an idea of the diversity and complexity of issues that are commonly involved in climate risk assessment. Many of these issues are explored in detail throughout the rest of this report.

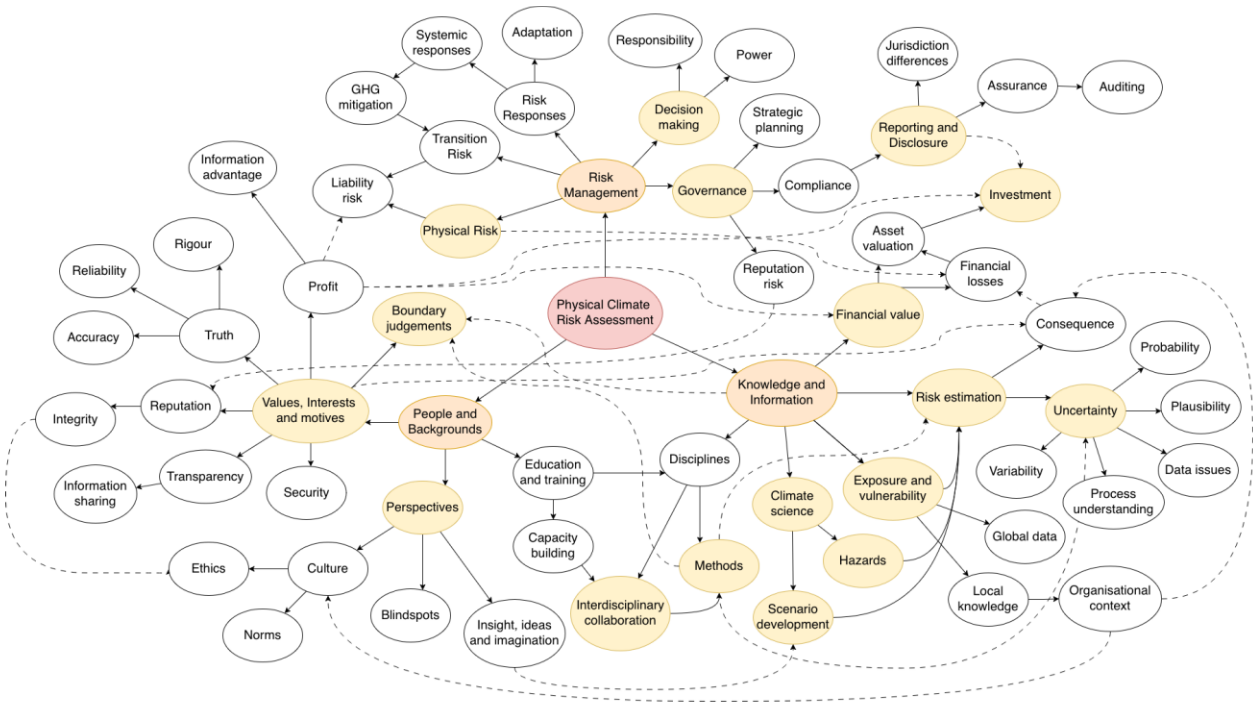

Figure 1: A mind-map of some issues in the PCRA space, as identified by the authors, that contribute to the complexity of the physical climate risk assessment. Some of the key issues discussed in this report are highlighted.

The physical climate risk space is highly complex, with many important interacting considerations, from details of analysis methods to broader institutional contexts. Each of these issues will be of different importance from different perspectives, and figuring out which are important to your collaborators or audience is important if you want your knowledge to have impact.

Disclaimer

PCRA in the finance space is a highly interdisciplinary and extremely complex emerging field. As such, it's not possible for any one person to have a comprehensive and deep understanding of the whole space. This report is an attempt to produce a high-level overview that touches on most of the critical aspects of the field, and particularly those where finance and science diverge. We have consulted with many people working in or around the physical risk assessment space, from multiple academic disciplines, including climate science, accounting studies, and behavioural science; and from various parts of industry and government. Report contributors are predominantly working in Australia, and so most examples provided are from an Australian context, but we have tried to keep the content internationally relevant. This report is inherently incomplete and imperfect, but it provides some entry points and signposts for the space that we hope can be useful.

List of Common Acronyms

APRA: Australian Prudential Regulation Authority

ASIC: Australian Securities and Investments Commission

ASRS: Australian Sustainable Finance Roadmap

ASSB: Australian Sustainability Standards Board

CDSB: Climate Disclosure Standards Board

CRFD: Climate-Related Financial Disclosures

ERM: Enterprise Risk Management

ESG: Environmental, Social and Governance

FSB: Financial Stability Board

G20: Group of Twenty (intergovernmental economic forum)

GFC: Global Financial Crisis

IASB: International Accounting Standards Board

IFRS: International Financial Reporting Standards

IIRC: International Integrated Reporting Council

ISSB: International Sustainability Standards Board

NCRA: National Climate Risk Assessment (Australia)

PCRA: Physical Climate Risk Assessment

TCFD: Taskforce for Climate-Related Financial Risk Disclosure

TNFD: Taskforce on Nature-related Financial Disclosures

Contents

1. Introduction

What's in this section

- What climate-related financial risk is, and why it matters
- Why physical risk in particular is important
- The purpose of Climate Related Financial Disclosures
- Why the problem has no simple solutions

Key take-aways

- Climate-related financial risk is the possibility of climate-related hazards (both acute and chronic) impacting businesses and financial transactions.
- Climate Related Financial Disclosures (CRFDs) are financial reports designed to reduce the possibility of undisclosed climate-related risks causing financial market instability and economic collapse.
- Physical risk is the component focussed on translating climate impacts into financial figures.
- Physical climate risk assessment (PCRA) is important as it allows business and finance to understand climate risks in their own language (and they have a lot of power to instigate climate action)

1.1 Why climate-related financial risk matters

Climate research has been influencing policy via the UNFCCC, the IPCC, and governments at all levels (national, state and local), through risk assessments, adaptation projects, and regulations. Practitioners working in the intersection between climate science and policy are familiar with these pathways, and understand how they can be managed for successful outcomes. Until recently there has been much less focus on linking climate science to the business sector (or private sector), and less understanding of how to do this successfully.

The business sector is large. In OECD countries, governments (the public sector) make up only 18% of total employment (OECD, 2025), most of the rest is the business sector. This means that the sector has significant decision-making power over a large fraction of all human activities. The finance sector, besides making up a substantial fraction of the business sector (20-25%, see Ross, 2024), provides support for business (and for government) activities via credit, insurance, and investment. As such, they can have substantial influence over major business and government projects. Perhaps as a result of this, financial thinking and approaches to decision-making are wide-spread across business and many parts of government. But financial professionals need a clear understanding of risks in order to make good financial decisions.

For more than two decades in the business sector, climate change has primarily been framed as a sustainability matter, focused on how businesses impact the climate (KPMG, 2022). In recent years, this framing has evolved to include organisational dependence on the climate, highlighting the financial risks climate change poses to organisations (Summerhayes, 2017). In response, regulators across most major national economies are mandating climate-related financial risk disclosures (CFRD)[1], which require all large businesses to report on investment-relevant climate-related risk information (see the History of climate risk disclosures appendix for more details). As a result, the finance sector and much of the business sector are beginning to pay significantly more attention to climate risk. Unfortunately, many in the sector struggle to use climate information well, because it is often presented in ways that do not readily align with finance needs, methods, and understandings (see sections 4. PCRA Requirements and 5. PCRA methodologies).

Now more than ever there is a need for climate scientists to engage with the context of finance, and help bridge the gap between scientific understanding of climate change and decisions being made in the finance sector, the business sector, and government. Meaningful collaboration between financial and corporate actors and climate researchers requires mutual understanding of each other's drivers, incentives, constraints, and professional cultures (see 6. How do different disciplines think about risk?). Only by fostering this shared understanding can we ensure that scientific rigour is upheld, while providing risk managers executives with the decision-relevant information they need.

1.2 What is climate risk?

For the purposes of this document, **risk** refers to *the potential of adverse consequences* (IPCC, 2022). Critically, this implies **uncertainty**[2], and **consequence**, which in this

[1] As of February 2025, of 169 jurisdictions surveyed, 161 have made a commitment to the IFRS standards, 148 require IFRS-aligned reporting for all publicly listed companies and financial institutions, accounting for over 45% of total GDP from those jurisdictions surveyed. A further 13 have partial integration with IFRS. The remaining 8 (including China, India, and the USA) have national standards that are not based on IFRS, but are substantially aligned (IFRS, 2025b).

[2] Uncertainty may be captured via probability, plausibility, or in other ways, see 4.2.5 Capturing uncertainty. "Uncertainty" can also mean different things in science and finance, see Interpretations of Uncertainty in Section 6.2.4 for details)

context entails some kind of **impact** on a system that results in a loss of **value** (which may be social, economic, ecological, etc.).

Broadly speaking "climate risk", or "climate-related risk", refers to any risk related to climate change. We note that some sources include the potential for positive outcomes in their definition of risk, but for the purposes of this document we restrict our focus to negative outcomes, and refer to potential positive outcomes as "opportunities" (IPCC, 2022). Risk assessments can be used to identify both risks and opportunities, often using similar approaches, but we also note that physical risk is primarily associated with risk and not so much with opportunities (TCFD, 2017). In order to keep the scope of this document constrained, we limit our focus to (negative) risks.

Climate-related financial risk is a broad framework for considering the impacts presented by anthropogenic climate change or responses to it, in a business context, focusing primarily on financial value. This approach to considering climate change developed as part of the ongoing response to the risk-induced 2008 Global Financial Crisis (GFC, see the History of climate risk disclosures appendix for more details).

Generally, climate-related risk is split into three key domains (Carney, 2015; TCFD, 2017):

- **Transition Risk** is the risk associated with transitioning to a clean energy economy. This includes:
    - Exposure to **regulatory** or **market** changes that disadvantage fossil-fuel-dependent businesses,
    - Risks of **technological** obsolescence and stranded assets, and
    - **Reputational** risks linked to perceived inaction or misalignment with climate goals.
- **Physical Risk** is risk that accounts for the *impacts* of climate change.
    - Physical risk is often split into **acute risks**, which covers event-based natural hazards such as fires, storms, and droughts, and **chronic risks**, such as temperature or precipitation distribution shifts, or inundation due to sea level rise.
    - This includes everything from **direct risks**, through to **systemic risks** (see 3.4 Degrees of risk: direct to systemic).
- **Liability risk** is the risk of potential legal claims by those seeking compensation for harm or negligence. For example, this might include:
    - Compensation claims for physical risk related loss and damages from entities responsible for contributing to anthropogenic global warming.
    - Claims against entities whose negligent operations exacerbated physical risk (e.g. powerlines causing wildfires).

- Decision-makers failing to adequately assess or manage risk may also be exposed to liability risk (e.g. via fiduciary duty, see 2.5 Why does business care about climate risk?).

1.3 Why focus on Physical Risk?

This explainer focuses on **Physical Risk**, for a number of reasons. Firstly, transition risk and physical risk have quite distinct knowledge bases, and involve expertise from different domains of business and academia, and different assessment approaches, so it makes sense to approach the topics separately. In particular, physical risk is more focused on climate hazards and impacts, and so is more closely related to the work of many climate scientists.

Secondly, transition risk assessment is an older and more well-developed field. Costing of transition-related activities (e.g. emissions mitigation) has been possible for a long time. Physical climate risk is a relatively new concern for much of the private sector (particular exceptions being reinsurers and some insurers and banks), and many businesses are only just starting to incorporate considerations of physical risk into their risk management processes and financial reporting, often as a result of incoming mandatory reporting requirements.

The increasing interest in *physical* risk in the private sector is important. While businesses have long been able to account for the costs of acting to mitigate climate change (transition risk, broadly speaking), emerging PCRA methodologies are finally beginning to allow businesses to account for the other side of the scales - the costs of *failing* to mitigate climate change.

1.4 What is the purpose of physical climate risk assessment?

The primary purpose of understanding risk is to help organisations avoid or minimise future losses. Physical climate risk assessments (PCRA) integrate information from climate science into relevant risk assessment processes.

PCRA is useful for decision-making and operational risk management at multiple spatial and temporal scales, from multi-year organisation-wide strategic planning, to asset-level adaptation planning. This is particularly true for large organisations, such as governments and corporations, who need the best available information about the future in order to make optimal decisions about resource allocation (for example, a state government trying to optimally allocate climate adaptation funding across regions and communities that are expected to be differentially affected by flooding, wildfires, storms, and drought). PCRA also provides one of the foundations for climate-related financial risk analysis and climate-related financial disclosures (CRFD).

It is important to note that PCRA is not just a sub-discipline of climate science, nor of finance or risk management. PCRA incorporates elements from each field (and many others, see 4. PCRA requirements), but will ultimately need new approaches and new understandings that expand on those contributions, and will potentially develop as a distinct transdiscipline (see 7. Interdisciplinary approaches).

One key distinction that is important for climate scientists to recognise is that risk management deals with uncertainty quite differently to science. Science tends to focus on Type II errors (false positives), in an effort to avoid making overly certain statements, and when it does make uncertain statements it is very concerned with including caveats around the uncertainty. Risk, on the other hand, is primarily concerned with Type I errors (false negatives), because a risk that is underestimated could plausibly be an existential problem for an organisation, while a risk that is over-estimated and over-mitigated may be costly, but is unlikely to be an existential threat. This can cause misunderstandings, and is explored in more depth in 4.2.5 Capturing uncertainty and 6.2.4 Understandings of risk and uncertainty).

1.5 What is the purpose of climate-related financial disclosures?

Key take-aways

- CFRDs aim to reduce financial system instability, by providing better risk information in financial reporting, which can be used to improve investment decisions

CRFDs are aimed at reducing climate-change induced financial instability and the risk of economic collapse. One of the primary aims of government is to keep society running smoothly, and one major component of this in a western capitalist democracy is ensuring market stability and reducing the risk of financial collapse (CFR, 2019a). After the GFC in 2008, which was substantially caused by over-investment in highly risky sub-prime mortgages, one of the major responses by the G20 global economic forum was to institute the Financial Stability Board (FSB). The FSB's primary focus is promoting international financial market stability.

Risk disclosure in publicly available general-purpose financial reports (e.g. annual reports) is one of the primary tools to that end. Disclosures are used by investors in determining their investment choices, including for private investments, stock trading, government bonds. Banks may also use them when deciding when to offer credit and loans.

In 2015, the FSB and the G20 instituted the Taskforce for Climate Related Financial Disclosures (TCFD), which focussed on improving the disclosure of climate-related risks, to allow for better informed investment decision-making. The TCFD released their first recommendations report in 2017 (TCFD, 2017). This has led to the development and implementation of accounting CFRD standards across several jurisdictions (see the History of climate risk disclosures appendix for more details).

1.6 Problems and pitfalls in physical climate risk assessment

Key take-aways

- Physical risk, PCRA, and the interdisciplinary collaborations required to produce them are extremely complex, and need to be approached with care.

Physical climate risk is a complex concept. The system of interest includes aspects of the physical climate, the biosphere, and human systems that range from physical infrastructure to markets and state economics, healthcare and tourism, each with their own disciplines or professions with diverse foci and decision making processes (see 4.2.3 Boundary Judgements). Each of these sub-systems is also made up of a multitude of moving parts, each with complicated relationships with other parts. All of which makes physical risk about as complex as any problem ever gets. In order to understand the risks to these systems, we need knowledge from a diverse array of the physical and social sciences, and we need to collaborate with people working on the problem from entirely different perspectives.

This process of assessing risk is also complex, and there are many possible problems and pitfalls that might be faced during collaboration. These include things as simple as terminology clashes (see 6.3.1 Linguistic uncertainty, terminology, and language barriers), differences in needs and expectations (see 6.1. Aims and needs: Who wants what, and why?), different methodological approaches which need clear explanation for less technical audiences (see 5. PCRA methodologies), and different approaches to dealing with uncertainty (see 6.2.4 Understandings of risk and uncertainty), all of which can confound our attempts to share meaning effectively.

There are also issues of ethics and governance. Bad players exist in every domain - the financial sector semi-regularly hits the news with stories of fraud or exploitation[3], and scientific fraud is not a rare occurrence[4]. Solving these problems is outside the scope of this report. This report assumes good intent from all parties, and aims to help solve problems within that frame.

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[3] See e.g. https://corporatefinanceinstitute.com/resources/accounting/top-accounting-scandals/
[4] See e.g. https://en.wikipedia.org/wiki/List_of_scientific_misconduct_incidents

1.7 The focus and structure of this document

The considerations explored so far in this section help to define the framing and focus of the rest of this report, which is **physical climate risk in financial spaces**. Our rationale for this focus is that:

- We focus on financial thinking because it is a dominant frame for large-scale decision-making across business and government.
- We see the finance sector as a key player that is intricately entangled with broader business and government.
- We see CRFDs as a current and critical frame for engaging business in particular, and
- We see PCRA as a key avenue for climate scientists to contribute to the process and have influence on large-scale decision-making.

The structure of the document is:

- 2. Who cares about Climate Financial Risk? provides an overview of the organisations that interact with PCRA and CRFD.
- 3. Business and finance perspectives on risk provides an overview of risk assessment and management in business and finance.
- 4. PCRA requirements provides an overview of common user needs for PCRA
- 5. PCRA methodologies provides an overview of some of the key issues, considerations, and pitfalls involved in designing and implementing a PCRA methodology.
- 6. How do different disciplines think about risk? discusses differences in aims, values, and world-views between different disciplines involved in the space (focussing in particular on finance and science), with a view to minimising cultural clashes in interdisciplinary collaborations.
- 7. How to do interdisciplinarity well provides a high-level overview of some issues with and approaches to interdisciplinary collaboration.
- 8. Conclusions and Motivation provides some concluding comments.

2. Who cares about Climate Financial Risk?

What's in this section

- Overview of key sectors and their relationships to PCRA and CRFDs
- Why the finance sector, and financial thinking are important
- How the business, finance, and government sectors interact

Key take-aways

- There are many different types of organisations in the finance sector, broader business sector, as well as government regulators and other players.
- Each organisation has different aims and objectives, and different modes of thinking. Understanding these differences can be important when collaborating with industry partners.

All sectors of the economy are exposed to physical climate risk, albeit in different ways. Some business sectors, such as agriculture, energy, construction and infrastructure are particularly exposed to direct impacts (Deloitte, 2022). The finance sector, and particularly institutional investors, which have diverse financial interests in most other economic sectors, is mostly exposed in a more indirect and systemic way (see 3.4 Degrees of risk: direct to systemic). Finance institutions are involved in most other sectors by way of financing (e.g. investments and loans, see 3.3.1 Financial Assets). As such, the finance sector is an important touchpoint between climate science and the broader world of business and economics, and a key focus of this and the following sections.

CRFD standards are coming into force in multiple international jurisdictions (see Appendix: History of climate risk disclosures for details). These commonly apply to large and/or publicly listed companies, including financial institutions, as well as governments. CRFDs are designed to be used by investors and creditors for better informed financial decision-making. Fig. 2 shows the major parts of the economy that are involved in CRFDs, and some of their key interactions. The rest of this section provides an overview of some of these key players, and their motivations.

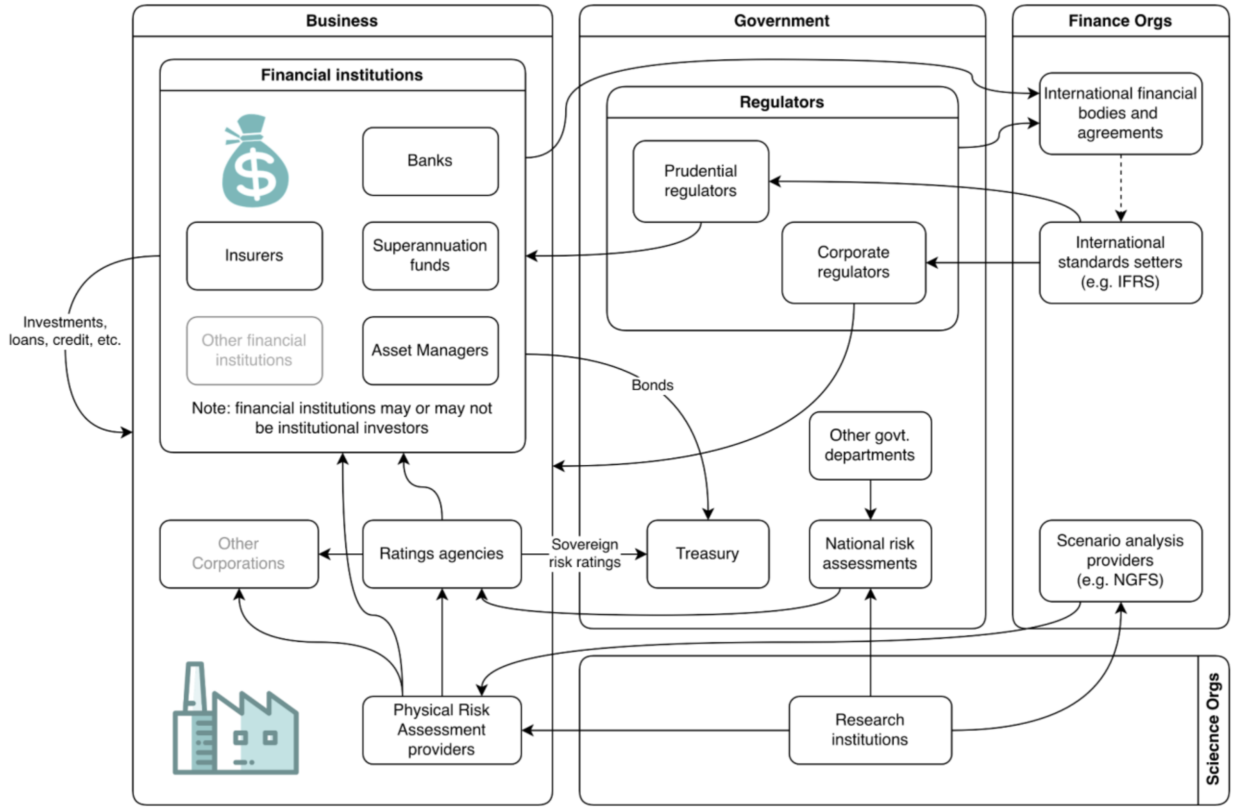

Figure 2: Some key organisations that interact with financial risk, along with some of the key relationships.

2.1 The Business Sector

The business (or private) sector is the part of the economy that is made up of private companies. All large **corporations** will be required to undertake CRFDs. How this is defined internationally will likely vary by jurisdiction, but will at least include all corporations publicly listed on a stock exchange, and other large businesses that may have private investment. Risks to these entities that might lead to their collapse represents a broader systemic risk to the financial system, and therefore to the broader economy.

In Australia, for example, this will eventually include all businesses with over $50m in revenue and 100 employees (Australian Treasury, 2024).

Many smaller businesses that are not required to include CRFDs in their annual reports may still be interested in PCRA for internal risk management purposes. And smaller businesses with relationships to larger businesses (for example, as part of a supply chain, or as a debtor), may need to provide some level of physical risk information to those larger businesses, even if they do not need to include it in their own annual reports. In such cases, there will be no regulated requirement to adhere to standards, so there may be challenges for larger businesses in aggregating disparate information from diverse third parties.

2.2 The Finance sector

The Finance sector is one of the world's largest power bases. Investor groups have controlling interests in substantial fractions of global capital (Gibadullina, 2024), insurers provide buffers for risk, and banks provide loans to enable development. As such, the finance sector has substantial influence over decisions related to whether major projects are approved, and what constraints are placed upon them.

The finance sector can be split into a number of subsectors (Maverick, 2024), each having different aims and approaches to risk:

- **Banks and credit unions**, etc., which take deposits from the public (including private businesses), and also offer credit and loans.
- **Insurance providers**, which provide financial protection against possible losses for a fee/premium.
    - This includes **Reinsurance**, which is insurance *for insurance providers*, against major losses.
    - Insurance's relationship to physical risk is complicated, see Degrees of risk: direct to systemic for further discussion.
- **Superannuation, pension, and trust funds**, which manage money on behalf of individuals, to be paid out at a later date.
    - Super and pension funds are particularly important because they provide income for a significant fraction of the retired population. If they collapse, the knock-on effects to the broader economy will be significant.
- **Asset managers**, which manage a diversity of investments on behalf of other investors.
- **Institutional investors**, which are large organisations that invest in broad swathes of the economy.
    - Many financial institutions of other types (e.g. Banks, Insurers, and large funds) also have investment arms, and so may fall into this category.
- Others (e.g. payment processors and fintech companies - mostly less concerned with climate risk).

Some of these sub-sectors will be interested in physical risk from the perspective of understanding risks to their own physical assets (e.g. property and infrastructure covered by bank loans or insurance policies). Nearly all of them will be involved from the perspective of investment - either in trying to reduce their riskiness as potential investments, or as investors looking to minimise their portfolio's risk exposure.

2.3 Government and Financial Regulators

Governments play a huge role in finance. National governments are a major issuer of bonds, and may sometimes also operate as investors, or provide loans or insurance. On top of this, governments also regulate financial markets. The aims of financial regulation generally include consumer protection, reducing fraud, ensuring market stability and reducing the risk of major institutional collapses. The latter two aims are the most relevant to climate-related risk.

Regulatory frameworks vary by jurisdiction. At a high level, there are a few key types of regulators that relate to physical climate risk:

- **Banking** or **Prudential regulators**: aims to ensure that banks, super funds, and other deposit-taking financial institutions are being managed responsibly so as to reduce the risk of financial system instability that could result from a collapse.
    - These regulators sometimes run system-wide stress tests that include climate risks.
- **Financial Market regulators**: aim to ensure financial market integrity (including stock markets), and to provide consumer protections related to financial services. These regulators ensure that financial service providers are acting responsibly on risk information.
- **Corporate regulators**: Regulate business in general, including financial reporting, and eventually CRFDs.
- **Central banks**: Oversee monetary policy, and aim to ensure national financial system stability.
- **Treasury**: Government department that oversees or advises on economic and fiscal policy.
- **Coordinating bodies**: Organisations that co-ordinate between regulators, and ensure that policy is reasonably consistent and coherent.

The specific distribution of these responsibilities between institutions may vary by jurisdiction.

Case study: Australian government interactions with climate risk.

In Australia, for example, the main financial regulators (CFR, 2019b) that interact with physical climate risk are:

- **APRA**: The Australian Prudential Regulation Authority is a statutory authority responsible for prudential regulation

    - APRA has conducted sector-wide PCRAs, called Climate Vulnerability Assessments (CVA), one for Banking (2022), and one for Insurance (announced Dec 2024, currently underway).
- **ASIC**: The Australian Securities and Investments Commission is an independent commission that is both the financial market regulator and corporate regulator.
    - ASIC has responsibility for regulating corporate financial reporting, including CRFDs.
- **RBA**: The Reserve Bank of Australia is Australia's central bank, and acts as the lender of last resort for the broader commercial banking system.
    - The RBA has undertaken its own climate scenario analysis, focused on macroeconomics risks.
- The **Australian Treasury**: federal government treasury department.
    - The Treasury has been conducting Intergenerational Reports every few years that incorporate aspects of climate-related economic risk.
- **CFR**: the Council of Financial Regulators is a coordinating body for the 4 regulators.
    - The CFR has had a Climate Working Group since 2017 (Kearns, 2022).
- At the state level, state governments regulate the finances of government agencies (including some government climate risk assessment processes).

The Australian example is relatively straight-forward, some other countries have much more complex systems, for instance the US has 8 banking regulators at the federal level, and some states have their own banking regulators as well.

In some jurisdictions, government departments and agencies may also be required to report on their own risks. This may take multiple forms. In Australia, for example, this includes:

- All federal government departments and agencies, which will report in a similar way to the corporate mandatory CRFD process, under the Commonwealth Climate Disclosure (Department of Finance, 2024). Similar processes are happening in some states.
- Federal Treasury and some state treasuries are also conducting Intergenerational reports that focus on multi-decadal economic outlooks, and include some consideration of physical climate risk.
- The Australia’s National Climate Risk Assessment (NCRA) is looking at climate risks more broadly than just financial and economic risks, but also includes aspects of both.

The outcome of many of these processes will likely play into **sovereign risk** ratings (see 3.3.1 Financial Assets)

2.4 Other players

Other relevant parties engaged in physical risk assessment include:

- **Assurers** and **Auditors** are certified practitioners and agencies that review other companies' financial reporting to ensure that it is trustworthy and complies with regulations, and to detect errors and/or fraud.
- **Standards setters** are national or international agencies that produce standards to which national regulators conform (sometimes with local modifications). The key international standard setters for CRFDs are the International Financial Reporting Standards (IFRS) Foundation and the International Accounting Standards Board (IASB).
- **Credit Ratings Agencies** assign credit ratings to organisations according to their ability to pay their debts, and to debt assets such as bonds and securities. Many ratings agencies are beginning to issue sustainability-related ratings, and CRFDs will likely play into these ratings.

2.5 Why does business care about climate risk?

At the broadest level, actors in the business sector are likely to have a number of interests related to climate risk. These include:

- **Profit**: To maximise profits and minimise losses. In particular:
    - **Fiduciary duty** is a legal obligation to responsibly use wealth held on behalf of another (e.g. banking deposits, superannuation contributions).
    - **Shareholder primacy** is a governance principle that shareholders interests should be prioritised above all other stakeholders. Shareholder primacy may be legally enforceable in some jurisdictions.
    - Physical risk has the potential to increase operating costs, and so decrease profit margins, and not acting on it may conflict with these duties.
- **Social good**: parts of the finance sector in particular provide services that support other parts of society, e.g.
    - Superannuation supports people in retirement,
    - Insurance provides financial support for quicker recovery after adverse events,
    - Banks provide credit (loans) to allow individuals and businesses to pay start-up costs over time.
    - Understanding risks, including physical risk, allows these products to be priced appropriately.
- **Security**: To reduce or avoid existential threats and major losses that could prevent the business from continuing to operate.

    - Physical risk could directly threaten an organisation's ability to operate, in some cases to the point of insolvency or collapse.
    - Physical risk may also negatively affect a business's market, reducing commercial viability.
- **Reputation**: To look good in the eyes of investors/creditors, as well as clients and customers (e.g. insurance policy holders, or super fund members). A reputation for good financial management might result in a higher credit rating, for example.
    - Reputation is most strongly tied to transition risks (e.g. being "green"), but choice of responses to physical risks may also affect reputation. Investors ignoring physical risks to their investments may also be seen as irresponsible.
- **Regulatory requirements**: To check regulatory boxes. Failing to comply with regulation might result in fines or lawsuits, and is likely to negatively impact reputation.
    - It's worth noting here that a poorly executed physical risk assessment might check boxes, but fail to adequately assess risk, exposing the business to unexpected losses (this is a form of **model risk**).
    - If shareholders can successfully argue that poor methodology resulted in bad decision-making, this may also expose the business to **liability risk**.

Sometimes these interests coincide, but they are often in tension. For example, often environmental pollution is caused because it is cheaper (and therefore more profitable) to dump toxins and other waste than to manage them responsibly. In such a situation, the profit motive, and liability risk of shareholder primacy related lawsuits may be in tension with the reputational or regulatory risks related to polluting activities.

The jurisdiction, market, and sector that a given financial actor is operating in will change the balance of interests that are important for that actor. For example, a business looking to expand and in need of investment may want to assess their operational physical vulnerability and risk and report on how they are managing it in order to build their reputation as a reliable investment prospect. A housing insurance provider or a residential mortgage bank might be interested in future changes to physical risk across their portfolio, and how that will affect their profit margins. An infrastructure provider planning a new major project is likely to be focused on **existential threats** (threats likely to cause the project to fail entirely), and could be looking for major physical risks that could jeopardize the project.

2.5.1 Ulterior motives: Greenwashing and physical risk

In the transition-risk space (and in ESG more generally), there is a real concern about **greenwashing** - companies intentionally presenting as much more environmentally friendly than they actually are, as a way of manipulating reputation. Variations on this phenomenon exist that may be less egregious in terms of regulation, but important in the scheme of things: **greenhushing** which is downplaying, concealing, or refusing to publish ESG information, and **greenwishing** which is unintentional greenwashing, where a commitment is made in good faith but the company lacks the wherewithal to achieve it (Fisher et al., 2023).

Greenwashing and greenhushing present substantial regulatory and reputational risks (Longo, 2024; Rourke, 2024), and so are a driving force for company directors to make good decisions (see 6.1.2 Roles and Organisational Structure for discussion of director's responsibilities). As physical risk assessment develops over the next few years to better consider second-order risks from supply-chains and investments, this may expand to include liability risks from other companies.

It's not yet clear what similar misrepresentation in the physical risk space would look like, but it might involve down-playing physical risks and their financial materiality in order to look like a more safe investment or credit opportunity - **safe-washing**, perhaps?

3. Business and finance perspectives on risk

What's in this section

- Overview of different ways of viewing risk in business and finance
- Comparison of two key perspectives, Business Risk and Financial Risk, and how they differ and relate.
- Discussion of degrees of separation of risk

Key take-aways

- Approaches to risk and aims of risk assessment may vary substantially depending on what type of organisations you are collaborating with, or which departments in those organisations your collaborators come from.
- Having an understanding of the drivers of these differences can help collaborations to run smoothly and productively.

While climate risk is a relatively new frame, understandings of risk and its relationship with decision making have existed for thousands of years (Aven, 2016), and likely longer. Academic research on modern risk assessment and management first appeared in the latter half of the 1900s (Dionne, 2013; Aven, 2016). But risk is a complicated subject that presents differently in different contexts, and there are multiple ways of understanding risk, even within the business sector.

3.1 Taxonomies of risk

Depending on your perspective, there are different ways to frame risk, each of which can have different primary foci. Two key taxonomies of risk that are relevant to physical climate risk in the finance sector are **business risk**, which is concerned with the risk associated with running a business (and therefore highly relevant to corporations), and **financial risk**, which is concerned with estimating risks associated with money and financial assets, e.g. loans and investments (and therefore highly relevant to the finance sector).

From a **business risk** perspective, risk is commonly split up into a few key categories (Kenton, 2024):

- **Strategic risk**: this is the risk of the business model not matching the business's operating environment, e.g. due to market shifts.

- **Compliance risks**: the risk of part of the business breaching regulatory requirements.
- **Operational risks**: Risks associated with the day-to-day running of the business
- **Reputational risks**: The risk of losing customers or suppliers due to unsavoury behaviour.
- **Financial Risk**: Risks associated with business budgets, and failure to make loan repayments.
    - Note that this is distinct from, but related to, *financial risk* as a broader taxonomy as mentioned above and in the next paragraph.

From a **financial risk** perspective, risk can be split into an orthogonal set of categories, for example (categories based on Law & Smullen, 2008; Bender & Panz, 2020):

- **Market Risks**: Risk associated with external market movements (e.g. share prices, consumer sentiment, regulatory changes).
- **Investment Risks**: Risks associated with investment and valuation.
- **Credit Risks**: Risks associated with loans, contracts, income, interest rates etc.
    - This is also called **counterparty risk** in the context of contracts and investment.
- **Capital & Liquidity Risks**: Risks associated with having sufficient money to meet financial obligations.
- **Company Risks**: Risks associated with the running of a company
    - I.e. this is all of the *business risk* taxonomy, as covered by the previous list.

Each of these taxonomies of risks is a subset of the other, viewed from a different perspective. Which perspective should be used is entirely context dependent, and will vary by type of business, and also roles within that business - a general manager will take a different perspective to an investment manager (see 6.1.2 Roles and Organisational Structure or more detail). For example, a fire in a factory would be considered an operational risk for the business that owns it (from a business risk perspective), but it would be considered an investment risk or credit risk from the perspective of the business's investors, insurer, or bank.

From the perspective of someone not involved directly in business or finance, many of the 5 financial risk categories may sound very similar. But from the perspective of a financial professional they may differ greatly, particularly in regards to how much *control* may be exerted over each. And each category of risk will relate to physical climate risk in very different ways.

Note that these taxonomies are not the only way to split up risk. For example in financial risk, **model risk** (i.e. the risk of bad model results leading to poor decision making) is included as a component of market risk by (Bender & Panz, 2020), but it may also be considered as a completely separate category. During its Prudential Inquiry into the Commonwealth Bank of Australia, APRA divided risk into Financial risks (credit, market, liquidity risks) and Non-Financial risks, including operational, compliance, and conduct risk (Laker et al., 2018).

Physical climate risk plays into these frames in different ways. From a *business risk* perspective physical climate risk may be relevant as an operational risk, if business infrastructure is at direct risk of natural hazards, or as a strategic risk, if systemic climate risk is likely to affect the market the business is operating in. For example, if climate impacts reduce the economic prosperity of a region, then the area may be less viable for luxury retail shops, as the community may have less money available for non-essential spending. For further exploration of systemic risk, see 3.4 Degrees of risk: direct to systemic.

These frames are important to keep in mind when working with people from the finance and business sector. Other sectors are likely to have their own domain-specific risk taxonomies too. Critically, regardless of which taxonomy is used in a given sector, it is important that climate-related impacts are considered *in each of the risk categories* (indeed, some in the finance sector see climate as a driver of other risks, rather that a distinct category of risk, see e.g. APRA, 2024). The following two sections cover how these two common taxonomies are approached.

3.2 Business Risk Management

Business risk focuses on any risk that might reduce a business's ability to remain solvent (e.g. able to pay debt obligations). This is a broad field that covers process- and management-related risks, operational health and safety, and physical risks to infrastructure - anything that may prevent the business from operating optimally.

There are a number of key standards that attempt to formalise approaches to risk assessment and management. Key among these are ISO 31000, which has seen broad adoption globally (including localised adaptations such as AS/NZS ISO 31000 for Australia and New Zealand), and the COSO Enterprise Risk Management Framework, which has wider adoption in the USA (AICD, 2024b). Specific industries may have additional standards, for example in Australia the Banking industry must also adhere to APRA's CPS 220 Risk Management Prudential Standard. It is important to note that though the standards are useful for ensuring consistency of risk management approaches, they can have problems in some contexts and should not be considered the final word on risk management (for some example critique of ISO 31000 see Aven & Ylönen (2019)).

That said, they do provide useful starting points for considering risk assessment and management processes. Comcover (2019) provides an overview of the key elements of ISO 31000 in more detail, but some key points are worth mentioning here:

- **Establishing the context**, including the organisation's objectives, operating environment (e.g. market, regional factors), and stakeholders, is critical before attempting risk assessment.
- **Risk identification** is the next step. Exposure and vulnerability to different risks can vary widely between different entities and contexts.
- **Risk Analysis** involves estimating the impact and likelihood of identified risks occurring. These estimates may be quantitative or qualitative, or even completely subjective.
  - **Risk matrices** are commonly used to show relative risk across severity and likelihood.
- **Risk Evaluation** involves determining whether each risk exceeds pre-determined **risk thresholds**, and deciding whether action needs to be taken, taking into account the broader context. Some risk thresholds that are commonly considered include:
  - **Risk tolerance**, which is the level of risk an organisation is capable of withstanding, beyond which major consequences are likely.
    - Stress-tests are a particular type of analysis that aims to understand the possibility of organisational collapse (see 5.1.1 Scenario Analysis).
    - Risk tolerance levels are a strategy-level threshold that can be used to inform acceptability for specific risk-related decisions (see 3.2.2 Risk response).
  - **Risk appetite** is the level of risk an organisation is willing to take on in pursuit of its objectives. This approach to risk is a cost-benefit comparison that compares risks to opportunities, and is common in financial approaches to risk (see 3.3 Financial risk).
  - Risk evaluation inherently implicates **value** judgements (see 4.2.3 Boundary Judgements)
- **Risk Response** (or **risk treatment**) involves designing and implementing actions to reduce or avoid risks that the organisation has decided need responses.
  - A **risk prioritisation** process may be required if there are insufficient resources available for dealing with all identified risks.
- **Monitoring and Review** is an ongoing process to determine whether treated risks are improving, if new risks are emerging, if risks are changing due to shifts in organisational priorities or wider context, and if further management is needed.

- **Communication and Consultation** is critical to ensure that all stakeholders stay engaged in the process, and contribute to information sharing and decision implementation.

These components should be driven by a clear set of principles and embedded in a framework (see Fig. 3). The **principles** provide the "why" of the risk management process (e.g. those in column 1 in Fig. 3), and the **framework** defines the structure and processes that ensure that risk management can be implemented reliably, with continual improvement (explored in more depth in 5.4 Iterative methods development). There is no broad-brush approach to risk assessment that can be applied uniformly across different types of organisation, so each of these components will vary according to organisational context.

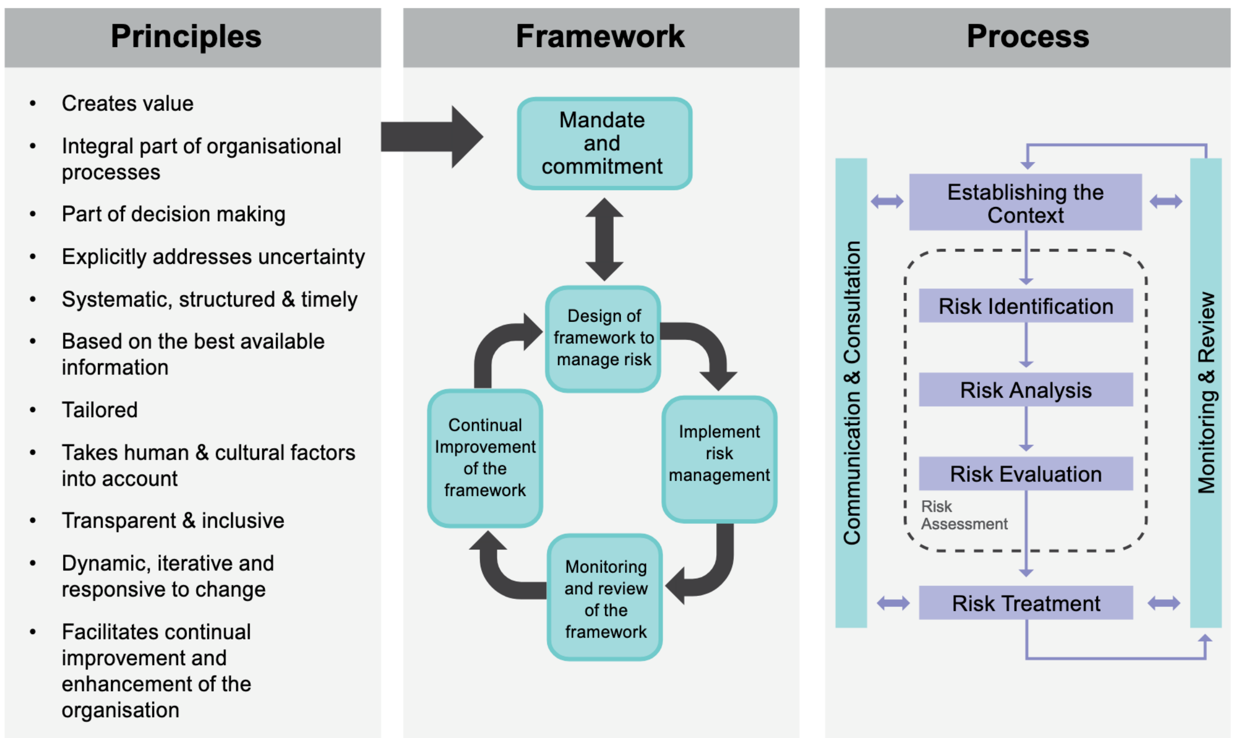

Figure 3: Overview of the AS/NZS ISO 31000 guidelines, from (Comcover, 2019). Many of the principles listed in column 1 are discussed in later sections of this document.

3.2.1 Context and risk identification

The space of all plausible bad outcomes is infinite, but any feasible risk assessment is finite. As such, it is inevitable that some risks will be ignored, whether through ignorance, or because they are considered irrelevant (see Ignorance and Irrelevance below). Whether given risk information is **relevant** is highly dependent on the context of the risk assessment, (including **materiality,** see 4.1 Common needs of PCRA users). For example, risks of forest fire are not likely to be material to most businesses in the IT sector, and it is certainly outside the scope of an IT business's management to implement any meaningful preventative response. Clear and correct definition of the scope of the risk assessment is needed at the outset for any risk management process to be effective.

Some key aspects of **context** that are important for helping to understand relevance and to identify key risks include (Comcover, 2019):

- The **external context** of the organisation, including its regulatory and policy environment, market and economy, socio-cultural context and physical environment.
- The **internal context** of the organisation, including its structure, strategy, capabilities, and culture(s).
- The **risk management context**, e.g. risk identification processes for CRFDs are likely to have a different focus than they are for operational risk management purposes.

Risk identification is the process of listing a broad and comprehensive set of risks that may be worth considering in risk assessment. Many tools exist for risk identification, such as SWOT analyses. Efforts should be made to ensure that risk is considered across most dimensions of the organisation.

Risk identification involves drawing on prior experience as well as imagination (Comcover, 2019), especially when it involves aspects of a changing external environment, as climate risk (both transition and physical) presents. External expertise is particularly useful in these cases. While standard business risk approaches can get away with mostly relying on existing internal expertise, this is not the case for physical risk, as most businesses will not have on-board climate expertise (although many larger financial institutions are beginning to hire for this purpose).

3.2.2 Risk response

Before delving into risk assessment approaches, it's worth considering what kinds of action can be taken by an organisation in response to identified risks. At the highest level, there are a few types of possible risk responses (ISO, 2018):

- **Avoid the risk**. This might be possible when considering whether or not to start a new project, when choosing locations for a project, or when choosing to make a new investment or loan.
- **Remove the risk**. This might be possible when the cause of the risk is clearly manageable.
  - For example, when a broken piece of equipment is a threat to workplace safety, it could be fixed or removed.

    - Planned retreat is an example of physical risk removal
- **Reduce the likelihood or consequence**: This might be possible for some unavoidable risks. For example:
    - Installing fire extinguishers reduces the likelihood of a severe fire.
    - Flood levies, fire trails, and sea walls are examples of interventions aimed at reducing the frequency or severity of climate-related impacts.
- **Share or transfer the risks**:
    - Insurance is an example of financial risk transfer - the insurer takes on the risk, while the policy holder takes on a certainty in the form of a policy premium.
    - Insurance excess, reinsurance, and catastrophe bonds are examples of shared risks.
    - How risk transfer is interpreted, particularly in relation to insurance, may depend on perspective (see 3.4 Degrees of risk).
- **Accept the risk**: An informed decision might be made to knowingly retain the risk, perhaps because the consequence is assessed as within the **risk tolerance**, or because the risk inseparably associated with some other benefit that outweighs the expected consequences.

Which of these management approaches is chosen for a given risk is dependent on the broader context of that risk and the organisation's risk appetite. Some considerations that might be important when deciding on appropriate responses include:

- The **resilience** of the system at risk, that is, the ability of the system to sustain functionality following a hazard event (Aven et al., 2018). This might include consideration of:
    - **Vulnerability** or **sensitivity**, the expected impact/loss the system incurs as a result of a given hazard event.
    - **Adaptive capacity**, the system’s ability to change in response to risk or to a hazard event.
    - **Buffers**, such as accumulated resources or capital, can increase resilience by allowing the organisation to respond to shocks quickly.
    - **Network connectedness** can increase resilience. For example, community support in response to local disasters, or supply-chain network redundancy.
        - Connectedness can also decrease resilience if it homogenises the risk profile of the network, or increases the transmission of risk. Examples of this include international travel increasing contagion in a pandemic, or the homogenisation of investment portfolios via securitisation in the lead-up to the GFC, resulting in most actors in

the finance system being highly exposed (see 3.4.1 Degrees of financial separation).
    - Whether connectedness increases resilience is related to the **redundancy** and **degeneracy**, **diversity** and **heterogeneity**, **modularity**, and **feedback timescales** within the system (Levin & Lo, 2015; Kharrazi et al., 2020).
- The degree of separation of the risk from the organisation, from **direct risk**, to **systemic risk** (see 3.4 Degrees of risk). This is related to:
  - The **scale** of the organisation at risk, i.e. small business operating locally vs an international business.
  - The **diversification** of the organisation's interests, i.e. having investments across many sectors and regions, which reduces the impact of any single hazard event.
  - A small organisation operating locally with few physical assets will likely need to focus on direct risks, while a diversified international institution will likely need a stronger focus on systemic risk.
- How much **control** the decision maker has over the situation. This may be related to whether the source of risk is internal or external to the business, or the position of the decision maker in the organisation (see 6.1.2 Roles and Organisational Structure).

3.3 Financial risk

Note: This section presents the difference between financial risk and business risk thinking as black and white, for illustrative purposes. In practice, the distinction is not so clear cut, and most practitioners sit somewhere on a spectrum between the two modes.

Financial risk is different to business risk, because it is not concerned with direct control over processes, personnel, and infrastructure, but rather with financial contracts and assets. **Financial assets** are *not* physical objects (such as buildings), but are generally defined as *a right to the economic benefits of some resource* (e.g. paragraphs 4.3-4.25 IASB, 2018). That is, the financial "asset" is the exclusive right to control and benefit from some physical object or process (e.g. buildings or companies).

The **financial value** of an asset is therefore solely related to its ability to produce or be sold for financial gain. This financial value may or may not be related to some underlying **intrinsic value**. For example, consider original collectors items that sell for orders of magnitude more than it would cost to reproduce them.

This financial contract (either an explicit contract, or a right granted by law), represents a degree of separation from physical reality (see also 3.4.1 Degrees of financial separation), and a corresponding reduction in control. For example, generally investors do not have direct control over management within a business, and residential banks and insurers do not have direct control over how well a property is maintained, e.g. in terms of wildfire risk reduction measures.

Investors and creditors can certainly influence those underlying processes though. Financial contracts may require specific action on the part of the counterparty. For example, the legal doctrine *uberrima fides* (latin: "utmost good-faith") used in some jurisdictions requires insurance policy holders to notify insurers of any information that may be relevant to risk estimation. Some business investment processes are also contingent on the business implementing specific management policies. Sustainable investing generally requires that the investee have ESG policies implemented - climate risk information is likely to play an increasing role in this area over the coming years.

Financial risk is also different from business risk the way it is treated, partly due to historical differences: Business risk is at least partly informed by occupational health and safety (Business.gov.au, 2025), while financial risk is predominantly informed by probabilistic thinking that stems substantially from gambling (Bernstein, 2012). Where some business risks are considered unacceptable (e.g. worker death or permanent injury), individual financial losses are always acceptable, provided the long-run average results in gains (i.e. as long as loan default and insurance claim rates stay within the expected ranges).

This kind of thinking is fundamentally based on the fact that individual bets (investments) are generally much smaller than the total pool of money available, so short-term losses can be absorbed by the financial buffer. The truism that in a casino "the house always wins" is based on the fact that despite the small margins in favour of the casino, their available money is always much larger than the largest bet they are likely to lose. A financial risk that is large enough to deplete the financial buffer of an institution is potentially an **existential threat**. This might include unexpected failure of a major investment or class of investments, such as the sub-prime mortgage failures that lead to the collapse and bailing out of multiple large financial institutions in the 2008 GFC.

This difference in the focus and conceptualisation of consequence from a finance perspective leads to very different attitudes to risk, and different behavioural responses and decision-making in the face of risk (see 6.2.4 Understandings of risk, uncertainty, and ignorance).

3.3.1 Financial Assets

Because investment inherently exposes the investor to the risk present in the investment, it's also worth considering types of investment that might be exposed to climate-related risks (van der Welle & Swinkels, 2022). These include:

- **Equity,** including **shares** or **stocks**, which represent part-ownership of a business.
    - This can include private equity, and equity publicly listed on a stock exchange.
    - If a business is highly exposed to risk, the value of the business is also affected, passing on the risk to the investor (e.g. via decreased dividends).
- **Debt** including:
    - **Private debt** such as **loans** and **credit**, or corporate fixed income investments.
    - **Bonds** - these are usually issued by governments, and promise to pay the holder the down payment plus interest after a fixed term.
        - Government bonds' value is related to the strength of the local economy, and the ability of the government to repay the debt. Bonds may be affected by systemic risks.
        - When risk affects the ability of a National government's treasury or central bank to repay the bond, this is known as **sovereign risk** (see A note on Finance and Economics).
- **Real Assets:**
    - **Real estate** - investment in land and/or the built environment.
        - Real estate investments may be exposed to direct risk from e.g. fires or floods. This risk is important for banks offering mortgages, as it may increase the rate of loan defaults (this is **credit risk**, see 3.1 Taxonomies of risk).
        - Real estate value may also be affected by regional systemic risk.
    - **Infrastructure** - investment in built infrastructure, such as transport or communication networks.
        - Infrastructure has similar risks to real estate, but impacts may have wide-spread knock-on effects on supply-chains.
    - **Natural resources**, including energy resources, minerals, and land used for agricultural or forestry.
        - Each of these are potentially exposed to multiple natural hazards, which can result in e.g. crop failure, or disruption to operations.
    - Other **physical assets**, such as commodities and art.
        - These may be exposed to physical risk if their storage facilities are exposed.

- **Investment funds** and **securities**: These are pools of investment from multiple investors that are generally managed by a finance professional or asset manager**.** They may incorporate investments in many other types of asset.

Tradeable financial assets are also sometimes called **financial instruments**.

3.3.2 Approaches to valuation

Valuation is the determination of the financial value of an asset. For example, a house may be valued using information from a building inspection, as well as information about the local market.

There are three basic approaches to valuation of investment assets:

- **Technical analysis** focuses solely on statistical analysis of price signals. It is commonly used in stock market trading.
    - Technical analysis assumes that an asset's market price inherently reflects all relevant information[5]. This nominally includes climate risk, although this is likely substantially **undervalued** at present (Trust et al., 2025).
    - Technical analysis also generally assumes **stationarity**[6] - an assumption which climate change likely invalidates (Milly et al., 2008).
- **Fundamental analysis** integrates broader quantitative information about an investment, such as metrics from financial reports, in an attempt to understand the *underlying* value of an investment.
- **Qualitative analysis** integrates a broader array of information including qualitative information, in order to understand the asset's underlying value.
    - This may include anything from interviews with company management and reviews of company policies, to assessments of broader factors, such as competition, regulatory changes, and qualitative risks (such as geopolitical risk or systemic climate risks).
    - Qualitative analysis is more likely to be used by well resourced institutional investors (such as superannuation funds, or asset managers) when looking at large investments, where it pays to carefully explore the risk surrounding an investment (this is known as **due diligence**).

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[5] This assumption is called the ***Efficient Market Hypothesis***, and is common in financial and economic thinking. It has attracted substantial criticism on both empirical and theoretical grounds. The [Efficient-market hypothesis] Wikipedia page has a summary of many of these criticisms.

[6] This includes assumptions of trend-stationarity: these approaches still assume a level of constant process-stationarity, which may also be invalidated by climate change.

It is important to know which of these approaches investors you are working with may be using, as users of each approach are likely to respond better to different types of knowledge and styles of communication.

Investors are beginning to include climate-risk related information in these processes (particularly the latter approaches), but it is likely that actually integrating this information into valuations will face difficulties for some time. Key issues include integrating relevant qualitative climate risk information into predominantly financial analysis (see 5.2.2 Qualitative vs Quantitative), and understanding the **credibility** of information from unfamiliar fields (see 4.1 Common needs of CRFD users).

Appendix B: Methods and metrics in financial risk assessment explores some methods and metrics used for each of these approaches in more detail.

A note on Finance and Economics

Although finance and economics are related, they are distinct disciplines. Finance deals mostly on the analysis and management of money and investments, while economics focuses more on the value of real resources, and the production and distribution of goods and services (S. D. Simpson, 2025). Finance and economics are interlinked, however: **Microeconomics** focuses on supply and demand between business and individuals within a market, and is closely related to business finance, while **Macroeconomics** aims to understand whole-of-economy behaviour (so, the aggregate of all business performance), often at a national or state scale, and focusing on aggregate metrics such as Gross Domestic Product (GDP) (Investopedia, 2024).

Macroeconomic risks at the national scale are captured in the concept of **sovereign risk**, which is the possibility of a national government defaulting on its debts, which includes the failure to repay **government bonds** (CFI, 2022). Sovereign risk has a huge potential to be impacted by systemic physical climate risk, and governments are beginning to acknowledge this (Dibley, 2023)

There are differences in terminology between economics and finance as well. For example “capital” in economics refers to the means of production (e.g. machinery and infrastructure), whereas in finance the same term is more abstract, and refers to money and wealth.

3.4 Degrees of risk: direct to systemic

Throughout the discourse on physical climate risk there is discussion of direct risk, systemic risk, and various degrees of risk in between. These discussions can get confusing, because what is meant by “direct” can vary by context, and is often left implicit.

A critical first consideration is that any definition of **risk** is dependent on the definition of **consequence**, and what is consequential is highly dependent on perspective and values (Boholm & Corvellec, 2013). For instance, for a family impacted by flooding or fire, the consequence might be repair costs, homelessness, loss of possessions, or loss of life. For the exact same impact, the consequence for a bank that has a mortgage on the property might be that some of the value of the collateral of the loan is lost, and the likelihood of default increases as the family’s ability to service the loan is reduced.

We can identify three broad categories of **degrees of risk**:

- **First-order**, or **direct risk**: risk where the consequence affects something owned by the individual or organisation concerned. For example:
    - The risk of flood or fire damaging physical infrastructure owned by the organisation.
    - For an investor, this might be collapse in the value of a financial asset.
- **Second-order**, or **indirect risk**: risk that is one or more steps removed from the concerned individual or organisation, but where **causality** is still clear and traceable.
    - This includes **supply-chain risk** in particular.
    - From the perspective of a home owner, losses incurred by the insurer or the bank holding the mortgage are arguably a second-order consequence.
- **Third-order**[7], or **systemic risk**: aggregated risk from multiple sources. These risks are more diffuse, and causality is usually not very clear.
    - An example is broad macro-economic impacts across a whole region.
    - It should be noted that **systemic risk** relates to the possibility of collapse in a given system (Gambhir et al., 2025), and so it can mean different things in different contexts (Sillmann et al., 2022).
        - In the finance literature, it generally relates to the collapse of the financial system, which may include collapse of major financial institutions and/or stock market crashes, which may lead to broader economic depression.
        - From other perspectives, systemic risk may refer to any other system, but is often used in relation to large socio-economic systems, such as healthcare systems (e.g. for pandemic risk), or national economies (Sillmann et al., 2022).

[7] Some sources use “second-order” to refer to systemic risks. We prefer the three-tier classification because it allows a distinction between supply-chain impacts that can plausibly be modelled directly, vs less tangible whole-economy impacts that can only be modelled indirectly.

- Sometimes system-wide (and therefore undiversifiable) risks that are not likely to lead to collapse (e.g. minor market-wide economic down-turns) are referred to as **systematic risks** (Law & Smullen, 2008)

Table 1 includes a number of examples of each degree of risk, from different perspectives. It is worth noting in particular that **what is a direct consequence from one perspective** (e.g. insurance payout for an insurer), **may be considered a second-order consequence from another perspective** (e.g. for a family who has lost a house).

Table 1: Risk directness from various perspectives. The items in this table are intended to illustrate differences only, are not exhaustive, and may not apply in all cases.

Perspective	Primary concerns	First-order/ direct risk	Second-order/ indirect risk	Third-order/ systemic risk
Family/ home owner	Home, Livelihood	Homelessness	Financial impacts, Service disruptions, Repair costs	Property prices, local socioeconomic factors
Business	Business operations, Profit	Infrastructure damage, Business disruption, Impacts to employees	Supply-chain disruption, including services, repair costs	Market risk (e.g. reduced spending capacity)
Bank	Credit, Profit	Loan defaults	Model risk: poor loan serviceability estimation	Market risk (e.g. reduction in ability to service loans)
Insurer	Premiums, Profit	Unexpectedly high annual costs Model risk: poorly performing risk models	Client losses	Market risk: reduced insurability (e.g. when premiums become prohibitively high)
Institutional investor	Investment decisions, Profit	Investment failure/ poor performance	Securitisation, Model risk: poor information for decision-making	Market bubbles, undisclosed risk
Local government	Maintenance of services, Budget	Infrastructure damage	External service disruption	Reduced income from property rates etc.
National government	Economic productivity, GDP	Reduced economic productivity?	Impacts on key trade partners?	Reduced global demand for exports, Sovereign risk

From a *financial risk* perspective (i.e. for banks, insurers, and investors, see 3.1 Taxonomies of risk), **direct physical risk** is mostly related to credit and investment risk, as physical risk flows from businesses and property owners to loans and investments. For most businesses, **systemic risk** can broadly be viewed as market risk. This understanding is particularly important for **"Universal owners"**, which are large institutional investors that have fully diversified investments across all sectors of the economy, and therefore have the same exposure to risk as the broader economy.

3.4.1 Degrees of financial separation

Key take-aways

- "Direct risk" may mean different things from different perspectives, depending on where the consequence is perceived.

Financial contracts provide a *degree of separation* from risk (see 3.3 Financial risk).

This can be magnified substantially by financial organisations packaging and re-selling financial instruments. This process is known as **securitisation**. Mortgage-Backed Securities, are an example of securitisation that package and re-sell debt (and the expected profits from repayment) associated with property mortgages. Collateralized Debt Obligations are a more general form of debt packaging that may repackage these debts again, sometimes multiple times. There is a fundamental problem with this process, as each set of contracts provides another degree of financial separation, and makes it harder to understand the underlying value as well as the underlying risk profile.

These processes were used extensively in the US and other markets in the lead-up to the 2008 GFC. In some cases, debt was re-packaged and resold multiple times. This is what allowed financial investors to build a bubble on the back of sub-prime mortgages (FCIC, 2011). The GFC was the result of this bubble collapsing. The collapse was triggered by loss of market confidence due the realisation that there was substantial undisclosed risk from sub-prime mortgages, as many mortgage holders were unable to keep up with repayment schedules (i.e. the actual underlying value of the mortgages and related securitisations were much lower than the market price). This initial collapse was primarily centred on the US[8], and was quickly followed by the realisation of more widespread excessive risk-taking in many other parts of the global financial system (Baranoff et al., 2009; RBA, 2018).

Insurance is another interesting example of this financial separation from direct impacts, because its whole business model is focused on **risk transfer** - buying financial risk from others. Because insurance is based on taking on the physical risk of many

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[8] The film "The Big Short" (McKay, 2016) is an entertaining and educational dramatisation of the GFC, and provides a good introduction to these issues.

customers, and accounting for expected rates of loss, physical risk acts something like a resource to an insurer, and the insurers themselves are not directly exposed to physical risk. Instead an insurer's primary climate-related risk is in the possibility of modelling risk poorly (**model risk**, which may be related to models not accounting adequately for climate change), and in customers' risks increasing to the point where premiums become unaffordable, leading to uninsurability (**market risk**).

The key take-away here is that "risk" and related concepts like "directness" may mean different things from different perspectives, depending on **where the consequence is perceived**. No single perspective is objectively correct. It is important to always ensure that you are using terminology coherently with your collaborators, and to clarify your meaning in external communications (see C6.3 Communicating results with finance for more on this).

4. PCRA requirements

What's in this section

- Common needs for PCRA and CRFDs.
- Why organisational context is critical.
- Overview of key components of physical risk.
- Key considerations for any PCRA methodology.

Key take-aways

- Every PCRA is unique, due to organisational context.
- It's not possible to understand the requirements of a PCRA solely from a science perspective, nor solely from a finance perspective.
- The process of defining the scope is inherently interdisciplinary, as is the process of conducting the assessment.
- Boundary judgements and systemic triangulation are valuable tools for determining what's important in a PCRA while incorporating multiple relevant perspectives.

Ultimately, the question physical climate risk poses in the finance sector is "how much should I expect to lose, given climate change?" This question is extremely complex, as it hinges on:

- Extremely **uncertain socio-economic futures**
- Resultant **emissions pathways** and how they are driving anthropogenic global warming (e.g. climate sensitivity)
- Regional trends in **drivers of hazards** as a result of global climate change
- Local and regional **drivers of exposure** (some static, some changing)
- **Vulnerability**, resilience, and adaptive capacity of the systems at risk
- Organisational **awareness** of exposures and vulnerabilities
- Organisational **willingness** and **capability** to assess risks (and then report on and/or respond to them).

Every item in this list is potentially very complex, and each one requires very different expertise, and yet all of them need to be addressed in some way for any reasonable risk assessment process. This section explores a (non-exhaustive) set of important considerations for any PCRA methodology.

4.1 Common needs of CRFD users

If PCRA information is to be useful and effective for decision-makers and users of CRFDs, there are some basic requirements that must be met. These include:

- **Relevance** for decisions. Considerations for relevance include:
  - **Materiality**, which describes whether information could be expected to influence decisions made by users (IASB, 2018)
  - **Comprehensiveness**, in that it captures all the material impacts of major knowable risks.
    - Which risks are material will differ depending on the purpose and scope of the risk assessment. For example, a health-focused heat risk study could reasonably exclude issues related to sea level rise. A generalised PCRA could not, but may exclude specific hazards from the full analysis if it is determined that the organisation has no exposure or vulnerability.
    - Comprehensiveness is always a trade-off with **feasibility** (see 5.2.1 Fitness-for-purpose), and comprehensibility (see 4.2.3 Boundary Judgements)
  - A **useful** method in one context may be inappropriate for another (see 5.2.1 Fitness-for-purpose). Interdisciplinary co-design can help here (see 7. How to do interdisciplinarity well).
  - Considerations of relevance must take into account the vulnerability and exposure of the organisation. A bank with many home loans in low-lying coastal areas will have a very different exposure to a bank focussed on agricultural loans, and an institutional investor with a diversified investment portfolio will be different again.
  - Usually general high-level summary climate information is not directly useful for risk assessment, as it is not easily possible to relate it to on-the-ground impacts. This kind of information can still be useful for contextualising risk assessment methods and results.
- **Comparability**: A key reason for PCRA for CRFD is for informing investor decisions. If inconsistent or incoherent methods are used to assess risk (e.g. because they focus on different aspects of risk, or the results contain different types of information), it may be difficult to compare investment options. Standards and frameworks can help here (see the History of climate risk disclosures appendix)
  - Note that comparability can sometimes conflict with *relevance*, in the sense that comparability requires generic approaches (Nguyen, 2024b) that can be applied in the same way to businesses that may have very different business profiles (see 6.1.1 Financial decision-making and integrating science)

    - Comparability is a key driver of the dominance of quantitative financial metrics, though this can be problematic (see 5.2.2 Qualitative vs Quantitative).
- **Credibility** of the methods is critical if the user is to **trust** the results well enough to make decisions informed by them.
    - This might include aspects of **transparency** (such as open source models or datasets), or evidence of model performance (addressed in 5.3 Validation, verification and evaluation).
    - Information must be **intelligible** for the intended audience, including clear guidance for how to read and interpret assessment results.
    - **Trustworthiness** requires that the methodology is explained in an audience-appropriate way. The amount of technical depth to go into will be context dependent (see 5.3 Validation, verification and evaluation for an overview).
    - Credibility can be particularly difficult to assess when dealing with knowledge and methods from other disciplines (see 6.2.3 Ways and means).

This list is drawn primarily from the authors' past experience, but overlaps substantially with the "Qualitative characteristics of useful financial information" from the Conceptual Framework for Financial Reporting (IASB, 2018), which outlines the rationale for the IFRS standards. The Conceptual Framework defines financial information as useful if it is **relevant** and **faithfully representative**, and states this usefulness can be enhanced by **comparability**, **verifiability**, **timeliness**, and **understandability**. These issues are largely captured above, and in the 5.2.1 Fitness-for-purpose section.

The following sections explore some of these issues in more depth.

4.2 What's important in a PCRA?

PCRA is complex. It can include tens of hazards - for example the European standards include 41 distinct hazards (see table in AR11, EFRAG, 2023), each of which is an entire scientific field of its own, some with hundreds of thousands of published papers (Horton, 2024). Each of these hazards can have a multitude of impacts, depending on the vulnerabilities of the assets being impacted, and each of these impacts is a complex process with many moving parts. Australia's National Climate Risk Assessment identified 11 key systems at risk, and a further 56 climate-risk related topic areas, each involving exposure to multiple impacts from 10 identified hazard categories (DCCEEW, 2023, 2024). Exposure and vulnerability for each impact can be highly variable, both spatially, and socio-economically. As such, it is fundamentally not feasible to have a perfectly comprehensive PCRA. Some decisions must be made about how much to include, and how much depth to go into.

4.2.1 Organisational context

The **context** of a PCRA is critical to understand and helps to define the scope of the assessment, including system boundaries and appropriate methodologies. Some key considerations include:

- Understanding the **organisation** the report is for - is this a government agency? A bank? An asset manager? Each of these will have different **values**, **aims**, and **risk appetites**, and will want to focus on different aspects of the physical climate risk as a result.
- The organisation's broader **context**, e.g. the environment and market it operates in, or its supply chain dependencies, will also affect what is important to report on.
- The **purpose** of the risk assessment is also an important consideration. Is the reporting being conducted solely for compliance purposes? Or is the organisation interested in conservative (worst-case[9]) risk assessments? Is the reporting for external communication, e.g. impressing potential investors, or is it for internal strategy and operational decision-making purposes?
- What **types of decisions** will be made in relation to the information in the risk assessment? Will the assessment lead to business risk responses, such as updates to operating procedures? Or will it affect financial planning or investment decisions? Or broader strategic direction? Which decisions need to be made will affect what metrics and qualitative information the analysis should aim to generate.

4.2.2 Components of risk

Once the context is reasonably clear, it's worth considering risk from a birds-eye view. Conceptually, risk has a few key components, and is commonly expressed as a combination of Hazard, Exposure, and Vulnerability[10]. N. P. Simpson et al., (2021) make the point that risk response interacts with the other components such that it acts as a driver of risk too (e.g. via **unintended consequences**), so the equation should be expressed as:

$$\textbf{Risk} \approx \textbf{Hazard} \times \textbf{Exposure} \times \textbf{Vulnerability} \times \textbf{Response}$$

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[9] See 6.3.1 Linguistic uncertainty, terminology, and language barriers for some discussion around this terminology.

[10] It's also worth noting that the hazard/exposure/vulnerability framework is not the only way to split up this conceptual space. For example, Zhou & Smith, (2022) instead look at *geographic heterogeneity, amplifiers, and mitigants*, which is an orthogonal framework that approximately captures many of the same concepts.

Figure 4: Venn diagram of major risk components.

Some things to consider within this framework:

- The **Hazard**[11] component captures information about harmful events, such as droughts, floods, and fires. The primary influence of climate change on physical risk is via changes in drivers of hazards.
    - Hazards are commonly split into:
        - **acute** (stochastic events like flood and storms), and
        - **chronic** (long term shifts in climatic conditions, e.g. sea level rise).
    - **Climate information** alone is *never* enough to tell you anything about risk, because it contains no information about the vulnerability of the assets that may be impacted, and because there are many non-climate exposure factors that can be highly spatially heterogeneous at fine scales.

> ⚠ Good climate science is a **necessary, but insufficient** condition for estimating physical risk.

-
    - Climate scientists sometimes use the word "risk" in the context of physical hazard projections, but the IPCC strongly recommends that "risk" only be used in the context of human and ecological systems, where some kind of **consequence** can reasonably be defined (Reisinger et al., 2020 p. 6).

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[11] This is also called a **Peril** in some sectors, including insurance.

- The **Exposure** component captures hazard-relevant conditions in the local area. For instance, are we near a coast or river that can flood? Are we near vegetation that can burn? Is this region prone to cyclones?
    - Climate information can interact with exposure in complex ways, for example antecedent precipitation has a strong effect on riverine flooding (on the scale of days to months), and on fuel stocks for fire (on the scale of months to years).
    - Some exposure-relevant conditions can change over time, for example land-clearing changes the likelihood of fires and floods.
- **Vulnerability** captures the impact incurred to a particular system or asset as a result of a hazard event. Impacts can include damage and other losses, as well as disruption. For example, a fire may destroy houses, or a road may become temporarily impassable due to a flood, interrupting supply-chains.
    - **Impact sensitivity** can vary a lot between hazard types, and asset and asset components affected. For example, drywall or electrical components in a flooded house will need to be replaced, where bricks/cement might just need to be cleaned up.
    - **Resilience** and **adaptive capacity** can significantly affect total losses. For example, cost and recovery time for homes in a strong, well connected and resourced community will be lower than in a more socioeconomically vulnerable community.
    - **Historical lived experience** is often important for vulnerability assessment. Every organisation is different, and recorded performance of a business in the face of past climate-related impacts can be critically informative, as can employee understanding of likely impact sensitivities (see 6.1.2 Roles and Organisational Structure).
- **Response** covers the actions taken in response to perceived risks. Responses can vary wildly depending on the context, and may include forms of adaptation, divestment, or planned retreat, etc.
    - Response is often not included in risk assessment directly, although N. P. Simpson et al., (2021) make the case that it should be. Response feedbacks into risk can range from relatively simple, e.g. flood levees reducing the risk of small to medium floods[12]; to extremely complex, e.g. managed retreat via buy-back schemes, which may reduce vulnerability in the short term, but has many complex socio-economic impacts (O'Donnell, 2022; Patch, 2023). Each of these changes can feed back into exposure and vulnerability.

[12] This example may be deceptively simple, as reductions in high-frequency, low impact flooding can sometimes result in increases in vulnerability, also known as the "levee effect" (Di Baldassarre et al., 2015)

    ○ Even if response is not included in initial risk assessments, assessment of plausible **unintended consequences** of a risk response should be explored during the development of the response, and should feed back into later rounds of assessment (see 5.4 Iterative methods development).

Fig. 5 provides a schematic view of the information flow in a simplified PCRA. A critical point is that **there is very little overlap between the domain of climate science** (left side of the figure)**, and the domain of finance** (right side) - the gap is necessarily bridged by some other impact-relevant information, including exposure and vulnerability, which are predominantly not related to climate expertise. This means that physical risk is necessarily an interdisciplinary process (see 7. How to do interdisciplinarity well).

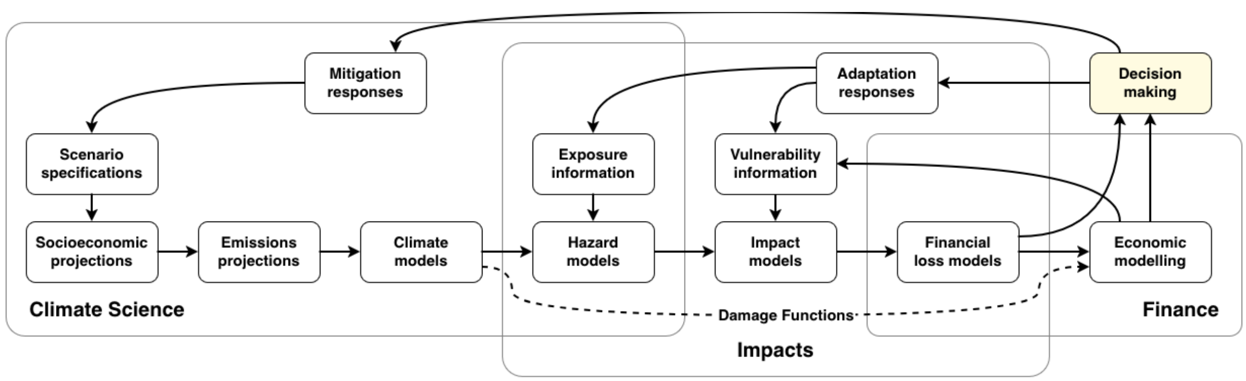

Figure 5: Schematic flow of information between components of a physical climate risk modelling system.

Each of the aspects of physical climate risk listed above may also potentially interact with a number of other broader considerations, including:

- **Compound risk**, which includes:
    - The possibility of temporally or spatially compound or multivariate hazard events (Zscheischler et al., 2020), as well as
    - Hazard events compounding with other drivers of risk, such as socioeconomic drivers, leading to cascading risk (N. P. Simpson et al., 2021; Zscheischler, 2024).
    - Compound risk assessment may also consider interactions between physical climate risk and transition risks, or even broader effects like geopolitical or non-climate related market risks, particularly as these shocks can act as multipliers (NGFS, 2022b).
- The **complexity** of the system being analysed, and the **degree** of risk, from direct to systemic (see 3.4 Degrees of risk: direct to systemic).
    - The distributional effects (e.g. differentiation of impacts across the socioeconomic spectrum, across regions, or across sectors) of climate risk should also be considered when assessing risk at a government scale (NGFS, 2022b).

The next section explores a key process for deciding which of the elements described in the last two subsection to include in a physical risk assessment, and how to include them.

4.2.3 Boundary Judgements

Risk, as described above, is uncertainty combined with adverse consequence. Adverse consequence is the combination of impact and **value**. Therefore, unlike much (positivist) science, risk can not be approached as an objective, value-free proposition. If there is no value, there is no risk (Boholm & Corvellec, 2013).

Risk always consists of three elements: a system-at-risk, a hazard, and the relationship between the two (Boholm & Corvellec, 2013). Defining the boundaries of the system-at-risk is a core problem for risk assessment[13]. What is important in the system-at-risk is entirely dependent on the value proposition embedded in the risk assessment. The values of science and finance differ in many ways (see 6.2.2 Values and Worldviews), so the question is "how do we define the boundary of the system?" (including the system-at-risk, hazards and hazard drivers, and the relationships between them).

This question is one of **boundary judgement** (Westra & Zscheischler, 2023), which is the process of deciding what should or should not be included in the system, and how to aggregate information at the boundaries (Curtin & Allen, 2018). Boundary judgments must necessarily integrate aspects of **knowledge**, **values**, and **system definition**. Each of these components contextualises the other, and so new information in any of these domains can result in a need to reassess the other two. For instance, new knowledge about an impact pathway might result in a reprioritisation of values, or a redefinition of the system boundaries to include previously unconsidered processes. This change in values or system definition is likely, in turn, to require some degree of change in the risk assessment methodology. The process of iteratively conditionally reassessing these three components is described as "systemic triangulation" (Westra & Zscheischler, 2023), and is visualised in Fig. 6.

[13] In climate science the system of interest is the earth's climate, and the boundaries are "obvious", at least in a spatial sense, as the outer layers of the atmosphere and the earth's crust provide a clear demarcation. However, even in climate science system boundaries are not always clear, for example in the question of which processes to include in a climate model (e.g. whether to include hydrological routing, or dynamic vegetation).

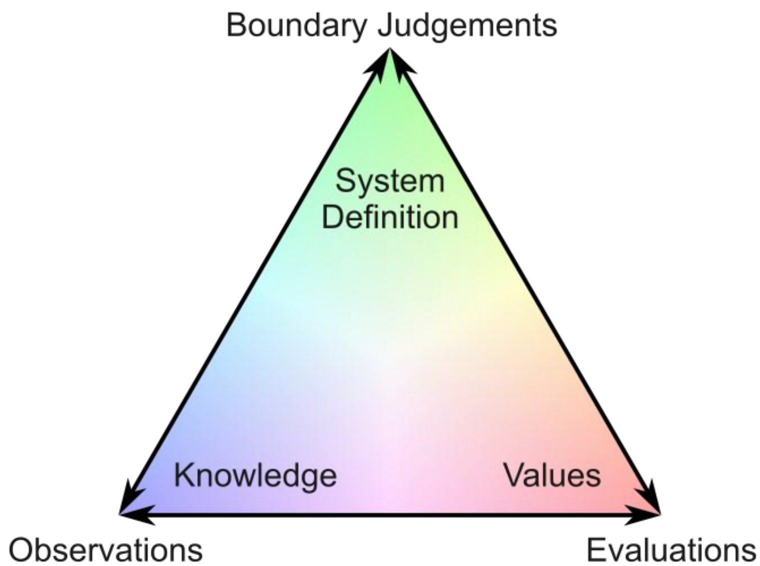

Figure 6: The process of systemic triangulation involves assessing one corner of the triangle (e.g. facts, values, or system definitions) from the perspective of the other two corners. Doing so often recontextualises the other two corners of the triangle, such that they may need to be re-assessed, and the process continues iteratively until all collaborators are satisfied. Figure adapted from (Westra & Zscheischler, 2023; Ulrich, 2005).

As an example, from the perspective of a residential bank, risk assessment is likely to involve:

- System definition: The bank, its mortgage portfolio, its risk management practices, and the property market.
- Values: Solvency, profit, stability, actuarial expertise.
- Knowledge: Asset locations, asset values, historical portfolio performance and risk profile (e.g rate of house fires).

Once physical climate risk becomes an important concern, then new expertise will be needed (e.g. climate science, impact experts), and this brings with it new knowledge. Some of this knowledge, such as hazard distributions or regional systemic risks, is likely to change the system definition, such that it now includes elements of the natural environment, or regional socioeconomic factors. This in turn is likely to require new knowledge, for example more detailed asset data, such as floor heights, construction methods, and exposure to expanding hazard zones. The interactions between financial professionals and scientists and impact experts may also change and expand the banks' perspective on the types of expertise that it considers valuable (it is also likely to change collaborating scientists' understanding of what is important!).

When boundary judgements and system definitions are being decided upon in an interdisciplinary space like physical risk, it is important to allow multiple perspectives to be heard, as no one disciplinary perspective understands the entire problem space. Pluralistic collaboration is a useful approach, and is explored more in 7. How to do interdisciplinarity well. Leigh et al. (2025) provides an excellent framework that explores a number of these issues in more depth in the space of physical risk assessment, and provides guideposts to tools suitable for each step of the development process, many of which integrate thinking about boundary judgements.

This remainder of this section outlines some key considerations that can play into boundary judgements and methodological choices in the context of PCRA and CRFDs.

4.2.4 Outputs of a physical risk assessment.

Outputs provided by a PCRA will obviously differ depending on the domain of impact, and agreed definitions of the boundaries of the system-at-risk (see 4.2.3 Boundary Judgements). In a financial risk assessment, outputs are likely to focus predominantly on financial metrics including dollar figure costs of impacts, which might integrate the costs of business disruption, clean-up, and reconstruction (see Appendix B: Methods and metrics in financial risk assessment for some detailed examples). Sector-specific risk assessments may also include more direct impact-related metrics, such as loss of life, business disruption, frequency of service disruptions, or rates of crop failure or loss of livestock in agriculture.

Ecological risk assessments may include loss of species or loss of viable habitat area, and these may feed back into financial risk. “Nature risk” assessment and reporting is a slightly separate process from CRFDs, and is still developing (for details see TNFD, 2023), so ecological impacts are not usually included in CRFDs. However, climate risk and nature risk are obviously closely related, and we would expect to see these reporting processes converge somewhat over time.

4.2.5 Capturing uncertainty

One of the fundamental reasons that decision-making is difficult is that the future is uncertain. As such, PCRA also needs to include some assessment of that uncertainty.

Prediction involves estimating **most likely outcomes** in the future, usually with some uncertainty, based on knowledge of the system’s long-term behaviours, as well as its recent past. Prediction is common in general financial risk and in weather, via **forecasting**, which aims to predict what will most likely happen next week, or next month. In climate science, even though we know that key driving variables (primarily greenhouse gases) are changing, we aren’t able to reliably predict the trajectory of those drivers, due to the high complexity of the socio-political systems influencing them. Because of this, and because of the chaotic dynamics present in the climate system, prediction of specific hazard events is not possible at climate timescales. Instead, climate science focuses on **projection**, which produces *conditional* forecasts that estimate what might happen to the system in the future, given some assumptions (e.g. specific emissions trajectories from scenarios such as the SSPs).

With this in mind, we can consider the presentation of climate-related risk information. Sometimes, risk projections might be requested as a "best-estimate", and it may be tempting to present a single number for a given risk metric. While a best estimate may sometimes be useful, this representation can be problematic because it may be misinterpreted as a precise prediction of the future (it is easy to forget that this is always a *conditional* projection in physical risk). A single value also does not allow the end-user to interpret assessment results under different risk thresholds (see Transfer functions, thresholds, and non-linearity). Climate risk disclosure standards do allow for reporting single amounts (paragraph 17, IFRS, 2023b), but we would suggest that doing so is only reasonable in conjunction with a very clear description of the meaning and interpretation of the value presented.

More information about the distribution of uncertainty can be provided by including error bars, quantiles, distribution parameters and functions, or diagrammatic representation of the distribution, or confidence and likelihood ratings. Which of these is most suitable will depend on the client's requirements. Note that it is also possible to qualitatively (non-numerically) indicate the existence of uncertainty using words, but this is risky, because it is non-specific and it can decrease trust in the numbers and in the source of the information (van der Bles et al., 2020).

It's also important to be clear about which **components of uncertainty** are included in any such representation (see fig. 7). Large ensembles of climate simulations already exist for the mainstream climate scenarios, and these can be used to estimate some elements of **climate uncertainty** (e.g. internal variability, or climate sensitivity). When climate information is used in a PCRA model, it interacts with multiple other important components, such as exposure and vulnerability information (see fig. 5 and 5.3.5 Connecting domains: Thresholds, and non-linearity), each of which also have uncertainty associated with them (which may be substantially larger than the climate uncertainty in many cases). If only the climate uncertainty is included in a PCRA, then the over-all uncertainty in the risk estimate results will likely be underestimated, perhaps substantially.

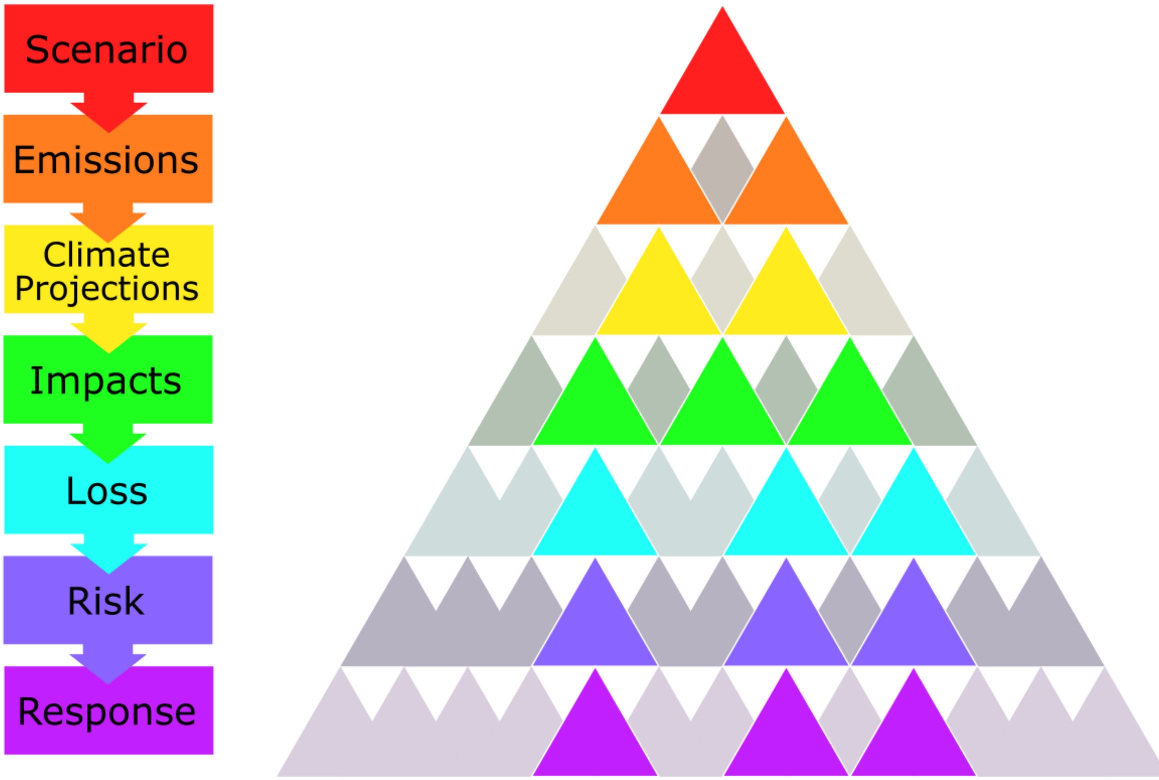

Figure 7: A cascade of uncertainty through various steps of the physical climate risk assessment process (after Wilby & Dessai, 2010). Each step adds its own uncertainty, and frequently throughout the process, these uncertainties are collapsed to a single value - for example, during the development of the Shared Socioeconomic Pathways (SSPs), the IAM-based scenario modelling process produced a multi-model ensemble of greenhouse gas concentrations, representing inter-model uncertainty. From this ensemble a single example was selected as a Representative Concentration Pathway (RCP), for use in driving climate models. This effectively collapses the uncertainty in this step (bottom of the orange triangles) into a single point (top of the yellow triangles) for each scenario. Similar processes happen at each step, but sometimes the uncertainty space of the preceding step is explored to some degree.

Climate scientists can struggle with the fact that PCRA models often disregard a large part of climate uncertainty. It is easy to focus on the component of uncertainty we know (e.g. climate sensitivity, inter-model uncertainty, etc.), and forget that we are also ignoring a large part of the preceding **socioeconomic scenario uncertainty** (e.g. SSP storylines and IAM modelling uncertainty) in a very similar way. This is predominantly due to our own discipline's normative understanding of the boundaries of the system (see 4.2.3 Boundary Judgements).

Model-based approaches can struggle with capturing uncertainty that compounds across domains (see fig. 7 and 5.3.5 Connecting domains: Thresholds, and non-linearity). While both climate and finance thinking tend to focus on quantitative, probabilistic forms of information, alternative qualitative approaches (e.g. see Storylines below) may be more informative in some cases, particularly when it comes to **deep**

uncertainties, such as tipping points, or future changes in complex climate dynamics (such as changes in the El Niño Southern Oscillation).

There are broader aspects of uncertainty too, including differences in scientific literacy, and differences in meaning and interpretation between disciplines/professions, so care must be taken when presenting risk projections and uncertainty associated with them (see 6.2.4 Understandings of risk, uncertainty, and ignorance and 6.3.1 Linguistic uncertainty, terminology, and language barriers).

4.2.6 Data quality issues

A key factor in consideration is the quality of the observational data that is used to train and run models. Observational data quality is always limited, as most climate scientists are well aware from their own disciplines. This may be significantly more true for some other types of data in the risk assessment chain.

Exposure data quality ranges from coarse and uncertain to extremely accurate at very high resolutions. For example, sub-surface properties, such as soil attributes tend to be more coarse, and are based models using satellite data and relatively few direct observations. Surface properties such as vegetation cover and topography tend to be readily available at reasonably high resolutions. All of these datasets can have substantial model or instrument errors in specific locations. For instance, though the SRTM digital elevation model dataset has a root mean square error of 6m (small relative to the heights of mountains), the authors know of one location where there is an erroneous 60m high hill in the middle of a sea-level mangrove swamp. In the context of sea level risk and coastal inundation, this is obviously a significant error.

Exposure-related problems can also occur in asset data. For example, the authors know of multiple cases, both from government data and from major financial institutions, where asset datasets place significant fractions of assets (including houses and farms) at centroids of suburbs or in the CBD of the state capital (usually this indicates that precise asset locations were not known, and partial addresses resulted in poor geocoding). This kind of information deficit is often easily rectifiable, but it gives an indication of the data limitations that are likely to face some businesses and financial institutions.

Vulnerability data may also be particularly difficult. For example, in the author's experience, property banks' asset data is rarely detailed enough to include ground-level floor heights of buildings in their portfolios. This can be a major problem, considering that many buildings in flood-plain areas are designed to handle major floods by having a floor height by many meters (e.g. buildings with raised ground floors, or with ground floor carparks as sacrificial flood zones). Other vulnerability data, such as construction methods or supply-chain network information, may be substantially more difficult to obtain or reliably estimate.

These data issues are likely to be more common for relatively new domains, such as PCRA, where it is still not clearly known what information is relevant or necessary for conducting analysis. Some of these issues will be ironed out over time. For now, when involved in PCRA collaborations, it is important to be on the look out for data issues that may not be well understood by the various disciplines involved.

5. PCRA methodological issues

What's in this section

- Overview of some different methodological approaches to PCRA.
- Methodological issues to be aware of that can make PCRA difficult.

Key take-aways

- There are many considerations that need to be taken into account before choosing an appropriate methodology for a PCRA.
- The space is complex, and comprehensiveness is always in a trade-off with viability given time and resources.
- As a result, all PCRAs are inherently incomplete, and the focus should be on regular evaluation and iterative improvement.

5.1 Ways of thinking about future risk

Risk assessment is fundamentally a process of thinking about the future. There are at least three broad approaches to thinking about the future that are applicable in a risk context:

- Predictive approaches that attempt to estimate future states or statistics (see 5.2.4 Mechanistic vs Empirical approaches).
- Scenario-based approaches that ask "what-if" questions, by assuming certain future events and then exploring the consequences.
- Reason based approaches that focus on causality and process understanding (see e.g. Storylines).
- Qualitative approaches, such as expert elicitation.

Both climate science and finance have a strong focus on quantitative methods (discussed further in 6.2.3 Ways and means), and so both fields tend to think about the future probabilistically, often using predictive approaches (e.g. climatologies, technical analysis) over the short-term. Scenario analysis is used in different ways by both climate science (e.g. ensembles of GCM simulations) and business (often simple projections based on macro-economic assumptions, see 5.1.1 Scenario Analysis), and both can also present probabilities, but these are contingent on scenario assumptions. While these two approaches may seem fundamentally different, probabilistic predictions usually have built-in assumptions of **stationarity**, which makes them effectively the same thing as a scenario analysis that explores the question: "what if things in the future stay the same as they were in the past?".

There are many useful methods for risk assessment, from creating simple analogies between similar situations and conceptual modelling, all the way through to complicated numerical physical simulations. Multiple models may also be used to explore the uncertainty space, for example in ensemble methods, or multiple lines of evidence approaches (explored more in 7.2. What makes interdisciplinary projects succeed?).

In the interests of clarity and usefulness, this section focuses primarily on common scenario and model-based approaches. The following two sections give an overview of scenario-based analysis, and the 5.2 Methodological considerations in PCRA section explores some key issues in methods development.

5.1.1 Scenario Analysis

Any prediction of the future of a socio-environmental system is inherently complex (discussed in the risk context in introduction to 4. PCRA requirements). **Scenario-based analysis** is a tool that can help us deal with some of that complexity. Scenario-based analysis allows us to approach complex problems with "What-if" thinking. A scenario is *a description of events that may plausibly occur in the future*, which may then be used to inform some other methodological approach (including predictive approaches). Scenario development involves **imagination** and **assumptions** about what is or is not plausible.

Fundamentally scenario-based analysis involves two steps:

1. Developing plausible scenarios, based on existing knowledge.
2. Use models to explore system response to those scenarios.

The two steps can and should be used iteratively, with new insight gained from scenario explorations feeding into the design of future scenario development (see also 5.4 Iterative methods development).

Scenario-based analysis can mean different things in different situations, so it is valuable to get a clear understanding of how the general approach works. Let's start with some examples:

- In military strategy, "war-gaming" is a type of scenario-based analysis where an initial situation is laid out, and commanders play out a plausible response using a simplified model of the situation.
    - War-gaming is already used by militaries for assessing situations that include climate-related risks (Burke & Cameron, 2022).
- In epidemiology, scenarios are used to understand pandemics by setting some initial situation, with assumptions about infection rates, and then simulating the spread of disease (Gerlee et al., 2024).

- In climate science, a “scenario” generally refers to a plausible future socio-economic trajectory (IPCC, 2022).
    - These trajectories are usually modelled using socio-economic storylines about the future, which are then used as inputs to Integrated Assessment Models (IAMs)[14], to produce projections of socioeconomic variables (e.g. SSPs) and greenhouse gas emissions and other climate forcings (e.g. RCPs). These outputs can then be used as drivers for climate models (where their output becomes inputs/assumptions to GCM simulations).
- In finance, a scenario analysis is a process used for estimating the performance of a business or an investment in response to assumed changes in some drivers (Tiberius, 2019).
    - A common type of scenario analysis is a **stress-test**, in which a major shock is assumed (the shock may be significantly worse than anything actually plausible in reality), and the response of the system is assessed, with particular focus on major modes of failure[15].

There are some commonalities in these approaches:

- It is not known how or when a particular event will occur.
- Instead, the analyst makes some assumptions about the initial situation, as well as the parameters that are expected to change, or a sequence of events.
    - **Plausibility** is optional here. A non-plausible assumption or set of events might be useful in testing the resilience of the system (e.g. stress tests that go beyond expected extremes) .
- Some kind of model is used to create simulated behaviour of the system. There are many types of possible models here, including:
    - Physical models (e.g. war-gaming, structural engineering)
    - Mathematical/analytical models (e.g. macroeconomics, financial analysis)
    - Computational simulations (e.g. climate science, system dynamics)
    - Qualitative models (such as Storylines)
- Some models produce a single result, which may be analysed in depth, others might produce many simulations, which can be analysed probabilistically.

In quantitative scenario analysis, probabilities are *always* contingent on the scenario assumptions. This is easy to forget. It’s not valid to say, based on climate projections,

[14] IAMs integrate economic modelling with coarse resolution climate modelling, and usually include components for energy systems, land use and agriculture, infrastructure, and other socio-economic elements. The wikipedia page gives a brief overview with many useful references: Integrated assessment modelling - Wikipedia.

[15] In recent years, multiple stress-tests have been run by financial regulators in various jurisdictions - many of these are based on climate-economic modelling, which has multiple known issues, see the footnote in Example approaches below.

that global mean temperature in 2100 will fall within a specific range, unless you also clarify that this assumes a particular socioeconomic pathway (such as SSP5-85).

An important point here is that, unlike modelling approaches calibrated on historical information, scenario-based thinking allows us to explore not only what is probable, but also what is plausible (but previously not experienced), even for complex systems over long time frames.

Scenario exercises are a method of disrupting entrenched patterns of thinking that may not be flexible enough to deal with oncoming change (Koch, 2021), and so are very useful for consideration of physical risk. Use of scenarios in business can also have a wide array of secondary affordances, including fostering systemic thinking and improving intra-organisational communication (Tiberius, 2019).

It should be noted that **scenario analysis means different things in business and climate science**. In climate science, “scenarios” nearly always refer to global socio-economic scenarios (e.g. SSPs) that focus on international scale development, and produce emissions pathways (among many other socio-economic variables that are mostly ignored by climate scientists). In normal non-climate-risk business usage, scenario analysis is focused on what would usually be expected to change in the outside environment of the business, including things like interest rates, policy and regulation, and market movements (Hayes, 2025). Future conditions are explored by creating scenarios that explore different sets of assumptions about these factors, and then modelling them using e.g. spread-sheet based Monte-Carlo simulations (Grube et al., 2022). This difference is a significant disconnect, while the approaches have a similar underlying intent, and a superficially similar quantitative focus, there will likely be some major hurdles to overcome in making methodologies from the two sectors speak the same language.

5.1.2 Scenario analysis in CRFDs

Scenario-based analysis is commonly required by CRFD standards and regulations. For example the IFRS S2 requires the use of “climate-related scenario analysis” (IFRS, 2023b). These requirements, however, are not usually very specific - IFRS S2 does not specify what kinds of scenarios, or even how many should be used.

Specific jurisdictional implementations may add additional requirements. For example, the Australian Sustainability Reporting Standards (ASRS S2, based on IFRS S2) also does not specify requirements for scenarios (see discussion in BC60-64, AASB, 2024a). However, some of the legislation surrounding the standards does: Treasury Laws require a minimum of two scenarios, that are “referable to” the two mandated scenarios, which include a scenario with a 1.5°C increase above pre-industrial global mean temperatures, and a scenario with an increase "well exceeding" 2°C - which effectively means +2.5C (ASIC, 2025b). But beyond that "referable" temperature increase, nothing is specified about the rate of temperature increase, the scenario assumptions, nor the method of analysis used in the scenario analysis. This is potentially problematic for comparability (see 4.1 Common needs of CRFD users), and the first few years of the phase in will likely include some diverse methodologies that will gradually converge into best practice. This presents a potentially very impactful opportunity for scientific critique of methods, as best practice emerges.

The following sections delve into considerations of assumptions and methods for PCRA likely to be used in scenario analysis.

5.2 Methodological considerations in PCRA

There are many ways to approach PCRA. Which method is the most appropriate for a given assessment will depend on the context and aims of the organisation. Regardless of method chosen, there are a few high-level concepts and categories of approaches that can be useful to consider:

- **Fitness-for-purpose** of the approach
- **Qualitative** vs **quantitative** approaches, as well as combined approaches like storylines
- **Top-down** vs **bottom-up** approaches
- **Mechanistic** vs **Empirical** approaches
- Model **validation** and **verification**

These are explored in the following sections. Here we use "models" to mean *representations of reality*, and "methods" (or "approaches") to describe the *processes used to conduct an assessment*. Methods in this space usually involve models of some kind, even if only conceptual, and most of the following commentary applies to both.

> ***Note:*** *the following is discussing considerations for* ***physical risk methods****, and while many of these points also apply to* ***climate models****, the purpose of each is different (e.g. estimating risk/consequences vs understanding climate responses), and so different choices will be made in a risk context relative to a blue-sky science context.*

5.2.1 Fitness-for-purpose

As most scientists know, all models are wrong, but some are useful (Box, 1976). For a model to be useful, it must be **fit-for-purpose**.

There are multiple possible purposes for scientific models, including *prediction, explanation, theoretical exposition, description,* and *illustration*. A model designed for one use is unlikely to be suited for another use (Edmonds, 2017). In the space of physical climate risk assessment and reporting, we are mostly concerned with estimation of risk (e.g. prediction), but we may also be interested in increasing understanding of the broader concept of physical climate risk using models (e.g. via explanation or illustration).

Hamilton et al., (2021) define fitness-for-purpose as any model that is **useful**, **reliable**, and **feasible**. In the context of PCRA and CRFDs, this means:

- **Useful**: That the results capture risk information that is **relevant** for decision-makers inside the organisation, for investors, and for regulators.
    - This means the method should be comprehensive (see 4.1 Common needs of PCRA users)
    - PCRA results need to be **accurate** in order to be useful for decision-making. They must not provide misleading information.
        - **Precision** may be important, but it depends strongly on uncertainty (see 4.2.5 Capturing uncertainty) in the method, and risk thresholds, and care should be taken to avoid **over-precision** (see 5.2.2 Qualitative vs Quantitative).
    - Sometimes partial information can be extremely useful, for example when the magnitude of change is highly uncertain, but the direction is clear.
- **Reliable**: That the methods can be depended upon to produce results that are useful. Reliability is a major contributor to credibility (see 4.1 Common needs of PCRA users).
    - The approach uses **up-to-date science** that captures the broad spread of scientific understanding, with minimal bias towards particular methods (e.g. no cherry-picking of particular results or methods without justification).
    - The results should be **robust** to small changes in input information. For example if an independent and unbiased subset of CMIP6 simulations is used, the results should be similar if a different unbiased subset is used.
        - The same applies to hazard, exposure, and vulnerability information.
    - If high-level results shift dramatically due to minor data updates, this suggests that some aspect of uncertainty is not being handled well (see 4.2.5 Capturing uncertainty).
    - However, care should be taken not to dismiss major results changes in updated risk assessments out of hand, as methodologies in this space are still developing (see 5.4 Iterative methods development).

        - Updates in other information, such as changes to a business portfolio, discovery of new impact pathways, or the inclusion of scenarios that explore tipping points or other large uncertainties (see 5.2.7 Extremes and Low-certainty futures), may also be expected to change results dramatically.
    - Providing evidence of reliability is best achieved via evaluation (see 5.3 Validation, verification and evaluation).
- **Feasible**: That the approach can be achieved within a reasonable budget and timeframe.
    - Given that risk disclosures exist within a paradigm of financial profit and economic growth, this presumably means that the disclosures should not cost so much that they themselves become a financial risk to the organisation.
    - This is ultimately a cost-benefit trade-off - ideally the cost of the assessment should be outweighed by the value of the results obtained.
    - CRFD is still a new field, and so expectations for time and finances that should be spent on PCRA are still not very clear, but clarity should emerge over the next few years.

Obviously a perfect model is not possible, and so there is always going to be a trade-off between these three factors. An optimal solution for one organisation may not be optimal for another.

Hamilton et al., (2021) argue that the overlap between these three factors can be improved by increasing end-user understanding of the assessment (increases usefulness), by improving the model developers' understanding (increases reliability), by increasing resources to the project (increases feasibility), or by encouraging closer engagement between users and providers. They also provide an in-depth framework exploring these three factors for use during model development that is appropriate for risk assessment processes.

The following sections explore a few concepts that can play into fitness-for-purpose, and that should be taken into account when deciding on a risk assessment approach.

5.2.2 Qualitative vs Quantitative

How information is conveyed is critical. Both finance and science have a strong focus on quantitative information, making it an obvious choice, as it has clear benefits for ease of integration and comparability. However, quantitative information can hide nuance, and is unable to fully capture some of the more uncertain, but potentially high-impact pieces of climate science knowledge (see 5.2.7 Extremes and High-Impact Low-Certainty futures).

Broadly speaking, qualitative approaches use descriptive, verbal or visual information to lay out a narrative description of reality, while quantitative approaches present numerical results that generally come from mathematical or statistical models that transform some numerical observations or estimations of reality. Each approach has strengths and weaknesses.

Quantitative assessment is obviously useful because it can slot easily into accounting and financial risk management approaches, and is compatible with data-based approaches to decision-making. This makes it immediately sought-after by financial analysts. However, quantitative analysis can have several pitfalls:

- Quantitative analysis can suffer from **over-precision**, particularly when uncertainty is insufficiently captured (and given there are always “unknown unknowns”, this is never completely avoidable).
- Numerical data can lead to **value capture** (Nguyen, 2024a) or **quantification bias** (Wang, 2016), where the user’s attention is narrowed to focus only on the information captured by the metrics, to the detriment of other information that might also be important.
- Quantitative metrics often capture high-level **aggregated** values (such as GDP) that arise as a result of many other smaller processes, but changes in these underlying processes are not necessarily captured due to uncorrelated variability in each process.
    - This can lead to important changes in the system going undetected until it’s too late (Wang, 2016), such that even well-understood systems can collapse into chaos (Snowden & Boone, 2007).

Qualitative analysis does not fit neatly into numerical financial reporting, but it can be extremely valuable in that it allows for nuance and important information that can not easily be captured in numerical data. Qualitative approaches can be useful for conveying meaning clearly in complex domains, such as physical climate risk, for example by describing conceptual models of complex interactions that are hard to convey using numerical models or are not represented in contemporary numerical models (e.g. High-Impact Low-Certainty futures, and systemic risk).

When choosing an approach, it is not an either-or decision whether to use qualitative or quantitative approaches - both can (and should) be used in conjunction, and the approaches can complement each other. Quantitative assessments also require qualitative components, for example when explaining the assumptions, limitations and caveats within a particular modelling approach, and qualitative description is usually necessary to communicate the meaning of numerical uncertainties (NGFS, 2022b). Qualitative approaches can be extremely useful for identifying key risks, particularly when relevant data is unavailable, they can also be useful for education, and for fostering the development of an expert community that can lay the groundwork for later quantitative assessments (NGFS, 2022b).

Storylines

Quantitative information can be embedded within a qualitative approach, for example in **storylines** (Fiedler et al., 2024; Shepherd et al., 2018; Baldissera Pacchetti et al., 2024), which use a narrative framework to describe a *plausible future* that is informed by and includes scientific knowledge and quantitative information (which may be drawn from observational data, the literature, expert elicitation, and/or model simulations). Storylines generally present a location- or event-specific scenario, for example a climate change-adjusted extreme fire season. They generally do *not* have associated probabilities, but focus instead on exploring plausibility and causality (probabilities may sometimes be assessed separately).

This means that storylines are not always easily insertable into predominantly quantitative accounting processes, which generally require expected values or some other precise figure that depends on quantified probabilities. And they are also not usually directly comparable across different locations or event types, due to spatial heterogeneity in climate and exposure. Storylines are therefore less likely to be suitable for broad-scale *many-small-risks* type assessments, such as a bank's nation-wide residential mortgage portfolio direct risk assessment. But they may be *very* useful for *one-large-risk* type assessments, for example major development planning, or the assessment of aggregated systemic risks to a state economy, in particular because they combine well with **bottom-up analyses** that look at vulnerability and exposure first.

Storylines may also be useful for exploring systemic risk, where storylines can be built around the effects of aggregate physical risk on broad socio-economic systems. This is, however, contingent on the possibility of building a *credible* storyline (see 4.1 Common needs of CRFD users), and the main methods currently used for exploring systemic risks are based on highly aggregated and empirical economic modelling, which is likely massively underestimating future impacts (see next section, particularly footnote 16). Alternative methods using other approaches are yet to emerge, and will face an uphill battle to overcome the cultural hegemony of mainstream economic approaches. The next few sections explore some considerations that would need to be addressed in such modelling.

5.2.3 Top-down vs Bottom-up approaches

Another common distinction that is made between modelling approaches is that of **top-down vs bottom-up modelling**. Unfortunately, this terminology, while perhaps superficially clear upon initial inspection, is not necessarily very clear-cut in reality.

Terminology and definitions

Part of the problem is that the terminology is common in multiple related fields[16]. For example, in business sales forecasting "bottom-up" refers to starting with granular forecasts from individual departments and then aggregating results, while "top-down" starts with high-level company performance metrics and broader economic information (Donnelly, 2023). In the financial risk space Kurian et al. (2023) uses the terminology to draw a distinction between regulator-run scenario analyses (top-down) and institution-run scenarios (bottom-up). In the climate adaptation space "bottom-up" approaches are focussed on understanding existing vulnerability and resilience, and building adaptive capacity in systems under threat, where "top-down" approaches aim to understanding climate change via GCM projections, and focus on modelling impacts and policy (Dessai & Hulme, 2004; Wilby & Dessai, 2010). In the context of IPCC processes, Sutton (2019) uses the terminology in an almost opposite fashion, where "bottom-up" means "starting with the scientists rather than with the needs of decision-makers".

PCRA is still a relatively new field, and although top-down/bottom-up terminology is used regularly (Arribas et al., 2022; Attoh et al., 2022; Pitman, Fiedler, et al., 2022), there does not seem to be a clear universal definition for the field. For the purpose of this discussion, we will use these definitions:

- **Top-down**: An approach that estimates whole-of-system risk directly, starting with aggregated metrics and high-level drivers.
    - System-level risk may later be disaggregated to system components (e.g. firms operating within a nation).
        - This approach risks significant loss of relevant context-specific information, particularly if risk drivers operate at the lower levels.
- **Bottom-up:** An approach that estimates risk at the component level, and then aggregates the risk up to the system level.
    - Aggregation can be complex, and may need to take into account interactions between system components (e.g. community resilience, market interactions between firms) that might lead to emergent behaviour at the system level (Curtin & Allen, 2018).

Where the "system" may be defined differently for any given context (e.g. which components to include, see 4.2.3 Boundary Judgements), for example:

- A national economy and the businesses within it.
- A local government and its departments and services.

[16] Top-down/bottom-up terminology is also used in fields outside of system modelling, https://en.wikipedia.org/wiki/Bottom-up_and_top-down_design summarises a number of them.

- A business, its assets, and critical supply chains.

In each of these system definitions, effects from components outside the system bounds (e.g. external businesses, the market and regulatory environment, neighbouring regions, and broader society and environment) may be aggregated or intentionally excluded (Curtin & Allen, 2018), as long as the choice to do so is justifiable.

Arguably there is no objective “bottom” or “top” to any systems that we might be concerned with in physical risk, because there are always broader systems, and components can themselves be considered systems (Curtin & Allen, 2018).

Example approaches

Some examples of different types of approaches, and how they fit against these definitions:

- CRFD standards require scenario information that is usually based on GCM simulations. Global is about as whole-of-system as could be relevant in the domain of physical climate risk.
    - However, knowledge gained from global climate simulations can also be used in bottom-up approaches (see e.g. Storylines above).
- **Climate-economic modelling** is top-down because it assumes that all firms within a sector/nation operate identically, and uses economy-level damage curves that do not allow for inter-firm variance.
    - Climate economic approaches often use **Dynamic Stochastic General Equilibrium** models (DSGEs), and relate highly aggregated climate variables (e.g. national annual averages of temperature or precipitation) to highly aggregated economic variables (e.g. GDP) using **damage functions**, which are usually a simple empirical function such as a quadratic or a sigmoid[17].
- **Asset-level modelling** is a common approach that is generally considered bottom-up. It certainly is for considerations of exposure, where asset location is known[18].

[17] A range of criticisms have been levelled at General Equilibrium model-based risk assessments, including that they grossly understate the risks of global warming (Keen et al., 2021; Neal et al., 2025), are highly sensitive to poorly constrained parameters (Pindyck, 2017), do not capture extreme risks (Stern et al., 2022), can not predict complex, dynamic and sometimes irreversible state shifts such as financial collapse or biophysical tipping points (Keen et al., 2021; Stern et al., 2022; Trust et al., 2023), generally have a “flawed description of the underlying economy” (Stern et al., 2022), and that they do not capture the complexity of the financial system (Monasterolo, 2020). (Trust et al., 2023) in particular presents an introduction to many of these issues from an actuarial perspective that is extremely accessible to both scientific and financial audiences.

[18] Although in our experience, in some sectors a disturbing number of firms do not know the precise locations of their assets, and asset datasets often include assets with obviously incorrect locations.

    - However, if asset vulnerability is modelled (e.g. via globally applied vulnerability functions) rather than based on real asset information, then the vulnerability component is actually top-down.
    - **Natural Catastrophe Modelling** (NatCat) is an example asset-level methodology commonly used in insurance. Historically it was applied at a much coarser scale (e.g. statistics applied over postcodes or local government areas)
- **Vulnerability-first** or **decision-first approaches** (Shepherd et al., 2018) are the most bottom-up approaches, although they may include globalised assumptions in some aspects of the modelling.
    - Vulnerability-first approaches are most suited to in-depth single-project risk assessments, where detailed vulnerability information is readily accessible.
    - These approaches are less likely to scale well, and it may be harder to translate the methodology to other similar projects, because vulnerabilities will vary by local context.

In practice no fit-for-purpose PCRA methodology is likely to be wholly top-down or bottom-up. Instead, each model component and model assumption may include aspects of each. Methodologies may benefit from both a decision-first approach, while using information from global climate simulations (see 5.2.6 Scale and Resolution issues).

Considerations for which approach to use

Strong arguments have been made that bottom-up approaches are preferable. Top-down approaches can hide spatial and temporal heterogeneity in exposure and vulnerability, and are likely to have lower local robustness (Arribas et al., 2022; Pitman, Fiedler, et al., 2022). However, while bottom-up approaches may be ideal for small-medium businesses in discrete geographical locations (where key hazards and vulnerabilities are well known), they may be less feasible for large and spatially diverse organisations (particularly for institutional investors), due to the scale and complexity of the system-at-risk and the analysis required.

This distinction is perhaps most useful because it begs some questions:

- To what extent can the needs and scope of a given PCRA be generalised across different contexts (e.g. across different regions, or socioeconomic factors)?
- When is it OK to assume that one PCRA can use the same approach as another?
- When is it OK to assume that system components (e.g. assets, firms) are homogenous in their exposure and/or vulnerability, or to what degree does the analysis need to account for heterogeneity among them?

So, for instance, a top-down approach may be useful for regional prioritisation by a national government, as a first-pass approximation for identifying key at-risk areas, but it is not appropriate for asset-level adaptation planning, where differences in exposure and vulnerability between assets can dramatically alter their risk profiles.

We would argue that these questions are critical to answer in any physical risk assessment in the scoping phase (see 4.2.3 Boundary Judgements), and that they should inform the choice of methodology and output metrics, and be reassessed during methodology review processes (see 5.4 Iterative methods development).

5.2.4 Mechanistic vs Empirical approaches

Another useful distinction to draw between physical risk modelling approaches, is between **empirical** models, which attempt to model system-scale effects directly from the data, and **mechanistic** models, which use theoretical knowledge of underlying drivers and processes.

Empirical approaches and AI

Empirical approaches use observed data along with statistical or machine-learning (ML) models to detect and model relationships between measured variables. For example, relating driving variables such as annual mean temperature directly to economic impacts. Empirical models have the benefit that they require minimal theoretical understanding, but usually make the assumption that relationships can be captured by functional regression. They can be quick to develop, and can potentially discover non-obvious relationships in the data (e.g. exploratory ML approaches that can capture multi-dimensional non-linearity).

Empirical approaches are used in both science and finance (e.g. climatologies, technical financial analysis). These approaches generally make assumptions of **stationarity** (or trend-stationarity) that are not valid in all situations. For example, climate change is a form of non-stationarity (Milly et al., 2008).

Drawbacks of empirical approaches include the fact that copious data is often required to train reliable empirical models, particularly when there is a lot of noise in the data. This can be a problem when data is not publicly available (this is often the case with impact and loss data in the physical risk space, see Transparency and knowledge sharing below). Care must be taken when using empirical models to avoid over-fitting on the training data, and these models should be used with caution when attempting to extrapolate outside the domain of the training data.

Machine Learning (ML) and **Artificial intelligence** (AI) based approaches are also worth mentioning, since many climate risk providers are attempting to use it to produce risk assessments (and since it is so prominent in the zeitgeist). ML approaches focus on detecting patterns in data. These approaches are generally reasonable if there is sufficient data to train a model reliably. More complex non-linear AI approaches, such as **deep learning** with recurrent neural networks, come with more power, but also more risk of over-fitting and capturing spurious patterns in noise in the training data - risks which can often be mitigated using careful training procedures.

Across AI and ML approaches, many training procedures produce **black-box models**, which can make results hard to interpret and understand (potentially reducing credibility, see 4.1 Common needs of CRFD users). This is a particular problem in the context of complex climate hazard drivers, such as circulation dynamics, as it can be hard to tell why a model is providing a particular response to a given set of inputs, and whether it is capturing known physical effects. **Explainable AI** (XAI) is an area of research that tries to examine black-box models in order to make them more transparent and understandable, and is potentially a good way around some of these problems (for an overview in the climate space, see Mamalakis et al., 2022).

Generative AI, due to its initialisation with random noise, is a bad idea in any situation that requires reliability and precision, and so it should not be used in the creation of PCRA results (Hicks et al., 2024). Given the risk of linguistic uncertainty (see 6.3.1 Linguistic uncertainty and language barriers), and the facts that GenAI does not understand the concepts that it describes (Mancoridis et al., 2025) and cannot make judgements (Perc, 2025), care should also be taken when using it to write or edit content for risk assessment.

Mechanistic approaches

In contrast, **mechanistic approaches** use our theoretical understanding of physical processes to inform conceptual models, which can then be encoded in mathematical formulae. Often this theoretical understanding is built on decades of empirical science that led to its development. This approach can benefit from pre-existing knowledge to build models with very little observed data, as long as the theory is well understood. If we trust the underlying theories and assume that the mechanisms captured by the model continue to hold over a broad domain, then we can also use mechanistic models for extrapolation to a greater extent than empirical models (e.g. GCMs use physical laws to provide imperfect but useful projections into the distant future).

Disadvantages of mechanistic approaches include that they can require substantial research and development time, and that they can neglect critical relationships that can result in biases. Mechanistic models of any complexity (particularly those with feedback loops) can also produce chaotic dynamics, which means that they can be useful for simulation and projection, but not directly for prediction, unlike some empirical models. It should also be pointed out that mechanistic models are only plausible in situations where the mechanisms are well understood (such as in climate science, which is dominated by a few well understood mechanical processes, such as the Navier-Stokes equations for fluid dynamics). In highly complex situations with many interacting and uncertain relationships (for example, social interactions or the functioning of large market economies), cause-and-effect may not be measurable, or even understood, and so a mechanistic model is not always viable.

In practice, all but the most simple mechanistic models are usually a combination of both empirical and mechanistic components. For example, NatCat models, while generally developed via an overarching empirical approach, may contain components that are informed by physical theory (for example storm surge calculations in the HAZUS mode, FEMA, 2024).

The key take-away for this section is that there is no single best approach, and approaches should be chosen based on the given risk assessment's context and needs. Whether risk is modelled via empirical methods, mechanistic methods, or (more likely) a mix of both will depend strongly on the hazards and impacts in question (see 4.2.3 Boundary Judgements), as well as the availability of data, prior research, existing models, and expertise, and in most cases should be combined with an iterative approach to model development (see 5.4 Iterative methods development). The next section explores why expertise in particular is critical when linking models across a chain of disciplines.

5.2.5 Connecting domains: Thresholds, and non-linearity

The domains of understanding of climate scientists and finance professionals are situated in distinct and largely disconnected parts of the PCRA space (e.g. the left and right sides of fig. 5), and intermediated by multiple other fields, including hazard- and impact-specific sciences (such as hydrology), engineering, risk management, social sciences, and economics.

If we want to assess physical risk via quantitative modelling, then we necessarily must create models that connect between these domains. Note that this is not the only approach (e.g. see Storylines above, and 5.2.2 Qualitative vs Quantitative), however the problems presented here also apply to many other approaches.

Fig. 8 presents a simplified example of a series of models connecting a climate driver (precipitation distributions) to a financial loss metric (repair costs for a house damaged by flooding). The figure shows how each intervening model responds to the drivers estimated by the preceding model.

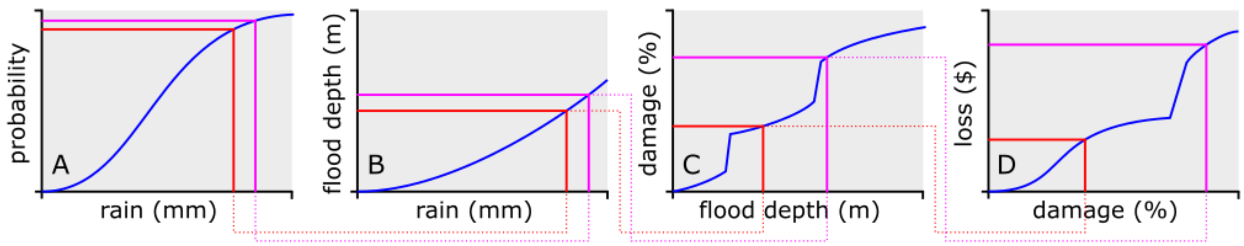

Figure 8: A schematic model of flood impacts that relates probability (y-axis, panel A) to financial losses (y-axis, panel D) for a hypothetical asset, through a series of simple empirical sub-models. Relationships between connected models are shown via dotted lines, for two thresholds (red and pink). Model A represents the probability distribution of rainfall in the local area, B represents flood depths as a function of rainfall intensity, C represents fractional damage to a house as a function of flood depth, D represents the financial losses (e.g. repair costs) incurred as a function of damage. Each transfer function is non-linear, and can have jumps or discontinuities e.g. as flood depths get high enough to require electrical systems to be replaced.

There are a few things we can take from this schematic example:

Firstly, non-linearity in models (which is nearly always present in real-world applications) means that very small differences in one part of the chain can result in very big differences elsewhere, and vice-versa. This means in particular that you can't know *a priori* what kinds of thresholds are important at the hazard or climate driver level, even if you can state your *risk* thresholds precisely, because each of these non-linear transfer functions vary in shape by location and asset (according to climatological, hydrological, structural, and financial parameters).

This is compounded by the fact that each of these sub-models usually has variability (e.g. spatial variability in precipitation distributions, or different damage functions for different types of asset, or different recovery times as a function of socio-economic factors), and uncertainty (e.g. modelled flood depths are dependent on catchment properties like soil composition that may not be well known). This means that it is not straightforward to associate thresholds at the end of the modelling chain, where bad outcomes occur (e.g. loss tolerances), with thresholds earlier in the chain, where climate change is happening (e.g. precipitation amounts).

These problems are compounded by the fact that quantitative approaches *within* disciplines are also information lossy (see 5.2.2 Qualitative vs Quantitative). Lots of knowledge, particularly around sources of uncertainty, edge-cases, and nuances and idiosyncrasies of particular corners of each discipline, can not be conveyed via quantitative approaches. Depending on the resources available for the risk assessment, these problems may be alleviated via a pluralistic approach that seeks deeper collaboration with each of the relevant disciplines (see 7. How to do interdisciplinarity well).

Financial risk (and all risk) is fundamentally concerned with variability of expected **losses**. These risk thresholds[19] (see 3.2 Business Risk Management) are *not* directly related to the variability of hazard events or climate drivers, they are only influenced by them in non-linear and variable ways. So knowledge about *hazard* probability or severity thresholds alone is not useful, unless those thresholds are informed by understanding that is drawn from across the entire information chain (see fig. 5 and fig. 8).

However, there is no discipline or profession that is capable of understanding this entire modelling chain in full depth. Climate scientists may have a deep understanding of local precipitation distributions, but are unlikely to have a strong understanding of how a house design will respond to floods of different depths and flow rates. A financial analyst might be able to relate damage figures to long-run average costs using historical loss data, but is unlikely to have a good understanding of a given location's flood profile as a response to precipitation and landscape heterogeneity.

There may be individuals who have a broad understanding of all of these fields (e.g. risk experts, see 6.1.2 Roles and Organisational Structure), but broad understanding tends to be shallower, and is likely to miss nuance that an individual with deeper understanding of a specific field might see. That said, individuals with a broad understanding across multiple disciplines can be very useful for high-level first-pass risk identification (see 5.4 Iterative methods development), and for coordinating development of deeper risk assessment approaches.

5.2.6 Scale and Resolution issues

A common complaint about physical climate risk assessment approaches is that the climate data doesn't support fine-scale risk assessment (e.g. Pitman et al., 2024). For example, at resolutions at the scale of GCMs or finer (100km or less), trends in most climate variables (perhaps excluding mean temperature) are extremely uncertain, often to the point of not even knowing the direction in which change is likely to happen. This is less of a problem at regional scales (hundreds to thousands of kilometers), because climate models are generally better able to represent the large-scale phenomena that dominate these scales, and because noise in the data is more likely to cancel out due to spatial averaging, leaving the signal more detectable.

But climate risk is *not* just a function of climate. It is also a function of exposure and vulnerability (see What's important in a physical climate risk model?). For many

[19] Arguably, threshold-based assessments don't capture quantitative risk fully, and should actually look at the entire shape of risk across the whole spectrum, i.e. the integration across all probabilities and severities. This quickly becomes infeasible due to complexity and computational costs though, and threshold-based assessments can still be very informative, as long as understandings of relevant thresholds and model limitations are developed collaboratively across the chain of disciplines.

hazards, exposure can be strongly constrained by available geospatial data, which is sometimes available at extremely high resolution. For instance, Digital Elevation Models (DEM) use satellite data combined with modelling to estimate ground level elevations at resolutions as fine as 1m. DEMs are useful in estimating exposure for flooding and sea level rise, and are a core component of flood modelling. Other data such as vegetation or soil composition maps can be useful in modelling various hazards, such as wildfire, and are commonly available at resolutions on the order of tens to hundreds of meters.

These high resolution datasets allow for reasonably fine-scaled **baseline** risk estimation when combined with historical loss and climate data. Combining this information with regional climate trends from GCM- or RCM-based projections allows for estimates of changing risk over the future, as long as a few conditions are met:

- That local **historical climate data** is sufficient to estimate baseline risk
    - Noting that historical climate distributions can be poorly constrained by data in some regions, particularly for extremes
- That the **meaning** of changing metrics are clearly articulated
    - e.g. that it is a climate shift applied to baseline risk assessment, limited by underlying model assumptions
- That relevant **uncertainties** are well managed
    - That it is clearly stated that local climate trends may differ from regional trends

In some cases, differences between local and regional trends might potentially be managed via **statistical downscaling**. However this approach makes the assumption that dynamic elements of the climate system remain constant, which is unlikely in many cases (Milly et al., 2008).

Dynamical down-scaling is often posed as part of the solution, but RCMs require a lot of computational resources, and as a consequence dynamical downscaling projects often produce small ensembles, from which it is not possible to draw clear statistical information about very localised trends anyway. RCMs are still extremely useful for process-based understandings though (Stainforth, 2024), and so these projects can provide extremely valuable insights that can be used via storyline approaches (see Storylines).

5.2.7 Extremes and High-Impact Low-Certainty futures

Extreme weather events are a key driver of physical climate risk, and so are of critical interest in climate risk assessment. Some “High-Impact Low-Certainty” (HILC) future[20] scenarios present plausible large increases in some types of hazards. For example an AMOC shutdown, or a shift to a permanent La Niña-like climate, would result in dramatic shifts in precipitation and temperature distributions in many regions. Both of these futures are very plausible but not well captured by mainstream climate scenario ensembles, and so it is difficult to assign a probability to either scenario.

This difficulty leads to problems with risk assessment in both directions. High uncertainty may cause some users to ignore the risk all together (see 6.3 Communicating results with finance). In other cases presenting plausible outcomes without probabilities may result in them mistakenly being interpreted as *expected*, perhaps worsened by existing incentives for scientists to overstate the potential impacts of their work (West & Bergstrom, 2021). If care is taken to present these futures as plausible, rather than probable, then information about them may still be usefully integrated into risk assessments.

There are many other difficulties faced by risk assessors interested in extremes. For example, how do you decide where to set your thresholds for very extreme events, especially considering that distribution tails are often less well constrained than the central tendencies? How do you integrate information from scenarios with unknown probability into quantitative risk frameworks? Or how do you deal with the possibility of many different low-probability **existential threats** (noting that for a given risk assessment, only some known HILC scenarios are likely to be relevant)? And if adaptation is possible in many of those cases, how do you prioritise resourcing?

Some research does exist exploring these questions. For example, Wood et al. (2023) presents a framework for exploring high-impact low likelihood climate futures in a risk context, which recommends a focus on outcome-defined storylines (see Storylines), early warning indicators, and monitoring systems. Other fields of risk that are less focused on probabilistic and quantitative impact estimation, such as cyber security or pandemic response, may also provide useful examples for how to approach management of these kinds of extreme risks.

Usually, these questions are highly context-dependent, and so can not be answered for physical risk assessment generally. Systemic triangulation (as described in 4.2.3

[20] “High-Impact Low-Likelihood” (HILL) is a term commonly used in this context, but it is potentially misleading, because many such scenarios have no agreed likelihood, and as certainty increases, likelihoods for some may turn out to be not all that low.

Boundary Judgements) provides a tool for exploring context-sensitive answers to these questions.

5.3 Validation, verification and evaluation

How do we know a given model or method is reliable, (and therefore credible, see 5.2.1 Fitness-for-purpose)? The naive view says that we should verify and validate our models, where (following Goosse et al., 2010) validation entails "determining whether the model accurately represents reality" (by comparing results against observations), and verification means "to ensure that the numerical model solves the equations of the physical model adequately" (i.e. the numerical model matches conceptual, with no bugs).

However, for a number of reasons, earth science models such as GCMs are not meaningfully verifiable or validatable (Oreskes et al., 1994)[21]. PCRA methods, which generally depend strongly on projections from GCMs, are therefore also not able to be meaningfully validated or verified.

(Parker, 2020) argues that a better approach is **model evaluation**, which is an attempt to assess a model's suitability for an intended purpose. Model evaluation focuses mostly on the reliability and usefulness components of fitness-for-purpose. Traditional approaches to model evaluation tend to focus on whether the model is a good representation of the target system being modelled, but in order to understand whether a model has adequately achieved its purpose, we also need to account for a number of other things (Parker, 2020):

- Whether our **observational data** is sufficiently comprehensive, unbiased, and large enough to constrain uncertainty,
- Whether the method has **limitations** or **assumptions** that might affect the result,
- Whether the **circumstances of model use** might affect the results, and
- Whether the user has capacity to **interpret and understand** the results.

We would suggest that any climate risk assessment provider *must* have some form of methodological evaluation in place, and that it should encompass all of these points. Providers with ongoing risk assessment modelling systems should have processes in place ensuring that model evaluations are updated on a regular basis. Individual assessments should include summaries of recent evaluations, as well as descriptions of

[21] Note that (Oreskes et al., 1994) uses different, but overlapping, terminology, where verification is to show that a model is true, and validation is to show that a model is legitimate and does not have any detectable flaws.

how the model was used for the assessment, and these should both be tailored to user capabilities.

What the precise details of a given model evaluation will look like depend on the context, purpose and approach chosen. The field is still relatively new, so best practice is not well defined, but will begin to emerge over the next few years. However, there are some high-level categories that should be considered in any model evaluation, and ideally included in model **documentation**:

- Description of the **purpose** and **capabilities** of the model.
    - This should include the **scope** of the method (e.g. the domain of fitness), with rationale for scope limitations
- A **literature review** capturing up-to-date and relevant science
- Description of the **methodology**:
    - At minimum an overview of the **model design**, with rationale for choices made, and ideally including technical details
    - Description of any **assumptions and limitations** of the methodology, and the rationale for each assumption (NGFS, 2022a).
    - An overview of uncertainty in any components drawn from the literature.
- Description of any **data** used in the model, including
    - Assessment of variance and **uncertainty** in the input data
    - Description of any **calibration** procedures for empirical parameters
    - Assessment of **model sensitivity** to inputs and parameter specifications
- Some **performance evaluation**, including:
    - Assessment of the model's **ability to recreate past behaviour** compared to observations, for climate drivers, hazards, and impact metrics, where possible.
        - Note that good performance over the past does not guarantee good performance over the future, particularly when dynamic system components are dominant (Oreskes et al., 1994; Reifen & Toumi, 2009).
    - Description of model's **behaviour over the future**, ideally compared to projections in the literature where possible, and including assessment of uncertainty.
    - Note also that while many parts of the modelling chain may already be well evaluated (for instance GCMs are frequently subjected to many diverse evaluations), good performance of individual components does not guarantee good performance across the entire modelling chain. Performance evaluation also needs to be undertaken on the physical risk model as a whole.

We recognise that there are sometimes constraints that limit the ability for a provider to undertake or share elements of a model evaluation process, such as availability of data or intellectual property rights concerns. Ultimately this boils down to trust from the perspective of the model end-user (and assurers and regulators). Model transparency (e.g. methods description, code, input data) and model output validation are both methods of building this trust (Arribas et al., 2022; Horton, 2024).

5.4 Iterative methods development

PCRA is a new and evolving discipline, and as a result, methods are not yet well developed. The IFRS standards do attempt to push the industry towards consistent and comparable disclosures, but so far they do not specify any methodological or validation requirements, particularly for physical risk[22]. In practice, the industry is currently a mishmash of actuarial science, consulting, AI start-ups, and sector-specific approaches (UNEP-FI, 2025). Given that comparability is a central need for CRFDs, but individual sectors also have diverse needs, it may take some time for broadly agreed methodological requirements to emerge. Put another way, **best practice can not exist yet, because good practice is only just starting to emerge**. So how do we approach methods development in such an uncertain space?

Continual improvement is a core part of risk management (see 3.2 Business Risk Management) that is absolutely applicable to physical climate risk assessment, as described in (Ranger et al., 2022). Australia's National Climate Risk Assessment (NCRA) is one notable example of methods development that embeds this idea (DCCEEW, 2023). The NCRA included a scoping phase (stage 0), followed by a literature review, an initial risk identification and an assessment of a small set of priority risks (stage 1), and then a deeper assessment including quantitative risk analysis and adaptation assessment (stage 2). The NCRA methods build on pre-existing research, and, assuming continued government support, are likely to continue to be updated every few years, in a similar way to the United State's National Climate Assessment (NCA) reports (Crimmins et al., 2023).

Reports for financial institutions and companies operate on a different scale, but processes like those used for the NCRA and the NCA provide useful learning opportunities[23]. The requirement for annual reporting also presents opportunities for learning year-to-year. Unfortunately this learning is at least somewhat dependent on transparency of methodology which, while common in science and government, is not

[22] IFRS S2 does require that the methodology is described, but does not specify how much detail should be provided (IFRS, 2023b).

[23] At least up until the 5th NCA in 2023 - the 2025 report provides learning opportunities of a different kind, https://interactive.carbonbrief.org/doe-factcheck/index.html

the natural approach in finance or corporate consulting (discussed in more depth in 6.2.3 Ways and means).

Iterative methods development approaches also depend upon reliable feedback systems. Unfortunately, physical climate risk assessment struggles with this process, predominantly because climate timescales do not allow for reliable feedback on risk assessment results - it may be decades before we can know if our risk assessments were “correct”. And unlike weather, where we can repeatedly test our predictions on a daily basis, with climate change we only get one climate future - one instance of all potential future climates, so it will be impossible to state with any certainty whether our probabilistic results were correct.

The solution to this apparent contradiction is not obvious. Part of the solution is to rely on existing science from the literature where available, and possibly expert elicitation (O’Hagan, 2019). This is particularly useful for the climate and hazards parts of the risk equation, many of which have well developed literature. This approach also allows more diverse and comprehensive use of existing knowledge, through **multiple lines of evidence** approaches (see for example Sherwood et al., 2020, and Wasko et al., 2024), the results of which can be integrated into storylines (pluralistic approaches are discussed further in 7.2. What makes interdisciplinary projects succeed?).

A second possibility is to consider the key components of the risk analysis chain (e.g. climate, hazard events, exposure, vulnerability, and financial loss), and to look for room for improvement in each. Vulnerability in particular is perhaps the least well understood part of the chain (Hain et al., 2022), and is also the most organisation-specific (particularly for sector-specific corporations), and may provide excellent opportunities for iterative improvement, as long as risk management processes include room for monitoring, review, and process improvements.

Any model improvement process should be incorporated into organisational governance processes. This should include linking model development into evaluation and documentation (see 5.3 Validation, verification and evaluation). Review and development processes should take into account risk assessment context and perspectives from diverse stakeholders (see 4.2.3 Boundary Judgements and 7. How to do interdisciplinarity well). Leigh et al. (2025) in particular provides a broad framework that takes these factors into account and provides guidance on useful approaches for ongoing context-aware development of risk assessment methodologies.

6. Disciplinary differences

What's in this section
● How scientific information interacts with financial decision-making ● How business roles affect aims, focus, and interactions with scientific information ● How different disciplinary/professional perspectives view risk and related issues ● Communication barriers to be aware of

Key take-aways
● Understanding how different disciplines, professions, and roles approach a problem differently can help reduce difficulties in collaborating and communicating

6.1. Aims and needs: Who wants what, and why?

If we want to successfully collaborate on risk assessments with finance professionals, it's critical to understand who we are collaborating with. We need to understand what kinds of questions they need answered, and why those questions are important, as well as how they will use the information we can provide. In order to do this, we need to understand their background and worldviews, and approaches to understanding risk. Each of these factors can act as drivers of, and constraints on, decision-making behaviour. Actively interacting with other disciplines is an excellent way to learn (see 7. How to do interdisciplinarity well), but introductions to some key ideas can speed up this learning. So this section explores some of these topics in overview.

6.1.1 Science in financial decision-making

Decision-making is a complex topic that is critical in many areas of society. It also has a rich research history, and pulls together knowledge from diverse fields including behavioural science, management theory, and economics[24]. Decisions in any field involve many factors, including the identification of **needs**, and **values**; access to information and broader context; management of uncertainty; application of logic,

[24] (Teale et al., 2003) provides a decent entry point for broader theory of decision-making in business, and integrates perspectives from many of these disciplines.

rationality and emotion; influence of external drivers (such as deadlines, or political pressures); and prioritisation of resources (Teale et al., 2003).

This section focuses on the implications of decision-making practices in high-level business contexts (e.g. investment and executive decision-making), for climate scientists interacting with the sector.

Science is often used in decision-making, for instance in healthcare, to determine efficacy and side-effects of treatments. Scientific information contributes to decision-making alongside a broader array of information, such as quality of care during treatment, working conditions of healthcare employees, and costs. This information is often not quantitative, and also interacts with multiple **values** from diverse stakeholders (e.g. patients, staff, pharmaceutical companies). This often means that there is no single outcome that is obviously the optimal choice from all stakeholder perspectives

Financial decision-making is different, because it aggregates all values down to a single metric, the price signal (see 3.3 Financial risk). Because financial decision-making has a single primary objective (profit), it becomes a unidimensional optimization problem. This focus on a single metric can be a problem when dealing with complex issues (such as climate risk), because it aggregates across variable, heterogeneous, and uncorrelated multi-dimensional value space down into a single dimension. This is inherently a process that results in information loss, and so it obscures knowledge that may be relevant for decision-making (Nguyen, 2024b). In particular, the methods used to aggregate from a multi-valued space down to a single dimension involve choices on how to prioritise those values, and those choices become effectively invisible after the fact (Nguyen, 2024b).

Fundamentally, there are three ways to interact with a system of decision-making that is focused on limited quantitative metric-based information: creating new parallel metrics, changing the meaning of existing metrics, or communicating non-quantitatively in parallel to metrics. Each option has pros and cons.

The first approach is to create new metrics that can be used alongside existing metrics. This entails measuring and reporting non-financial phenomena, for example the successful tracking and phasing out of CFC usage via the Montreal Protocol (UNEP, 2018). Thousands of metrics and indices that attempt to capture sustainability issues in supply chains have been proposed and used, but most suffer from a lack of continued use (Ahi & Searcy, 2015), and despite three decades of the Triple Bottom Line framework, there are still no widely used metrics focused on the social or environmental components. This perhaps indicates a general difficulty in shifting the business sector away from a uni-dimensional worldview.

The second approach is to expand the meaning of the metric to encompass more of the wider value space. In financial terms, this means costing things that were previously considered **externalities** or otherwise irrelevant, and integrating those costs into the market, such that they affect the price signal. This is the purpose of environmental economics[25] in general, and various attempts have been made to put a financial value on ecosystem services. Carbon pricing, via a carbon tax, or an emissions trading scheme, is an example of this in the climate mitigation space.

Climate risk is also a form of this approach. Transition risk attempts to capture the financial materiality of strategy and governance failing to keep up with shifting market conditions related to climate responses. Physical risk integrates expected financial losses from climate impacts into financial accounting.

This approach still collapses a multi-dimensional risk space into a single metric (price), as described above. This is inherently problematic, as the relationships between transition risk, physical risk, and other market forces are complex and non-linear, and compressing them into a single dimension loses substantial information, some of which may be relevant to decision-makers. But some physical risk information is almost certainly better than no information, and can help instigate deeper and broader exploration of climate impacts on finance.

The third approach is to engage without using metrics, for example via qualitative and narrative information (e.g. see Storylines above). Narrative and qualitative information must be credible (see 4.1 Common needs of CRFD users), but it can be harder to establish the credibility of qualitative information for audiences who are not familiar with the science that it is based on. Qualitative information must also have clear implications for costs, or it is likely to be considered irrelevant by decision-makers focused on financial responsibilities like fiduciary duty and shareholder primacy (see 2.5 Why does business care about climate risk?). This means that broad summary information about climate change is not usually useful in PRCA (see Ignorance and Irrelevance below), and narratives need to be framed in relation to impacts on assets, firms, or their broader context and markets.

While financial information is predominantly quantitative, all quantitative information is ultimately presented to decision makers (e.g. executives, investors) in narrative forms, via presentations, visualisations with descriptions, or executive summaries that describe how well the firm is doing or how the market is changing. Fitting scientific information

[25] As distinct from ecological economics, see https://en.wikipedia.org/wiki/Environmental_economics#Environmental_Versus_Ecological_Economics

into finance decision-maker friendly narrative formats is a difficult task, some of the pieces to this puzzle are discussed below (see 6.3 Communicating with finance).

This section has focused on high-level financial decision making. But in business contexts there is a much broader array of decisions that need to be made on a regular basis that may interact with physical risk information (e.g. operational management decisions). How each of these decisions interacts with science will depend strongly on the domain of the decision, and the roles and responsibilities of the decision-makers, which we explore in the next section.

6.1.2 Roles and Organisational Structure

Every organisational context is different, but it can be useful to consider broad classes of roles that are involved in creating and using physical climate risk information. Fig. 9 provides a stylised example of the end-to-end information flow within an imaginary corporate financial institution (noting that in most cases, this information flow is bi-directional, e.g. via stakeholder input to codesign).

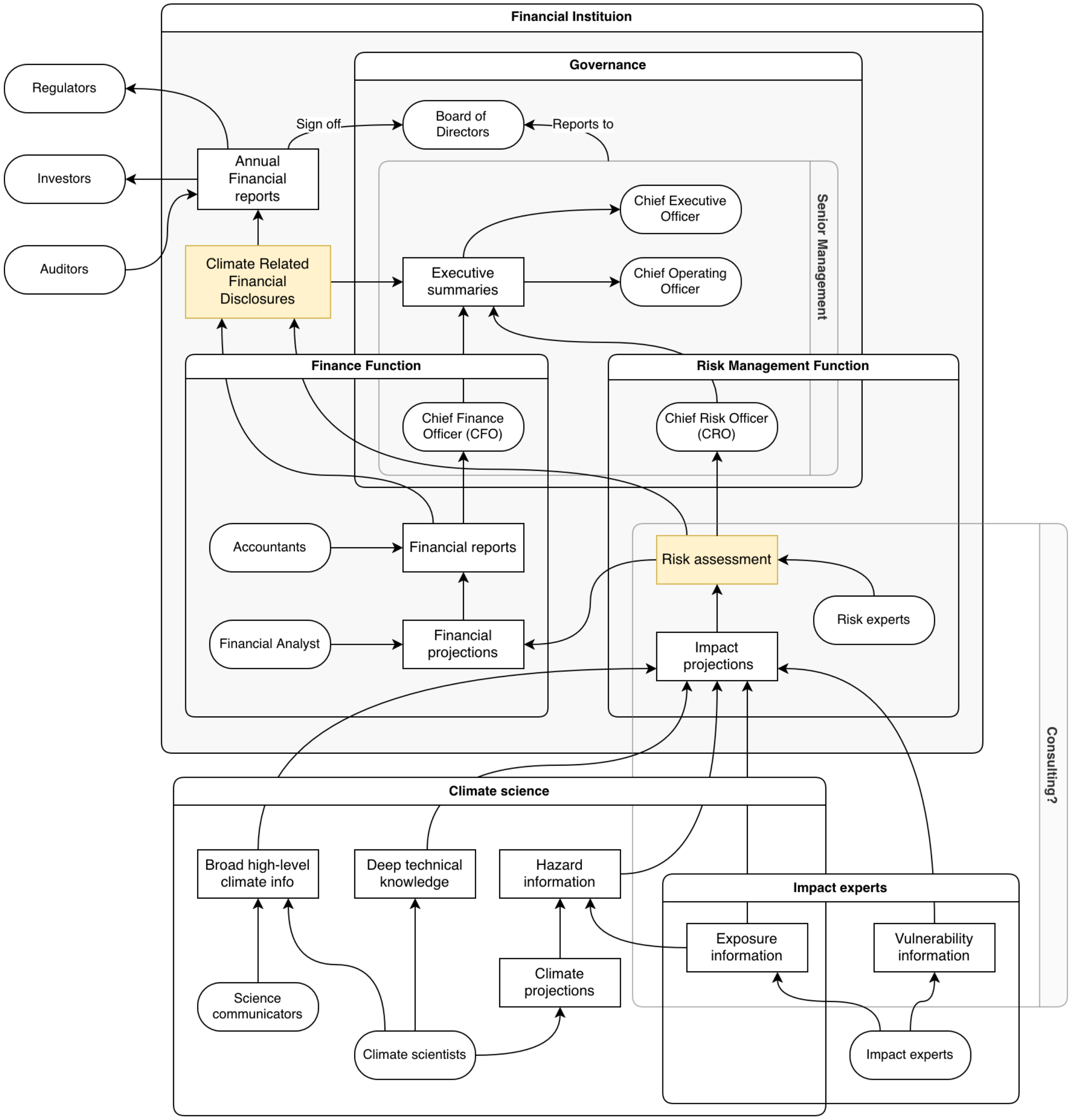

Figure 9: An flowchart of key roles and outputs that might exist within the information chain of a PCRA for an idealised financial institution. Note that many other functions are excluded from the graph for simplicity, because they are less directly involved in PCRA and CRFDs, but all functions can/should be involved to some degree. Most elements in the flowchart will exist in some form in other organisational contexts (particularly in any publicly listed company), although different roles may take on different names, and responsibilities may be distributed differently. Note that this figure is specifically describing CRFD-related PCRA processes, and that previous ESG-related PCRA processes would likely be coordinated via a sustainability function, rather than the finance function.

In general, ultimate responsibility lies with the board of directors of a company, but all roles in the chain are likely to have some responsibility for ensuring reliable PCRA development and usage. Responsibilities of different roles will vary to some degree by jurisdiction. The following list covers some key roles, with a general overview of their responsibilities:

- **Board of Directors:** A governing body that supervisors the organisation, usually composed of multiple experienced independent directors. In many jurisdictions, directors personally hold ultimate legal responsibility for the organisation's decision-making (AICD, 2019). Decisions made by directors focus on planning and strategy, and they must review and approve annual financial reports before they are released publicly. In general, the board has a responsibility to consider risks to the company including climate risk (Bremers, 2024).
- **Executive**: The executives are the senior management of the organisation. At minimum this usually includes a Chief Executive Officer (CEO) or similar role. Some members of the executive may also be on the board of directors, particularly the CEO (Lamm et al., 2024). Some key climate-risk related positions may include:
    - **Chief Finance Officer (CFO):** this role oversees the organisation's finances, which includes financial risks of all types. The finance officer is responsible for delivering annual reports, including CRFDs, along with methodological information, such as the scenarios and methods used in assessments.
    - **Chief Risk Officer (CRO)**: This role is concerned with ensuring risk management and assessments are undertaken across the organisation regularly. The Risk officer's focus is broader than financial risk, and includes operational risk and may include strategic risk assessments.
- The **finance function** (or department) is overseen by the CFO, and looks after the organisations' budget and includes:
    - **Financial accountants:** The financial accounting team produces financial statements and reports that make up a large part of the annual reports. Financial accountants need results from financial analysts to integrate into their reports.
    - **Managerial accountants** and **financial analysts:** This role is focussed on analysing future financial performance, using a variety of financial methods. These methods need to incorporate climate risk information, the shape of which will depend on the context of the report (see 4.1 Common needs of CRFD users).
- **Risk experts:** This role is a bridge between disciplines. Risk experts have a broad knowledge of many areas. For physical risk this may include financial analysis, accounting, and actuarial techniques, as well as climate and impacts science. They know how to bring different types of expertise together, should

understand the limitations of current knowledge, and are able to communicate nuanced concepts across domains. This role may be filled by consultants.

- **Impact experts**: This role specialises in understanding hazard events, and how they interact with exposure and vulnerability factors to cause specific impacts.
    - Impact expertise varies a lot depending on the impact. For example, for some well understood impacts, such as the relationships between heatwaves and excess mortality, a climate scientist with some experience working with the health sector may have enough knowledge to be able to act as an impact expert. In other cases, such as flood damage or loss of livestock, other experts such as hydrologists, civil engineers, or agricultural scientists may be needed to provide reliable impact information.
    - Who is needed for a given risk assessment will depend on the scope, focus and depth of that assessment. The hazard, exposure, and vulnerability data needed also varies by impact type.
    - **Managers** and long-standing **employees** are likely to have extremely valuable knowledge and **on-the-ground experience** of impact pathways a company might be exposed to, and are likely to be extremely valuable when assessing an organisation's vulnerabilities to physical risk.
- **Climate scientists**: This role understands the climate, the way it is changing, and how that affects different hazards. Climate scientists usually have a deep technical knowledge in at least one sub-domain of climate science, as well as a broad understanding of other parts of the domain.
- **Science communicators**: This role helps to lay out climate information in a way that's accessible to end users.
- External players including **regulators**, **auditors**, and **investors** are discussed in 2. Who cares about Climate Financial Risk?

Obviously this set of roles will vary in any given risk assessment context. In some cases, one person might fill multiple roles, in others a single role may be filled by a team of people. The roles listed above may not be the only relevant roles. And any given individual may have other roles that could influence their knowledge and skills. But being aware of these different types of roles and how they vary is useful for making sure that communication is as clear as possible, and needs are fulfilled with minimal mistakes.

It's also important to note that the **aims** of each of these roles will vary across institutional contexts (e.g. business, banks, insurers, local planners, state government health departments). Some key aspects of **organisational context** that may influence the aims of each role include:

- Higher-level **institutional aims**, such as solvency, profit, human health outcomes, etc (see 2.5 Why does business care about climate risk?).
    - Organisational **culture** can also influence how decisions are approached.
- **Accountability** for the decision: Who gets to make a decision is largely a consequence of accepted understanding of where the **responsibility** for that particular decision lies. Major investment decisions might require board approval, while operational decisions might sit with a risk officer or a department manager.
    - Accountability is a regulatory requirement for the finance sector and sometimes for the broader business sector. For example, Australia's Financial Accountability Regime (APRA, 2024b) requires accountabilities of each senior executive to be clearly articulated.
    - Institutional investors may have expectations of governance and executive accountability beyond what is required by regulation (IGCC, 2025).
    - Ultimately, metrics used in risk assessments need to be linked to incentives for decision-makers (IGCC, 2024).
- The **types of decisions** they might be making. Short-term reversible investment decisions have different information needs and foci, compared to a long-term infrastructure planning proposal.
- Various aspects of **decision context**, including:
    - The **risk thresholds** they might care about, and whether they are focused on existential **risk tolerance**, or weighing up their **risk appetite** against potential gains (see 3.2 Business Risk Management).
    - **Time scales**, especially for strategy and planning, affect perceptions of risk (see Timescales below for discussion of discounting, for example)
    - **Spatial distribution**, and **diversification** of risk can vary substantially by context.
    - **Definitions** of vulnerability, resilience, adaptive capacity may vary depending on the sector and organisation.

How individuals interact with decision making

Individuals bring their own background and strengths and weaknesses to a role. As a result, individuals' relationships to their roles and associated decisions can vary substantially. Some dimensions worth considering include:

- **Expertise**: Each role and individual will have different expertise. In general, people in roles closer to the top of fig. 9 are less likely to have detailed technical expertise (e.g. climate science, impacts), but more likely to have financial expertise. Roles in the middle are more likely to involve some level of risk-management expertise.

    - For technical content, it can be useful to group users by capability. For example the Alf, Bob and Carol personas for climate science expertise (Murphy et al., 2023). This allows for information to be better tailored to specific audience needs.
- **Power**: When it comes to large-scale decisions (e.g. planning and strategy), power is concentrated at the senior management levels in most corporate contexts (e.g. the top half of fig. 9). However, there are many smaller operational decisions made regularly throughout the organisation that may relate to physical risk, and most of these involve power relationships to some degree. Power can come in a number of forms (French & Raven, 1959; Graeber & Wengrow, 2021):
    - Positional power: the socially-agreed power conferred by the individual's organisational role. This is often associated with access to resources that can be used for enacting a decision.
    - Charismatic power: The power conveyed by interpersonal skills, or leadership.
    - Expert power: the power conveyed by being perceived as an authority on a given subject, or having access to knowledge.
    - Reward and Coercion: This might come into play in the form of bonuses for a well performing decision-maker, or fines from a regulator.
        - In most bureaucratic organisations, reward and coercion play a strong role in defining accountability.
- **Individual idiosyncrasies**: An individual's identity, values, ethics, and past experiences will affect how they approach a decision, as well as their motivation, interest, and care around making a good decision.

If you want to ensure that your expertise and information is put to good use and has a positive impact, it can be critical to understand the position and disposition of the people you're working with, and how they are likely to interact with you, your information, and their broader context. Each role (and each individual in each role) will have different motivations, incentives and constraints, and each will also be operating within different work cultures.

It is also critical to keep in mind that **what a scientist considers important may not be what others consider important**. For example, very few people working in a financial analyst role care about atmospheric variables or how they are changing, unless that data is interpreted through some kind of impact model/metric (see also 4.2.3 Boundary Judgements). Being aware of these factors can help you ensure that you contribute to the relationship in appropriate and useful ways.

6.2 Finance and science perspectives

The previous section focused on the drivers and aims of people in different roles within the PCRA landscape. This section zooms out a bit, to look at cultural differences between some of the key perspectives.

6.2.1 Views on climate change

A first, obvious aspect to consider is differences in understanding of climate change and the need to respond to it. Views on climate change do differ between people in science and finance, for obvious reasons, such as key focus and priorities. However, differences are perhaps smaller than expected - for example, Gsottbauer et al. (2024) found that while fewer finance sector professionals in the EU considered climate change a *very serious problem* than climate academics (42% vs 73% respectively), still the vast majority (79%) considered it a *serious* or *very serious problem* (92% for academics). They also showed that second-order beliefs (in this case: what you believe about what others believe) indicated that both finance professionals and climate academics perceived that the other group's beliefs were more different than was actually the case.

Stroebel & Wurgler (2021) showed that across a large group of self-selected finance-academics, professionals, regulators and economists, there was broad agreement that financial assets are **under-pricing** climate related risks, particularly in real estate and stock markets. This opinion was held much more strongly by those actively working in the finance sector than those in the public sector or academia, and also more strongly by those working in the private or public sector compared to finance academics. Professionals in the finance sector see regulatory risk as the biggest climate-related risk over the next 5 years, but expect physical risk to become the top risk within 30 years.

While there may be biases present in these studies, they do indicate a general understanding among the finance sector of the importance of physical risks now and into the future. This provides some reason to be optimistic about the potential for climate scientists to have meaningful impact in the sector.

6.2.2 Values and Worldviews

An individual's role and workplace can also substantially affect an individual's worldview, at least in the context of their behaviour while acting in that role. **This section is focused on values and worldviews of individuals *while in workplace roles***. Since disciplines and professions constitute and contribute to differing worldviews, taking these differences into account can be very important in complex interdisciplinary spaces such as climate risk assessment.

An individual's worldview encompasses their knowledge and understanding of reality, philosophies, and values. Worldview significantly affects how a person will interact with any given situation, in particular, what their priorities are, and how they will interpret (and therefore respond to) new information (Goldberg, 2009). An individual's worldview is influenced by many things, including their cultural background, education, and personal experiences.

Finance and science effectively constitute two distinct subcultures in modern capitalist societies (Snow, 1956; Williamson, 2010). While they exist within a broader culture, and so share a lot of history (Porter, 1995), they have quite distinct educational foci and professional environments, resulting in differences in values and perspectives.

One key obvious difference is in core values. The finance worldview is focused primarily on profit and economic growth, where science is focused on truth, and understanding the physical world (Chalmers, 2013). These are not necessarily always in conflict, but there are some disconnects. For example, finance and economics often make an assumption that unlimited growth is possible. However, if we assume that financial value is dependent on underlying social and ecological, and physical systems, this unlimited growth assumption is contradicted by science's understanding of physical constraints, such as the laws of thermodynamics and the energy throughput of the earth's system (Meadows et al., 1972). The concept of "externalities" in economics, which involves indirect costs (such as the impact of carbon emissions) which are usually unpriced (and therefore ignored), is also contradicted by ecological science's understanding of the dependence of our economies and societies upon underlying ecosystem services[26].

On a more immediately applied level, reliability of information and models is important in both domains, but is treated differently. In science, a reliable model is valuable because it encodes existing knowledge of the system, and can be used to run experiments to discover new knowledge. In finance, a good model is useful because it provides reliable information with which decisions (e.g. investments, loans, bets) can be made (Preda, 2007). If a model has large errors in science, that may be OK, as long as the errors are not hiding the underlying truth. In some cases it may even be useful if, for example, analysis of model error helps to clarify gaps in our understanding. In finance, errors are OK, as long as they are not hiding a bias that will damage your return on investment over the long run.

Table 2: Differences in some aspects of approach: Climate Science, Finance, and Physical Climate Risk. Like Table 1, these examples are intended to be illustrative, they

[26] To some extent this is accounted for by the non-mainstream discipline of ecological economics (Costanza, 1991)

are not exhaustive, and in practice, most individuals/roles will exhibit aspects of multiple perspectives to varying degrees. Column 4 treats Physical Climate Risk Assessment as a new emerging transdiscipline (see 7. Interdisciplinary approaches), and attempts to identify some key attributes that set it apart from both Climate Sciecne, and Finance.

Perspective	Climate science	Finance	Physical Climate Risk
Risk	Contingent on scenarios, and assumptions	Probabilistic (assumes stationarity)	Understanding gaps in knowledge
Consequence	Physical: Loss of life, infrastructure, species	Long-run return on investment	Linking hazards to values
Aims	Understanding climate response to warming	Profit, financial system stability	Identifying out what's important
Focus	Physical processes, Hazard distributions, Thresholds for unacceptable change	Price signals, major $ losses, financial crisis	Interdisciplinary collaboration Pragmatic: Use what's available Pluralistic: Figure out the shape of the problem from different perspectives.
Values	Truth, objectivity, Rigour, reliability, Openness and information sharing	Growth, Reputation, Information advantage (e.g commercial-in-confidence)	Pluralism Pragmatism
Scope	Global	Company	Context-dependent
System boundaries	Physical earth systems	Financial contracts, Market	Context-dependent, 4.2.3 Boundary Judgements
Timescales	Long-term (decades-millennia)	Short-term (3-5 year planning horizon) Discounting	Context-dependent
Uncertainty	Quantitative, plausibility	Probabilistic, or not decision-useful	Shape of knowledge gap

Gsottbauer et al. (2024) suggest two possible underlying reasons for these differences: **Priorities**, and **political ideology**. The key priority in finance is maximizing returns and managing risks, whereas climate experts are more focused on improving knowledge about climate-related impacts (both ecological and social), and, through contributing to evidence-based decision-making, minimising those impacts. Ideological differences include more opposition to hard market interventions from finance professionals, perhaps indicating a tendency towards supporting individual rather than systemic solutions. Some other dimensions of difference are explained in Table 2.

6.2.3 Ways and means

Quantitative focus

Finance and science both have a strong focus on quantitative metrics and analysis. However, climate science tends to focus more on understanding the physical mechanisms in operation, and using quantitative models to both explore hypotheses and develop theoretical understandings about those mechanisms, as well as using them to predict and project. Finance, on the other hand, tends to focus less on the mechanisms of action, and more on empirical estimation of price signals (Alexander, 2012).

Transparency and knowledge sharing

Science and finance have quite different approaches to knowledge and information sharing (this is true of science and industry more broadly too, see Evans, 2010).

Science is commonly seen as a public good (Dalrymple, 2003), and scientists tend to put more emphasis on public information sharing (Merton, 1942). Public sharing of scientific information is also useful as a method of ensuring rigour, for example via peer review. Recent developments such as the FAIR Principles (Wilkinson et al., 2016) have sought to improve the reusability of scientific data, emphasising findability, accessibility, and interoperability. In practice though, there are still some restrictions on the openness of scientific knowledge, mostly related to the commercialisation of knowledge by universities and research centres, as well as paywalls in scientific publishing (Caulfield et al., 2012).

Aside from annual reporting, most risk-related information in commercial institutions is private, and is considered commercial-in-confidence. This secrecy can mean that sharing learnings about climate risk assessment approaches between institutions and across disciplines can be difficult. For instance the majority of detailed loss information for housing and infrastructure is held in private by insurance companies. Approaches such as the FAIR principles are potentially at odds with commercial-in-confidence and competition laws.

This disconnect in approaches between science and business may stymie efforts to build consistent physical risk processes across the private sector, as transparency around methodologies and data will be more difficult to obtain in commercial spaces. This may turn out to be a major tension in the future development of useful and reliable CRFDs.

Science's openness is a key reason for its reliability. If we are to have reliable, intercomparable approaches to physical climate risk assessment, it seems likely that this openness in data and methods sharing and review will also be needed on the financial side of the collaboration.

Despite these differences, productive and useful science-industry collaborations do exist in many domains, and there are a handful of ongoing projects in the physical risk assessment space.

Timescales

Timescales are another disparity between the two domains. Climate science is often focused on decadal timescales or longer - 30 years is a commonly agreed minimum for climatological analysis to be able to cope with interannual variability[27]. Finance, however, generally has much shorter timescales. Financial investment timescales range from day trading, up to the decade scale (e.g. bonds), while physically related investments (e.g. mortgages, or loans for infrastructure) are generally on the order of a few decades.

This difference in timescales is also reflected (perhaps coincidentally?) in project timescales - academic research programmes usually run for years, sometimes even over a decade, while consulting projects for business are often shorter, on the order of months. The relatively short-term focus of finance thinking is compounded by short-term executive **performance incentives** (Baeten & Van Hove, 2021) and **discounting**, which is a systematic devaluing of future rewards assumed in financial and economic modelling. The prevalence of discounting in financial thinking leads to a strong emphasis on short-term thinking and planning at many scales of decision making (Irving, 2009). Fig. 10 shows a number of the key processes considered in this document over temporal and organisational scales.

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[27] Longer term projections of thousands of years are also common, and paleoclimatology includes timescales of hundreds of millions of years, shorter timescales such as seasonal forecasting are generally more associated with weather prediction.

While some specific sectors may have longer planning timescales (or multiple timescales), this means that many businesses demand physical climate risk information over the next 5 years - something that may stump climate scientists. There are many approaches that could help bridge this gap, including focusing on changes since historical baseline periods, or interpolating between current and projected future changes (and framing those interpolations relative to those future projections).

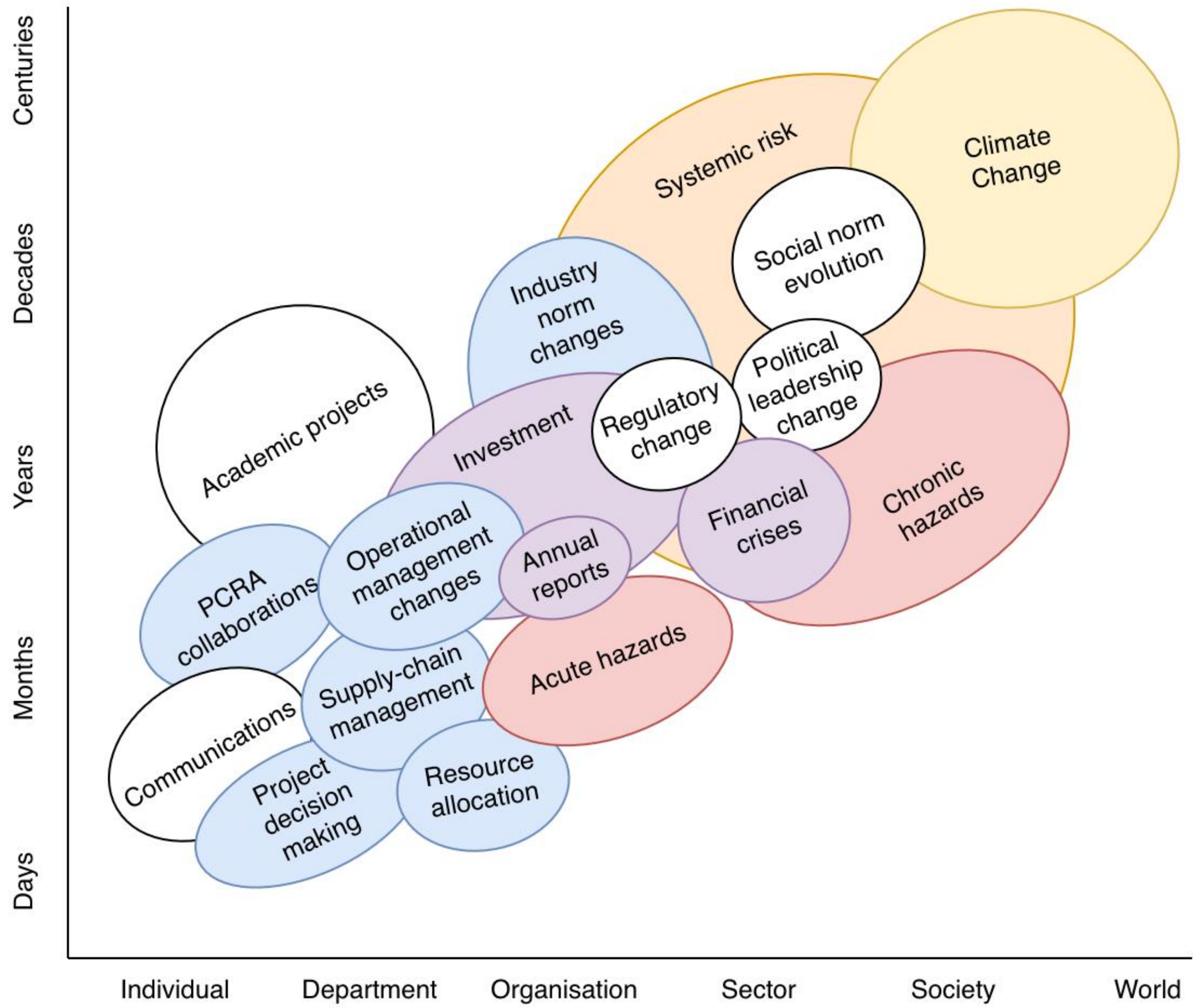


Figure 10: Comparison of some key processes by temporal and organisational scales (both scales are somewhat correlated with spatial scale too). Business concerns are in blue, financial concerns in purple. Other colours highlight key physical risk processes. Figure is inspired by (Reeves & Whitaker, 2021).

6.2.4 Understandings of risk and uncertainty

Uncertainty is present in most domains of life, and is central to understanding risk and decision-making. But how different professions and disciplines understand risk, uncertainty, and consequence can vary a lot.

Interpretations of Consequence

Understandings of *consequence* in finance and climate science differ due to the different foci of each discipline.

In finance, consequence is primarily framed in terms of financial losses, and is largely decoupled from physical impacts that might cause those losses (see 3.4.1 Degrees of financial separation). Climate science, on the other hand, is focused primarily on drivers, mechanisms, and physical impacts (i.e. the left side of fig. 5), and only considers financial or economic impacts as a secondary concern, if at all[28].

In science, risk is mostly associated with negative consequences, however in finance risk is sometimes seen as a good thing, in that it is the trade-off for reward: for example in investment, high risk is often associated with high returns (Yeh, 2023). This may colour the perspective of financial analysts when looking at climate risks, and seems particularly problematic when considering **existential risks** (risks that would lead to the collapse of the system-at-risk).

Interpretations of Uncertainty

In a risk context, both finance and climate science predominantly tend toward a probabilistic understanding of uncertainty, where the risk associated with any event is a product of the **probability** and consequence of that event. This is, however, not the only definition of risk, and more general definitions focus instead on the *possibility* of something negative occurring (Law & Smullen, 2008; IPCC, 2022). The narrower focus on probabilistic calculation may be a problem if it leads to non-quantitative knowledge being ignored (ignorance is discussed in more depth at the end of this section).

Uncertainty is also approached differently in the two disciplines. In finance, thinking is substantially influenced by the work of economist Frank Knight in the 1920, who made a distinction between “risk”, where the probability of different outcomes can be calculated, vs “uncertainty” where probabilities are not calculable (this is known as “**Knightian uncertainty**”, or sometimes “**deep uncertainty**” (Pitman, Pui, et al., 2022)). These two frames are treated differently for decision-making purposes, and Knightian uncertainty is often taken as a reason for decision avoidance or deferral (Sunstein, 2023).

The idea of uncertainty generally indicating a lack of useful knowledge has been weaponised for political purposes in the past (for example in the US in the early 2000s, see Wagner, 2024). The counter argument is that deciding not to act until better

[28] In fact, climate scientists focused on the physical climate and hazard modelling components often neglect to even consider impacts, and the use of the term “risk” is not uncommon in studies that don’t consider impacts at all. The IPCC has released recommendations against the use of the term “risk” in this context, and suggest that “risk drivers” may be appropriate instead (Reisinger et al., 2020).

information is available is itself just another (likely poor) decision outcome (Soares, 2014). This approach leads to underevaluation of plausible futures, which can lead to increased risk from **black swans** - unforeseen events with catastrophic impacts (Soares, 2014; Taleb, 2005). Pluralistic collaboration with a focus on understanding gaps in what is known can help reduce this problem (see 7. How to do interdisciplinarity well).

Science also has a concept of **deep uncertainty**, but as part of a more nuanced taxonomy of the spectrum of uncertainty. Fig. 11 describes uncertainty from a decision-theory perspective. The financial concept of "risk" corresponds to levels 1 and 2 in this figure, where Knightian uncertainty corresponds to level 3, 4 AND total ignorance.

Table 1.1 Progressive transition of levels of uncertainty

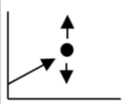
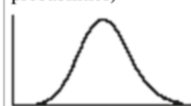
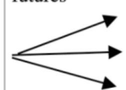
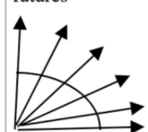
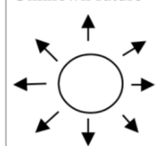
	Complete determinism	Level 1	Level 2	Level 3	Level 4 (deep uncertainty)		Total ignorance
					Level 4a	Level 4b	
Context (X)		A clear enough future 	Alternate futures (with probabilities) 	A few plausible futures 	Many plausible futures 	Unknown future 	
System model (R)		A single (deterministic) system model	A single (stochastic) system model	A few alternative system models	Many alternative system models	Unknown system model; know we don't know	
System outcomes (O)		A point estimate for each outcome	A confidence interval for each outcome	A limited range of outcomes	A wide range of outcomes	Unknown outcomes; know we don't know	
Weights (W)		A single set of weights	Several sets of weights, with a probability attached to each set	A limited range weights	A wide range of weights	Unknown weights; know we don't know	

Figure 11: Different depths of uncertainty (from Marchau et al., 2019). Translated into the context of physical risk, "context" refers to the distribution of hazard events, "system model" corresponds to a PCRA method, "system outcomes" correspond to impacts or consequences, and "weights" correspond to values associated with those consequences.

We would also note that there are other divisions of uncertainty in science that are not captured within Fig. 11. For example prediction uncertainty is often split up into **epistemic uncertainty**, which is related to what we know about a system, and **aleatoric uncertainty**, which is due to noise and chaotic dynamics in a system (Gong et al., 2013). Epistemic uncertainty is often considered reducible, in that we can learn and improve our models, while aleatoric uncertainty is generally considered unpredictable (e.g. the result of a fair dice throw).

Another distinction within epistemic uncertainty is between uncertainty in model parameters and model structure (Abramowitz, 2010). Uncertainty in model parameters can generally be quantified and explored probabilistically (e.g. via Monte Carlo analysis), while model structure is not a quantifiable space, and so can not.

Finally, it is worth drawing a distinction between **variability**, variations in a metric's value over time or space, and **uncertainty**, our lack of knowledge. Most physical processes have some variability (Begg et al., 2014). We can have uncertainty both about a system's processes (e.g. "how does the climate system work?"), and about specific outcomes of a system ("What will the weather be like this time next year?"). We often treat measured variability as a proxy for the uncertainty of future outcomes. For example, a climatology is a statistical model of historical variability, which we often use to estimate future outcomes (e.g. the best guess of the weather this time next year is the average for this time of year for all past years, perhaps adjusted for climate change). Because finance is substantially focused on empirical modelling of variability (e.g. technical analysis, see 3.3.2 Approaches to valuation), it is primarily interested in uncertainty of a final outcome given market variability, rather than uncertainty in underlying system processes.

Ignorance and Irrelevance

The total ignorance column in fig. 11 is potentially deceptive in its simplicity.

Kutsch & Hall (2010) provides a broader taxonomy of types of ignorance and irrelevance, and shows how they relate to various types of uncertainty. Concepts explored include, for example:

- Vagueness, when definitions are unclear,
- Ambiguity, when information can have multiple reasonable interpretations,
- Confusion, where information is misinterpreted, and
- Incompleteness, where important information is missing.

Each of these can be important for understanding how even a perfectly performing model can result in poor decision-making.

The concept of **irrelevance** is important for similar reasons, and due to the differences in values and worldviews explored above (section 6.2.2 Values and Worldviews), is likely to differ substantially between individuals in each discipline. In some cases, exclusion may be intentional and justified, if the risk is determined to be irrelevant or immaterial, while in others risks may be neglected in error, due to lack of knowledge or data, or due to social taboo (Kutsch & Hall, 2010). People working in a finance context are likely to only see things as relevant if they have some kind of reliably estimable financial impact that has a bearing on decision-making (IFRS, 2023a). People working in physical sciences are likely to see things as relevant only if they are measurable, or have understandable mechanisms (much of the less measurable world is left as a problem for the social sciences, see Snow, 1956).

In an interdisciplinary space like PCRA, figuring out how to combine these two (or more) disciplines becomes a decision around the definition of the system (see 4.2.3 Boundary Judgements). This is precisely the reason that physical climate risk assessment in the financial sector is such a critical avenue for impact. It is focussed on the intersection of what is seen as relevant in each of the two fields, but it seems likely that in the long-run, PCRA will emerge as a new transdisciplinary field that is much greater than the sum of its parts (see 7. How to do interdisciplinarity well).

Understanding the causes of differences in interpretation of relevance, uncertainty, error, and other forms of ignorance can help to minimise cross-cultural misunderstandings, and ensure that projects provide benefits for all stakeholders (including scientists!).

6.3 Communicating with finance

There is copious material on how to communicate scientific findings, and science communication is an entire field of research and work. Distinctions are often made between lay audiences and expert or technical audiences (e.g. Murphy et al., 2023). Less common is research or guidance on how to communicate with specific disciplines, or non-academic professions such as finance. A comprehensive understanding of how to communicate climate science to the finance sector is beyond the scope of this report, but this section attempts to lay out some key concerns.

Firstly, it's important to note that people's existing beliefs can be strongly held, and hard to shift, a concept in psychology called "belief perseverance"[29]. The **backfire effect** is an extreme example of this, where new information contradicting an existing belief can sometimes counterintuitively result in strengthening the belief. Part of the issue is that beliefs are often entangled with our sense of identity, cultural identity, and existing worldviews and narratives. If a new piece of information is presented in a way that conflicts with or contradicts those existing narratives, it may threaten our identities, resulting in a psychological drive to reject the new narrative (Snowden, 2024). Understanding the existing narratives and beliefs of another person (as explored in 6.2.2 Values and Worldviews) may help to identify ways that new narratives can be framed and delivered in such a way that they are more likely to be accepted.

Secondly, it's incredibly important to identify the technical capability of your audience. Different roles will have different abilities with numerical, statistical and scientific concepts (see 6.1.2 Roles and Organisational Structure). Financial analysts and accountants will likely have strong numerical and statistical background, but less

[29] For an overview, see https://en.wikipedia.org/wiki/Belief_perseverance

understanding of climate science concepts. Sustainability officers are likely to have a good grasp of high-level climate information, but may have less ability with complex statistics and maths. An ability to be flexible with your communication style, and to switch between describing concepts scales from high-level summary to fine technical detail, can be extremely valuable (Hutchins, 2020).

The communication of uncertainty overlaps with beliefs and literacy in complex ways. Scientists tend to be at home with process uncertainty, and are comfortable framing scientific knowledge as uncertain, particularly when it relates to less certain future scenarios (see 5.2.7 Extremes and High-Impact Low-Certainty futures). This can present as caution and an unwillingness to provide simple, direct answers for specific questions about the future. From a financial perspective, this unwillingness to estimate quantitative probabilities can sometimes be interpreted as a reason to treat results as unusable for decision making (see Interpretations of Uncertainty above), even though the state of the science might allow for useful statements about plausibility of certain outcomes (Pitman, Pui, et al., 2022).

Approaches that focus on scenario-based exploration of plausible futures are more common in some other domains, such as government (for example, see APSC, 2024). Storylines approaches are a useful vehicle to explore here, as they allow clear elucidation of plausible futures, without being constrained by the need for explicit probability (see Storylines above), although figuring out how to fit them in to standard financial analysis and reporting remains a challenge (Fiedler et al., 2024).

6.3.1 Linguistic uncertainty and language barriers

Linguistic uncertainty is the uncertainty in interpretation of knowledge transferred via language. Even the most quantitative information is always wrapped in language - figures have captions, metrics and datasets have descriptions, equations have explanations, etc. And all languages are prone to errors of various kinds, including ambiguity, vagueness, incompleteness, and inconsistency (see Ignorance and Irrelevance above). These problems can be difficult or impossible to avoid, especially in complex interdisciplinary contexts. Open dialogue focused around disconnects in understanding can be very useful (see 4.2.3 Boundary Judgements and 7. How to do interdisciplinarity well).

Glossaries can help, and well-made glossaries already exist for climate science (IPCC, 2022), and there are whole dictionaries of financial risk (Gastineau & Kritzman, 1999). But while clear definitions are crucial, in interdisciplinary spaces like physical risk, a bigger problem is similar terminology being used to mean different things in different contexts. These terminological overlaps can cause miscommunications and difficulties in learning for people working in interdisciplinary spaces. Some examples are included in the next section.

Examples of terminology clashes

This section focuses on some common terminological pitfalls in the overlap between climate and finance, so that you can avoid them, and to give you an idea for how to spot terminology problems as they appear. It's important to recognise that there is no "incorrect" terminology, there are only terminological differences between fields, and poorly defined terminology within any given context. If you come across a use of terminology that seems wrong, that should immediately raise a flag that the terminology usage needs to be clarified.

- "**Uncertainty**" has a fairly clear meaning in climate science - it refers to a lack of knowledge about a process (IPCC, 2022). In finance, "Knightian uncertainty" instead implies "not useful for decision-making" (see Interpretations of Uncertainty above).
    - In accounting things are even more vague as there is no clear or standardised terminology - even within IFRS thirteen terms of likelihood are used, sometimes interchangeably (Seo & Thomson, 2016)
- "**Resilience**" is commonly understood as "ability to withstand shocks" in a general sense, in practice it can mean different things in different disciplines, e.g.:
    - In engineering it generally means "the ability to bounce back" (to a normal state), whereas in ecology it means "the ability to shift to a new stable state" (Koch, 2021).
    - In climate science, social science and government, "resilience" often means the ability to withstand impacts from climate events. It often involves elements of government and community-level services for disaster response, recovery, and rebuild, as well as network-redundancy for critical services (e.g. transport, utilities).
    - In finance, capital is seen as resilience, because it acts as a buffer for risk.
        - This is a much more abstracted understanding of the concept (see 3.4.1 Degrees of financial separation).
        - Diversification of investments is also seen as a resilience measure (Markowitz, 1952). Some risks are diversifiable, some not.
- "**Scenario**" means something slightly different in every discipline, as their window of relevance shifts (see 5.1.1 Scenario Analysis).
- "**Sensitivity**" is used in multiple domains, often without a qualifier.

    - In physical climate science, it generally refers to *equilibrium climate sensitivity* - the expected global temperature change as a result of a double in CO_2 concentration.
    - In climate adaptation, sensitivity is a component of resilience, and refers to "impact sensitivity", the amount of damage, disruption, or other loss that occurs as a result of a hazard event of a given severity.
    - In finance, it refers to the expected financial loss as a result of some shock (https://www.investopedia.com/terms/s/sensitivityanalysis.asp)
- "**Conservative**" is a particularly confusing example for science and finance:
    - In climate science, a "conservative" climate projection is a projection with a *less extreme* increase in global mean temperature,
    - In risk management, a "conservative" risk management approach is a risk-avoidant one, which usually implies assessing the *more extreme* tails of the risk distribution (usually associated with more global warming).
    - These two uses of "conservative" are almost polar opposites, and this can lead (and has led!) to confusion.
- "**Mitigation**" in also means different things in different contexts:
    - In climate science, "mitigation" almost always refers to greenhouse gas emissions reduction.
    - In risk management, "mitigation" refers to mitigating *risk* itself, which can entail any kind of risk response aimed at reducing risk. This means that it often corresponds to **adaptation** in climate science.
    - We recommend using more explicit terminology when working in the physical risk space, eg. "emissions mitigation", and "risk mitigation", or using alternative terminology.
- "**Asset**" means different things in different parts of the business sector:
    - To a risk manager, it's a physical asset to be at risk of physical damage.
    - To an accountant or an investor, it's a financial asset with financial value, depreciation and financial risk, and may not be tied directly to anything physical (see 3.3.1 Financial Assets).

7. Interdisciplinary approaches

What's in this section

- Why does interdisciplinary work fail? What makes it hard?
- What makes interdisciplinary projects succeed?
- How to approach getting better at interdisciplinary work
- How to get involved in interdisciplinary physical risk projects?

Key take-aways

- PCRA is an emerging transdisciplinary field that integrates knowledge from multiple academic disciplines and industry professions
- Climate science has a tendency towards isolationist or imperialist approaches to collaboration, but pragmatic and pluralist approaches may often be more useful in complex spaces such as PCRA
- Taking part in transdisciplinary collaborations has the potential to broaden your understanding, not just of the problem at hand, but also of your home discipline.

Physical risk is a new field emerging out of the confluence of climate science, impacts science, business management, and financial analysis. It is inherently interdisciplinary, and that brings with it difficulties and opportunities.

Interdisciplinary studies has been an active field of research for more than half a century (the term itself is 100 years old, Keestra & Menken, 2017), with even more focus recently due to major socio-environmental problems that transcend disciplinary boundaries (Ellingsen, 2023). There are multiple forms of interdisciplinary work (Bailey, 2019; Choi & Pak, 2006; Rutting, Post, et al., 2017), but most notably **transdisciplinary** work is highly collaborative and pluralistic interdisciplinary work that also integrates *non-academic knowledge* (e.g. industry knowledge, indigenous knowledge) as well as stakeholder values. Transdisciplinarity offers the possibility of disciplinary contributors *transcending their disciplinary boundaries*, and broadening their understanding of the world in ways that have potential to change the disciplinary paradigms within which they usually work (Choi & Pak, 2006).

We would argue, given the involvement of non-academic contributors from business, finance and government, that **PCRA and CRFDs are inherently transdisciplinary**, and should be approached as such. Managed well, physical risk could emerge as a new transdisciplinary field that is greater than the sum of its parts, and may also lead to useful new understandings in climate science, finance, and other contributing disciplines.

There are signs that this emergence is already underway: there are already journals, research centres, and postgraduate courses focused solely on climate-risk. However, while both climate science and finance have well established norms and standards related to evidence, legitimacy, and methodological approaches, these have had many decades to develop. A conceptual framework for a new transdisciplinary field is more than just the sum of its constituent fields' approaches, and will take time to emerge clearly.

For the purpose of this document, we are using "interdisciplinary" in the broad sense that includes transdisciplinary approaches (as we are also sometimes using "discipline" in a broader sense to refer to non-academic areas of work).

This section explores some of the key issues that make interdisciplinary work difficult, and provides some signposts for approaches that might prove more successful. The next two subsections look at different approaches to interdisciplinary collaboration, and their advantages and disadvantages. The following two subsections provide some practical advice for climate scientists wanting to get involved in PCRA.

7.1 What makes interdisciplinary work difficult?

This subsection focuses on some key problems with interdisciplinary projects that are likely to appear in a PCRA context. There are obvious differences between disciplines in e.g. aims, worldviews, and methodological, including assumed knowledge (see 6. Disciplinary differences). These issues can usually be managed with an appropriate approach to collaboration. There are, however, common issues with interdisciplinary collaboration itself. In the PCRA context, these could include clashing approaches to collaboration, as well as time pressures, and an overemphasis on quantitative information.

One of the key drivers in the push for interdisciplinarity in general is the need to find solutions to known, broad-scale socio-environmental problems threatening society (Keestra et al., 2017). In this regard, PCRA is somewhat of a microcosm of the broader issue of dealing with climate change at a societal level. In both cases, the need for solutions is urgent, but like most complex problems, they usually have multiple diverse stakeholders with correspondingly diverse (and sometimes conflicting) aims and values, and as a result clear solutions often do not exist (see Alford & Head, 2017), but may be managed (Doran, 2024).

This push for rapid solutions to problems also has a tendency to lead to rushed solutions that often produce reductive answers that do not capture the complexity of the issues at hand (Schipper et al., 2021). This can in particular include an over-emphasis on simplified quantitative messages (via numbers or visualisation), and a corresponding de-emphasis of contextual information (Schipper et al., 2021), which is critically important (see 3.2.1 Context and risk identification and 4.2.1 Organisational context). Good interdisciplinary approaches can help overcome these issues

Halfon & Sovacool (2023) identify 4 broad collaborative approaches that each have strengths and weaknesses. They also identify that different combinations of these collaborative styles can work more or poorly together. Each of these are explored briefly in this section and the next.

If we approach the task of interdisciplinary collaboration under the assumption that we can hold fast to our own disciplinary standards, and that other collaborators must conform to our theories and methodologies, this is an “**imperialist**” collaboration style (Halfon & Sovacool, 2023). In both climate science and finance, the theories and methodological approaches underpinning each discipline are strongly held: in climate science the core approach is numerical simulation incorporating many relevant processes; in finance approaches are predominantly based on price statistics and assume the efficient market hypothesis to be true (see 3.3.2 Approaches to valuation). Imperialist approaches to collaboration are common in climate science, and particularly earth systems science, which tries to pull important socio-economic aspects into the numerical simulation paradigm (Lam & Rousselot, 2024). Similar criticisms could be made of financial and economic approaches to collaboration. Unfortunately, when two imperialist approaches appear in the same collaboration, this is likely to result in conflict and project failure.

An alternative collaborative style is an “**isolationist**” approach (Halfon & Sovacool, 2023), in which collaborators remain mostly siloed within their disciplines, with minimal interdisciplinary integration (i.e. it is more aligned with cross-disciplinary collaboration). Practically, this might involve information-handovers along the information value chain, for example. This type of interaction is only likely to work well in situations where the problem being explored is extremely well defined (Halfon & Sovacool, 2023). This is certainly not true for physical risk in finance at the moment (and may never be, given the complexity of the problem).

7.2. What does work in interdisciplinary collaboration?

So what *does* work? To a large extent, what makes interdisciplinary project work is going to be largely defined by the specific situation, including the project context, aims, scope, and system definition (see 4.2.3 Boundary Judgements), as well as the aims and worldviews and idiosyncrasies of the disciplines and individuals involved in the project (see 6. Disciplinary differences). There are, however, some collaborative approaches and practices that can be useful.

The first approach that (Halfon & Sovacool, 2023) identifies that's worth exploring in the PCRA context is **pragmatic collaboration**. Pragmatic approaches are focused on efficiency, and make use of whichever methods are readily available. This approach has the advantage that it can get results quickly. This approach is often used in consulting contexts. The main problem with pragmatic approaches is that they tend to be less concerned with theory and rigour and comprehensive considerations of broader concerns (Halfon & Sovacool, 2023), and so run the risk of making major mistakes. In the context of simple problems, this may be OK, since evaluation processes might be able to catch mistakes before they become catastrophic. In the context of complex problems on long time-scales, such as physical risk, it is less likely that major mistakes will be caught in evaluation.

An approach that may be more suitable for complex interdisciplinary problems is **pluralistic collaboration** (Halfon & Sovacool, 2023). Pluralistic approaches focus on exploring complementarity and discord between diverse perspectives to help define relevance and to foster the emergence of creative new approaches (Schipper et al., 2021).

Most climate scientists are already used to the idea that a plurality of *methods* contributes to more robust understandings of the world, for example via multiple lines of evidence approaches (e.g. Sherwood et al., 2020, Wasko et al., 2024). In finance, diversity is also already valued in some analogous ways - it is directly linked to better performance in teams (Forrester, 2021) and in investment portfolios, where diversification is an industry norm (Forrester, 2021).

Pluralistic collaboration is a logical extension of this concept for dealing with complex problems that involve multiple stakeholders(Keestra et al., 2017; Koch, 2021), such as physical risk. Leigh et al. (2025) provides an in-depth framework for iterative development of risk assessment and management methodologies, with a focus on pluralistic boundary judgments. It is very applicable for PCRA, and worth reviewing for new and existing projects.

Pluralistic approaches have the obvious benefits of looking at a problem from multiple perspectives. This can help to reduce the possibility of missing critical nuance that can lead to poor results, and to increase the possibility of finding solutions or management approaches that meet all stakeholder's needs. Outside of the project work, interactions between disparate disciplines can also provide better understanding for each contributor of the contributions that other disciplines can make (Urbanska et al., 2019).

Pluralistic approaches also have drawbacks, however, including that they can become complex in a project management sense, and are often slower to make useful progress (this is the flip side of making more reliable progress). This could be particularly difficult in the context of CRFDs for business, which will have heavy time pressures. Given that critiquing a methodology is often easier than building one from scratch, we can see a useful approach involving a combination of pragmatic and pluralistic approaches: Using a pluralistic approach towards context collection and scoping (see 4.2.3 Boundary Judgements), using a pragmatic approach to rapidly build PCRA methods that make use of what is readily available, and then a pluralistic approach towards evaluation and making recommendations for improvements (see 5.4 Iterative methods development).

7.3 Breaking down silos and building bridges

Our overarching aim is to improve collaborative efforts between climate science and the financial sector, under the assumption that if the finance sector can better understand the severity of climate change, they will shift towards making better decisions on emissions reduction and adaptation. We want to avoid culture clashes, and minimise communication problems.

There a number of ways to help break down silos and build bridges between the sectors, including:

- **Building relationships** outside your discipline. Connect with people in the finance sector or other parts of industry of government, and ask them about their experiences and understanding of climate science and how it relates to finance.
  - **Networking** is a critical skill that is not hard to build with a bit of practice. Approaching people with openness and curiosity about their interests is a good strategy. There's lots of existing guidance on how to network well.
  - Good places to find people include climate risk focused industry events and LinkedIn. Many universities have research groups that are explicitly focused on industry collaborations around climate and risk.
  - Reach out to climate scientists in your network who have interacted with the physical risk assessment space, and ask them how to get involved.
  - Ask the people you meet for recommendations for who else to talk to!
- **Broaden your knowledge base**. This might include reading or listening to things outside your discipline.
  - There are multiple podcasts and news platforms focused on the intersection between climate and finance, and organisations like UNEP-FI,

    - NGFS, and IFRS regularly release special reports dealing with relevant topics.
    - Following up on key concepts may be easier than trying to understand all of finance at once.
- **Look for analogies**. If you can explain your knowledge using analogies related to finance or everyday life, then people on the other side of the divide will have an easier time following what you're saying.
    - Like models, all analogies are flawed, but they can be very useful for getting ideas across, after which dealing with details and nuance is easier.
    - Risk is a broad area that intersects with many disciplines. Other risk disciplines may be excellent sources for analogical learning. For example cyber security, geopolitical, pandemic, and regulatory risk are all regularly considered by many large businesses, and each presents similar problems of complexity, uncertainty, and interdisciplinarity.

Jumping in the deep end is another sure-fire way of forcing yourself to learn a new topic. The following section describes some more concrete steps that can be taken to get involved in physical climate risk assessment processes.

7.4 How to get involved in climate risk processes

There are many avenues for a climate scientist to get involved in climate-related risk assessment work. These can range from doing research related to hazards and impacts, through commentary and advice on risk assessment approaches, to getting directly involved in PCRA. Some avenues that may be worth exploring include:

- **Industry-academia collaborations**. Many universities already have programs that are focused on building industry collaborations. Long-term industry-lead research networks also exist.
    - As an individual scientist, you may not have the leverage to get new industry collaboration off the ground. If that is the case, talk to your team leader or head of department.
    - **Research leaders** hold responsibility for getting their colleagues involved, and should be thinking seriously about how they can contribute to the industry collaborations.
- Talk to **knowledge brokers** or the **comms team** at your research organisation, and discuss the kinds of projects you might be able to contribute to.
- Look for **existing research projects** that intersect with your work, and get in contact.
    - Offer to review reports, if they relate to your expertise.

- It may be easier to collaborate with **service providers** and **consultancies** than directly with corporations. This can also be helpful in that they will better understand corporate culture, and will be able to help you translate your work more clearly.
- If you have work that is already directly relevant to the physical risk context, make sure that it's as accessible as possible to a non-scientific audience.
    - **Webinars** aimed at the public can be particularly useful for sharing information with an interested audience. Ask your organisation about existing webinar programs.
    - Publicly available **datasets** will be used, especially if they are well-documented. Commercial licensing may be a barrier for some users.
- Look for climate-risk related **grants** that might target your area of research.
- Look for **job listings**. Many consultancies and large businesses are actively looking to build their in-house climate expertise. Be aware that the work culture is very different from academia though!
- **Review** and comment on CRFDs, as they are made public. There is no standard procedure for this yet, but feedback will be necessary for the development of best practice (see 5.4 Iterative methods development).

Involvement with the physical climate risk assessment space can take many forms, from simply making data/information accessible, all the way up to formalised relationships. Where you get involved is up to you.

8. Conclusions and Motivation

In 2021, at COP26 in Glasgow, the Secretary-General of the United Nations declared the 2020s the “Critical Decade” for climate action (Guterres, 2021). Which might be fortunate, because the Australian Climate Commission had already declared the previous decade the “Critical Decade” ten years before (Steffen, 2011), and we missed that boat. Either way, we are now well into the period of history where climate action is clearly critically needed and urgent. As the saying goes, “the best time to plant a tree was thirty years ago. The second best is now.”

Climate science is still a relatively new science. It’s also a science that is deeply entangled with a multitude of other issues - other sciences, sociological and political issues, and broader ecology. Because of this, it is deeply and unavoidably complex - climate science problems can not be dealt with via reductionist approaches. As a result, climate science has begun to change the way we view science (Lewis, 2017), and perhaps also the way broader society views humanity’s place in the world, as an interdependent part of the earth system (Jasanoff, 2021; Mazzocchi, 2023).

Business and finance have a culture that is predominantly focused on profit-making, sometimes to the detriment of the broader concerns of a society that is interconnected with and dependent on broader ecological and biophysical systems. Climate risk, and in particular physical risk, is a frame that may provide an avenue for finance professionals to better connect with science and an understanding of social-ecological interdependency. This is particularly the case because it frames climate concepts in financial terms, *and* because a large portion of the sector is being forced to engage with it via climate risk disclosure regulations in many jurisdictions. As a result, CRFDs and the process surrounding them may provide an interesting opportunity to break down some ideological divisions.

Given the leverage controlled by the business and finance sectors, this could potentially be a powerful avenue for shifting broader society towards better mitigation and adaptation action. Regulation is being phased in over the next few years in Australia and many other international jurisdictions. The space is full of potential, but also ripe for mistakes, especially if *standard practice* isn’t guided towards credible and useful *best practice* by experts from all of the relevant perspectives. Standards are gradually developing, and what happens in the next few years is likely to decide how effective climate risk closures are in the long term. This means now is the perfect time for climate scientists to step into the space, and contribute to making physical climate risk assessments as useful, reliable, and effective as possible.

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Appendix A: CRFD reporting standards

History of climate risk disclosures

This section describes some of the history that has led up to the current state of physical climate risk assessments, climate risk disclosures and the standards related to them.

Prior to CRFDs, there have been many other reporting frameworks and principles focused on the disclosure of climate or other ESG related risks (e.g Global Reporting Initiative, Carbon Disclosure Project and the Climate Disclosure Standards Board, Equator Principles), and the thinking behind these has fed into the development of the IFRS standards. IFRS-style CRFDs differ from these previous standards in that they not only focus on the business's impact on the environment (**impact materiality**), but also on the environment's impact on the business (**financial materiality**). They also differ in that they are becoming a mandatory regulatory requirement in many jurisdictions, where previous frameworks were voluntary.

CRFD Standards development

- The Global Financial Crisis (GFC), the biggest financial crash since the Great Depression in 1929, came to a head in 2008 (see 3.4.1 Degrees of financial separation).
- In the years following, the Group of 20 (G20) established the Financial Stability Board (FSB), as a successor to the Financial Stability Forum (FSB, 2025). The FSB was tasked with promoting regulation reform aimed at increasing financial market stability, with a strong focus on systemic financial risk (FSB, 2024).
- In early 2015, the G20 requested the FSB consider climate-related financial issues (TCFD, 2023). Later that year FSB chair and Governor of the Bank of England, Mark Carney, gave a speech at the Bank entitled "Breaking the Tragedy of the Horizon – climate change and financial stability", arguing for a climate disclosure task force (Carney, 2015). The Taskforce for Climate-Related Financial Risk Disclosure (TCFD) was established in December 2015 (TCFD, 2023).
- The TCFD was established with the aim of producing recommendations on the provision of climate-related risk information that would allow financial agents, such as investors, lenders, and insurers, to appropriately assess and price those risks.

- In mid 2017, after a few drafts, the TCFD released its first climate-related disclosures recommendation report.
- Every year from 2018-2023, the TCFD released an annual status report tracking disclosure and investment practices, and sometimes including updates on recommendations. By late 2023, the TCFD has 4,000 supporting organisations internationally.
- Between 2021-2023, the International Sustainability Standards Board (ISSB) was instituted as part of the International Financial Reporting Standards Foundation (IFRS, est. 2001), to mirror the existing International Accounting Standards Board (IASB), and began work on standards for climate disclosures that built on the TCFD recommendations (IFRS, 2025a).
- This process also consolidated work from a number of other existing climate standards bodies, including the Sustainability Accounting Standards Board (SASB), the International Integrated Reporting Council (IIRC), the Climate Disclosure Standards Board (CDSB), and the Value Reporting Foundation (VRF) (AICD, 2024a).
- The new standards were released in mid 2023 as **IFRS S2** (S1 is the general sustainability reporting standard).
- The TCFD handed over responsibility for maintaining the disclosure standards to IFRS/ISSB and was disbanded in late 2023.
- In 2022 the European Financial Reporting Advisory Group (EFRAG) released the draft European Sustainable Reporting Standards (ESRS), which builds substantially on the IFRS standards.
- In late 2023, the Australian Accounting Standards Board (AASB) released the first draft of the Australian Sustainability Reporting Standards (ASRS), and the standards were officially released the following year (AASB, 2024b). The AASB S1 and S2 are largely a direct copy of the IRFS standards, with some minor tweaks to adjust for existing Australian regulation around carbon accounting[30]. These standards came into effect in January 2025 (Trace, 2025).

Climate risk assessment and disclosure internationally

Perhaps the biggest drivers of uptake of PCRA in the private sector are mandatory CRFDs and regulator-driven stress-testing exercises (primarily focused on the finance sector). As of late 2022, there were more than 70 climate risk assessment exercises either completed, currently underway, or announced, in 39 jurisdictions. 42 of those

[30] For a more detailed history of Australian climate related risk reporting standards, see https://asic.gov.au/regulatory-resources/sustainability-reporting/historical-development-of-climate-related-financial-disclosures/

exercises included a physical risk component (FSB, 2022), with some approaches requiring bottom-up assessment, some top-down, and some a hybrid.

Significantly, 47 of those exercises required assessment to include “counterparty” level assessment. Here, counterparties are external organisations involved in financial contracts (e.g. investee companies, or borrowers/debtors). Since these exercises generally cover all major national banks, and sometimes insurers and superannuation funds, all of which are large institutional investors, this effectively means that a broad swathe of companies from outside the financial sector are also included.

That said, this is an emerging field: Of 109 Banks and 79 Asset owners reporting in 2022, only 59% of banks and 35% of asset owners included some physical reporting (Zhou & Smith, 2022). This means that the finance sector is still figuring out how to approach the problem, which means that this is a critical time for climate scientists to get involved and help ensure that climate information is being used appropriately and effectively.

Climate risk disclosures in Australia.

Financial climate risk reporting in Australia, as with most jurisdictions, is still in relative infancy. (ASIC, 2025a) provides an in-depth overview of historical developments. Key events include:

- 2016: Hutley legal opinion on directors duties and climate change (updated 2019 and 2021, see Hutley & Hartford Davis, 2021)
- 2018, Sep: ASIC encourages companies to consider voluntary reporting aligned with the TCFD
- 2021, Sep: APRA initiates a Climate Vulnerability Assessment (CVA), involving a set of climate-related scenarios and stress tests for the Banking sector.
- 2022, Apr: the AASB starts consulting on the ISSB exposure drafts
- 2022, Jun: Australian Government commits to ISSB-aligned reporting for climate risk
- 2022, Nov: APRA releases the findings of the Banking CVA.
- 2023, Oct: ASSB releases an exposure draft of the Australian Sustainability Reporting Standards (ASRS) - Australia’s slightly modified version of the IFRS S1 and S2 standards.
- 2023, Jul: APRA initiates a second CVA focused on the Insurance sector.
- 2024, Sep: Commonwealth Treasury Act is updated to introduce new mandatory climate-related disclosure requirements.
- 2025, Jan: First mandatory reporting period begins (ends June 2026).
- 2025-2028: staged phase in for reporting, for progressively smaller companies, eventually including all companies above 100 employees.

These latter points are crucial: we are now in a short open window where CRFDs and PCRA are emerging practice, but best practice is not yet defined. The standards define *what* must be reported on, but not *how* to assess or report it. This is an opportunity for climate scientists to influence the course of the development of best practice, before it solidifies over the next few years.

Appendix B: Methods and metrics in financial risk assessment

This section identifies some key metrics used in financial risk assessment, explains how they are interpreted, and how they might be related to physical climate risk.

Fundamental analysis tries to get a detailed and nuanced understanding of a business's financial position through qualitative and quantitative analysis. Business and accounting metrics that can feed into fundamental analysis include (Stobierski, 2020):

- Balance sheet metrics, such as:
    - Liquidity or working capital metrics, which integrate information about assets, liabilities, and inventory, and include forward-looking metrics.
    - Equity and leverage metrics, which relate asset values to equity and debts.
- Net income and Profit margins, which compare profits with costs.
- Running costs and Capital Expenditure (CapEx), which capture maintenance and upkeep.

Physical climate risk is capable of impacting all of these to some degree. Direct physical risk can damage assets and increase maintenance costs, increasing CapEx and reducing liquidity. These in turn are likely to reduce leverage, liquidity, and profits. Systemic physical risk may also impact profit margins by affecting the market the business is operating in.

Technical analysis focuses on statistical analysis of financial market metrics, such as stock price, volatility, and trading volumes. There are a multitude of statistical methods that attempt to pull information out of those primary metrics. These secondary metrics are usually calculated **endogenously** (e.g. using time series analysis on variables that the model can derive, such as price), rather than using regression analysis or more complex conceptual modelling. This means that predictions are made by treating the prior performance of financial assets as a sample, and estimating distributions over that and extrapolating forward, with no regard for **exogenous** factors (e.g. "outside" variables that might drive price), beyond the assumption that such information is already implicit in price.

Technical analysis often focuses on price movement relative to recent trends or volatility. For example, a simple approach is to compare a short-term moving average of share price over the recent period with a longer term moving average, and buy if the short-term average drops below the longer one. This kind of analysis inherently assumes **stationarity**, i.e. that the distribution of past behaviour is also representative of the distribution of future behaviour.

However, projected impacts from climate change will affect many underlying drivers of stock prices, as will technological and energy shifts, potentially invalidating stationarity assumptions. These impact pathways are not yet well understood in finance, and as a result markets are **under-pricing** physical risk (Condon, 2022).

Sector-specific methods and metrics

There are countless analytical methods and metrics used in finance. This section provides some examples of key metrics in major sub-sectors of finance, in order to give some idea of what is important to the sector.

- Business
    - Operational Expenditure (**OpEx**) and Capital Expenditure (**CapEx**): These are both forms of business expenses, OpEx focuses more on short-term costs, such as wages, rent, and material costs, where CapEx focuses more on longer term investments, such as machinery or infrastructure.
    - **Revenue**: This is the sales over a given period.
- Investment
    - **Return on Investment** (RoI): The expected rate of return relative to investment costs.
    - **Value-at-Risk** (**VaR**): This is a measure of the expectable losses on an investment over a given time period, relative to the investment cost. Commonly expressed as e.g. "A 5% VaR of $X", which would mean that there is a 5% probability of loss of greater than $X. VaR is perhaps the most commonly used **technical analysis** tool, as such the probabilities are calculated solely on the distribution of past prices, assuming stationarity.
    - **Unexpected Losses**: This is an estimate of the tail of the loss distribution, calculated as the difference between the tail risk (e.g. the 99th percentile of loss) and the mean expected risk (e.g. the average historical loss).

    - **Valuation**: A quantitative approach to determining the value of an investment, by taking into account various business and investment metrics, in the context of the broader market. Usually accounts for future expected returns on investment using a discounting rate.
- Banking
    - **Loan-to-Value ratio**: This is the dollar value of the loan relative to the underlying asset value, or replacement value. Lower LTV generally indicates a lower risk investment.
    - **Loss Given Default**: The value that is lost when a borrower defaults on a loan, as a fraction of the total value of the asset.
    - **Probability of Default**: the rate at which borrowers default (breach loan contracts).
    - **Delinquency Rate**: The rate at which borrowers fail to keep up with loan repayments. (delinquency is a type of default).
- Insurance
    - **Average Annual Loss** (AAL): annual loss amortised (averaged over several years). Often calculated as a mean of stochastic simulations (or Natural Catastrophe [NatCat] modelling, in the case of property insurance).

Climate change is likely to affect each of these in different ways. For example, direct climate impacts will cause increases in OpEx and CapEx for some businesses, as short-term costs increase and infrastructure and property needs to be repaired or rebuilt. Systemic climate risk may affect market values of required materials, increasing OpEx. Systemic risk is also likely to affect revenues in complex ways. For example, tourism-focussed business may be impacted as tourism may become less popular after a cyclone. Similarly, luxury goods are less likely to sell well in a community spending its resources on disaster recovery.

Climate Systems

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