THE PHYSICAL CLIMATE RISK ASSESSMENT METHODOLOGY (PCRAM)

Guidelines for Integrating Physical Climate Risks in Infrastructure Investment Appraisal

Coalition for Climate Resilient Investment

For more information please visit resilientinvestment.org

Forewords

"PCRAM is an essential building block for investment in resilience.

The Physical Climate Risk Assessment Methodology (PCRAM) is an essential and timely resource for members of the Investor Group on Climate Change (IGCC) and the Asia Investor Group on Climate Change (AIGCC). By integrating climate science, asset management and engineering, as well as infrastructure finance, PCRAM provides a credible process to include physical risks into investment decision-making over the life cycle of an asset.

For investors, the incorporation of physical risk into the design and delivery of assets has a variety of potential financial benefits. These can include increasing the value of assets, reducing costs of climate adaptation in the future, and improving the quality and predictability of revenue streams. Additionally, this approach reduces physical climate risk being transferred outwards to insurers, the public sector, and communities, which can lead to detrimental financial and social outcomes in the long-term.

PCRAM is an essential building block for investors to increase the resilience of their own portfolios and the communities they invest in. Additionally, it repositions physical risk as not only cost minimisation (for loss and damage) but as an opportunity for value creation."

Rebecca Mikula-Wright
Chief Executive Officer
IGCC and AIGCC

"Climate change could have huge financial costs for governments, corporations, and investors that don't act now. S&P Global's own analysis, as well as others, illustrate the vulnerabilities to economic losses because of the physical risks from climate change.

Despite progress understanding the physical impacts of climate change, a significant challenge remains: How do market participants quantify the benefits of and widely adopt new or improved climate-resilient processes as part of investment decisions for infrastructure projects?

To tackle this challenge, there must be a global and collaborative approach with a shared goal of improving transparency and standardizing definitions, terminologies, and use cases. That is exactly the way in which CCRI produced this report. S&P Global welcomes the leadership and cooperation fostered by the CCRI through its work with the private and public sectors, including the UN. The authors and contributors of this report have taken an important step forward on the path to allocating the capital needed to enhance the resilience of infrastructure assets.

New, deeper analysis that leverages powerful climate data should lead to better decisions about adapting infrastructure projects to withstand the physical impacts of climate change. At S&P Global, we are committed to improving transparency that helps market participants better understand the risks posed by climate change."

Douglas L. Peterson
President and CEO
S&P Global

About the Physical Climate Risk Assessment Methodology (PCRAM)

PCRAM has been conceptualised and developed by the Asset Design & Structuring (ADS) working group of the Coalition for Climate Resilient Investment (CCRI). CCRI is especially grateful to Mott MacDonald for their instrumental support as lead partner throughout the development of the methodology, and the opportunity to leverage the global capabilities of the engineering and development consultancy. PCRAM is a global public good made possible by the collaboration of 35 different institutions, ranging from investors, engineering firms, climate risk data providers, lenders, credit rating agencies and academic institutions.

The methodology captures the collaborative approach of various specialists in a joint effort to advance a dynamic impact assessment of physical climate risks (PCRs) that can be incorporated in investment decision making. The document combines three main expert subject matter areas: climate science, infrastructure asset management[1] & engineering, and infrastructure finance.

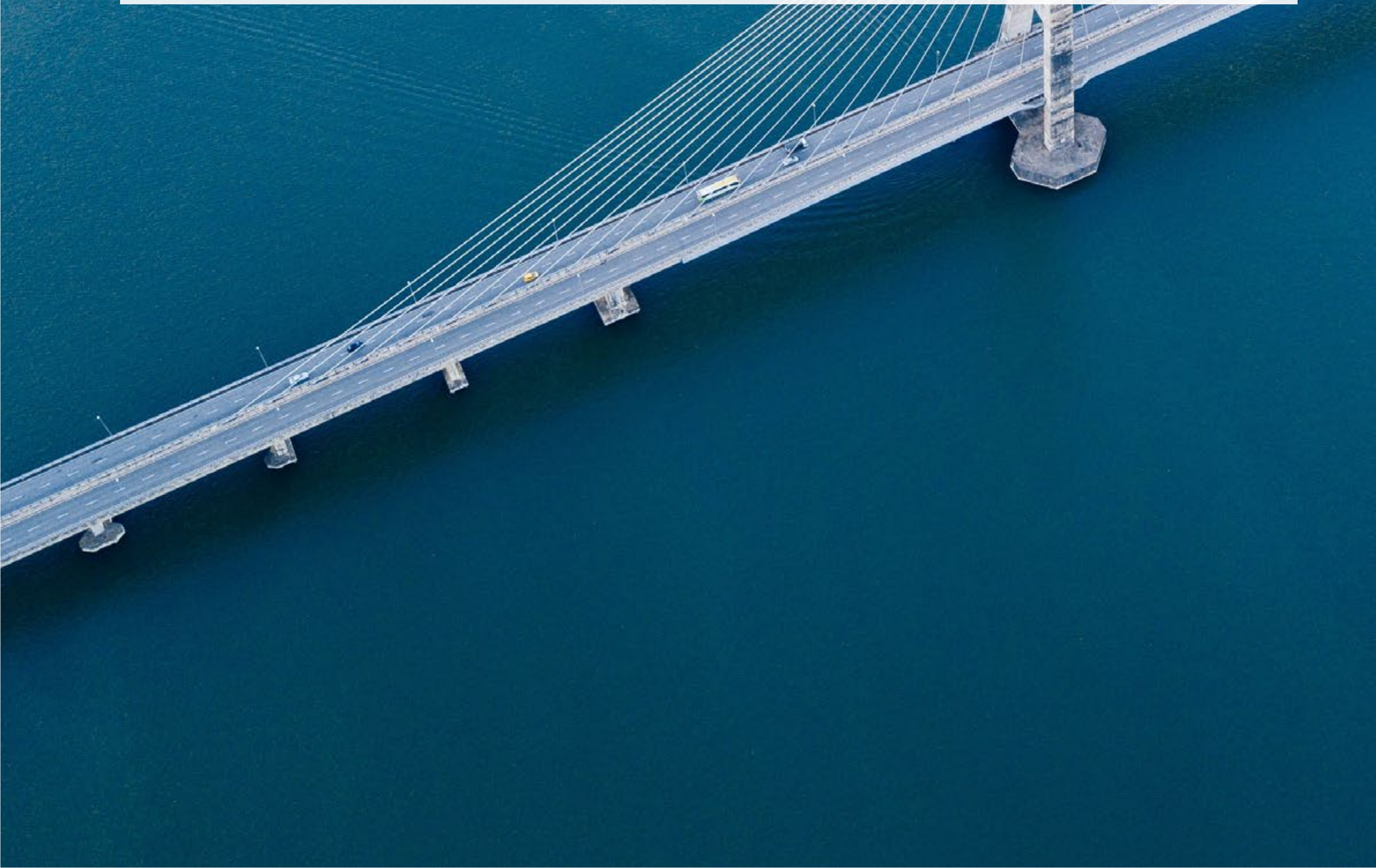
This methodology is the first of its kind given the depth and breadth of expert groups and related technical disciplines that have contributed to different stages of the analysis. PCRAM enables a rigorous interpretation of climate risk analytics and related science to assess the operational, commercial and financial materiality of an infrastructure asset, well beyond a traditional approach exclusively focused on i. loss & damage assessments, ii. acute hazard only, and iii. immediate to short-term horizons. PCRAM takes into account the impact of PCRs on revenue and cost projections and changes in credit quality simulations. In sum, PCRAM is expected to contribute to a shift in the perception of resilient investments from being loss-minimisation exercises to contributing to strategic reviews that lead to value optimisation and the enhancement of investment appraisal practices.

The Authors and Contributors recognise that the industry is continuously evolving. Therefore, the intention is that PCRAM will be continuously refined as the methodology is implemented on more infrastructure assets. This should allow room to further address highly complex and interdependent risks and bring nuances to the way PCRAM is applied at different stages of an asset life cycle.

[1] Asset Management in this document refers to the operations and maintenance of physical assets and not financial portfolio construction and risk management. Please refer to Glossary for further information.

A Message from Nigel Topping, UN's High-Level Climate Action Champion for COP26

"PCRAM represents a critical contribution to both CCRI's and the global resilience agendas. This methodology facilitates a profound shift in the resilience narrative, by which resilience is no longer perceived as downside-minimisation exercises only, in often ex-post ways. Instead, resilience becomes a core component of innovative strategic decision-making. A rigorous integration of these risks should allow the unlocking of the upside, enabling countries and investors to become more competitive, attractive and strategic, instead of being penalised for acknowledging their exposure. As a COP26 Flagship Initiative, I am encouraged by the way CCRI is constantly adjusting its ambition upwards based on its great delivery rate".



Contents

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Glossary

Due to the richness of and interconnection between the disciplines involved, some of the terms used in this document may have different meanings to different practitioners. The most relevant example is the term "asset management", which has both a financial and an engineering definition. We use the terms asset manager and asset owner in their engineering application in this document, unless indicated otherwise.

A number of key terms are used throughout this document and, as such, are defined here to ensure common understanding and application across those involved in delivering PCRAM. They are based on definitions used by the IPCC in its Sixth Assessment Report, tailored to the context of PCRAM.

Adaptation – the process by which an actor and/or an asset evolves to improve its capacity to minimise negative impacts, return to pre-impact configurations and performance as fast as possible, and evolve from impact to impact to improve its resilience.

Asset management (engineering) – the International Standard ISO 55000 regards asset management as the coordinated activity of an organisation to realise value from its infrastructure assets. This is the term used in this document. NB. Asset management (financial) – the activities of a company holding a capital markets services licence under a given jurisdiction. This document does not utilise this term.

Asset owner (engineering) – publicly or privately owned organisation owning physical infrastructure assets with a responsibility for management and stewardship of those. This is the term used in this document. NB. Asset owner (financial) – an organisation that represents the holders of long-term retirement savings, insurance and other financial assets. This document does not utilise this term.

Base case – the quantifiable performance of an infrastructure asset without consideration of future increases in PCRs (basis for investment).

Climate case – the quantifiable performance of an infrastructure asset including consideration of future increases in PCRs.

Climate hazard – conditions that manifest from climate variables (e.g. drought, flooding, heatwave). These are broadly divided into acute (extreme events) and chronic (progressive changes in average climate conditions).

Climate impact – the effect on a natural or human system which results from *climate hazards*. Impacts can be adverse or beneficial.

Risk – the potential for adverse consequences arising from climate impacts (including financial, physical and operational consequences). Risk results from the interaction of the likelihood of climate impact occurrence and the *materiality* of the impact occurring. Likelihood and *materiality* are affected by *exposure* and *vulnerability* to climate hazards.

Exposure – the nature and degree to which an asset is exposed as a function of its geolocation.

Vulnerability – the propensity or predisposition of people, services, resources, infrastructure, assets or investments to be adversely affected by *climate hazards*, i.e. its structural and design attributes.

Materiality – effects on the financial, commercial or other performance KPIs, e.g. damage costs, downtime, loss of service, socio-economic losses, i.e. what might be lost.

Resilience – the capacity of an asset in a given point in time to achieve the quantifiable performance and maintain its essential function and objectives in the face of Physical Climate Risks (PCRs).

Resilience case – the quantifiable performance of an infrastructure asset including consideration of future increases in PCRs and adjustments to the design, operations and/or management of and investments in an asset to improve its resilience to PCRs.

Acknowledgements

CCRI is profoundly appreciative of the invaluable expert input and support receive from its members towards the advancement of PCRAM. The level of commitment, contribution and collaboration captured within this document provide an illustration of the most fundamental values of CCRI. In particular, member institutions of CCRI's Asset Design and Structuring working group have contributed with invaluable expertise to PCRAM in its conceptualisation phase. More generally, the following group of experts, practitioners and academics, all leaders in their respective professional fields, have contributed with critical input towards the development of both PCRAM and this document.

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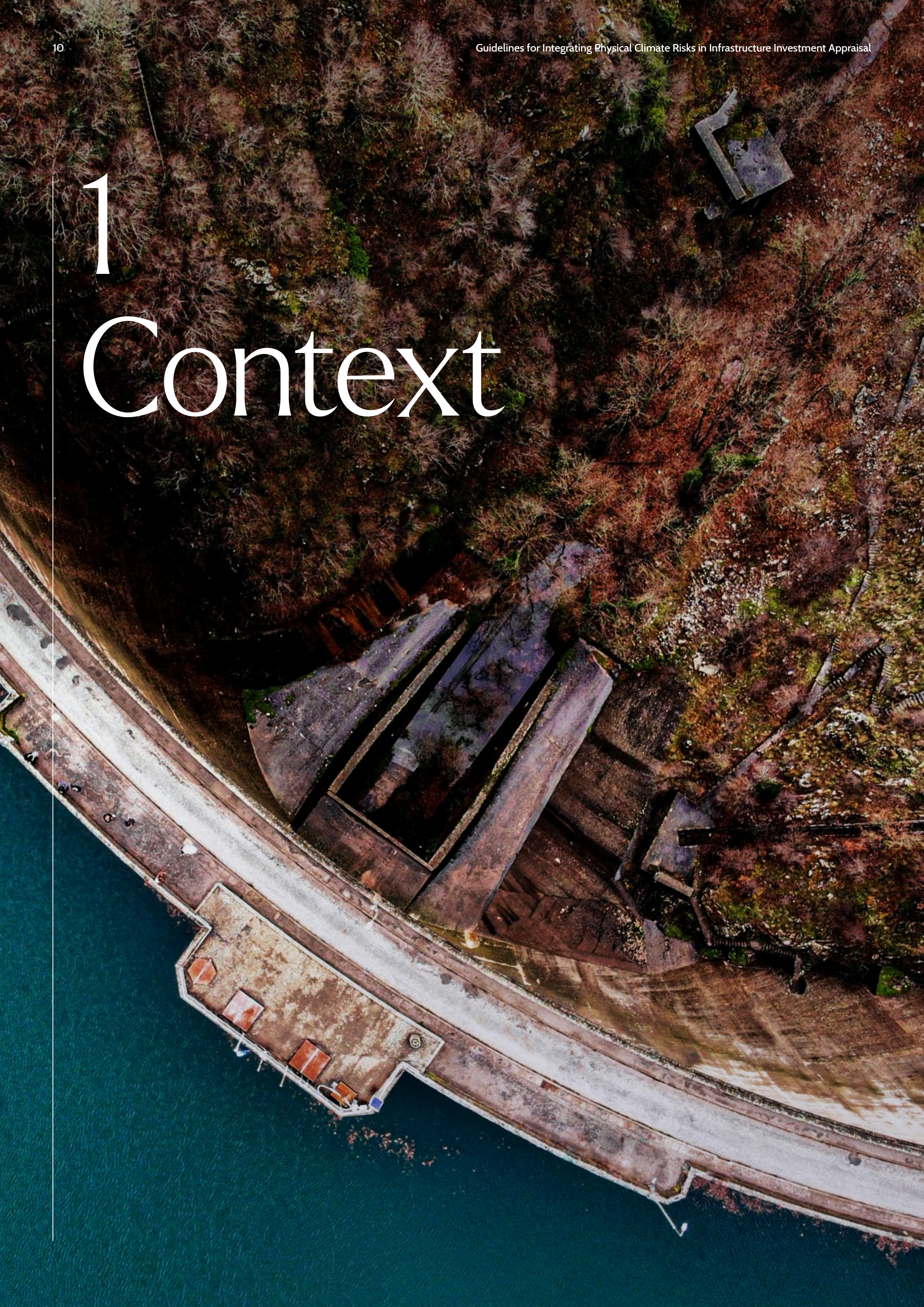
1 Context



1.1 — The Coalition for Climate Resilient Investment

Launched at the UN Secretary General's Climate Action Summit in 2019, the Coalition for Climate Resilient Investment (CCRI) is a private sector-led initiative dedicated to supporting investors and governments to better understand and manage physical climate risks (PCRs). CCRI is a flagship resilience COP26 initiative, convened by the Global Centre for Adaptation, the World Economic Forum, the World Resources Institute, WTW (Willis Towers Watson) and the UK Government.

CCRI is of the view that the perils associated with climate change are insufficiently incorporated into investment decisions in real assets, especially those having to do with infrastructure. The mission of CCRI is to mobilise private finance, in partnership with key public institutions, to develop and implement practical solutions for the effective integration of PCRs in investment decisions and the acceleration of investment flows in climate resilience. CCRI relies extensively on an analysis of case studies and real life projects.

CCRI has a membership of over 127 institutions, covering the entire financial and physical infrastructure ecosystem and including international convening partners and organisations, governments, multilaterals, non-profits, think tanks and academics, institutional investors, asset managers, pension funds, banks, insurers, standard setters, ratings agencies, lawyers, engineers and developers, consultants, auditors and financial and climate data providers. As of April 2022, financial sector participants represent over US$25tn of assets. Deliverables for each working group are progressed through time and expertise contributed by CCRI members. CCRI was incubated and has been hosted by WTW, who have provided operational support for the Coalition's secretariat, alongside the UK Government.

CCRI has developed public good solutions in three technical working areas, namely i. national planning, called CCRI's Systemic Resilience Forum, ii. asset investing, known a CCRI's Asset Design & Structuring working group, delivering solutions for investors to integrate PCRs in cash flow modelling practices, and iii. capital mobilisation & financial innovation working group, focused on the actual mobilisation of capital towards resilient investments. The publishing of PCRAM is part of the CCRI Asset Design and Structuring (ADS) workstream's mandate. Complementary to PCRAM, the ADS and other CCRI working groups continue to advance a range of innovative investor solutions.

> "The publishing of PCRAM represents a critical milestone in CCRI's commitment to deliver to investors' strategic needs. This is achieved thanks to a methodology that relies on science to inform finance."
>
> John Haley
> CCRI Chair
> Former CEO, WTW

[2] For more information on CCRI please refer to https://resilientinvestment.org/

1.2 — Climate Science Considerations

The success of CCRI and its various activities is intimately related to the emphasis the initiative places on the role of climate risk data as the key input to all its deliverables. CCRI has reviewed the issues associated with different analytical approaches and techniques in the field of climate data to assess their relative merits. CCRI and PCRAM have benefitted from the commitment and dedication of climate risk data experts and providers who provided rigorous climate data to allow for collaborative PCR exposure assessments for selected case studies on a pro bono basis. A crucial early takeaway from this area of work is that, contrary to general belief, analytical and climate uncertainty has ceased to be an excuse for inaction to become a manageable consideration. An additional lesson learned by CCRI is that beyond the rigour and quality of climate data, it is equally crucial to define bespoke methodologies for the interpretation of such data in terms of materiality impact for decision-making processes.

In its Sixth Assessment Report, the IPCC concludes that it is "unequivocal that human influence has warmed the atmosphere, ocean and land". The IPCC sets out a range of possible climate futures, which explore climatic responses to five different scenarios of greenhouse gas (GHG) emissions and land use change.

Categorising climate risks

Climate change risks are generally split into two intertwined but broad categories: physical risks and transition risks.

Transition risks are risks arising from the transition to a lower-carbon economy. Transitioning to a lower-carbon economy may entail policy, legal, technological and market changes which may pose varying levels of economic, financial and reputational risk.

Physical risks are risks arising from a changing climate and can result from long-term changes in climatic patterns (chronic risks) and frequency increases of extreme weather events (acute risks).

> "Even if we were to stop emitting today, the infrastructure sector would need to implement climate resilience measures for decades to come."
>
> Carlos Sanchez
> Executive Director, CCRI

The IPCC concludes that 'global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered'. Compared with the 1850–1900 baseline, average global surface temperature over the period 2081–2100 is very likely to be between 1.0°C and 5.7°C higher, depending on the emissions scenario pathway that is followed. Global warming of 2°C, relative to 1850– 1900, would be exceeded during the 21st century under the high and very high GHG emissions scenarios and is extremely likely to be exceeded in the intermediate scenario. Only under the low or very low GHG emissions scenarios are we likely to keep warming under 2°C.

The more global warming we experience, the greater the changes in the climate system will be. These changes will include increases in the frequency and severity of heatwaves, marine and terrestrial temperatures, heavy rainfall, droughts, intense tropical cyclones, sea level rise and reductions in Arctic sea ice, snow cover and permafrost. Furthermore, many changes are irreversible for centuries to millennia, especially changes in the oceans, ice sheets and global sea level, due to past and future emissions.

The effects of these changes are being felt across every region of the world and across all economic sectors, with the IPCC report revealing that approximately 3.3 to 3.6 billion people already live in "contexts that are highly vulnerable to climate change". In the past two decades, the USA alone has endured over 250 weather and climate disasters with cumulative costs of over $1.6tn[3]. However, impacts of climate change are not uniformly distributed across society; they disproportionately affect the poor and marginalised groups.

Infrastructure assets often have a long lifetime (50 years or more), high upfront costs and limited flexibility, therefore understanding PCRs and embedding resilience from the outset is critical to ensuring assets meet their objectives in terms of serviceability, financial return and social outcomes.

Physical risks from climate change may not only affect existing infrastructure in the next decades but are likely to increase over the longer term. The nature and scale of risks become more uncertain over longer time scales as the degree of global warming, and therefore climate change, we experience in future depends on the GHG emissions pathway we follow.

Until credible methodologies and respective analytics are developed and tested by practitioners, the integration of PCRs in cash flow modelling practices may be penalised from a net present value standpoint. However, encouraging progress across science, analytics, finance and regulation globally allows to envisage a future in which systematic forces such as regulation and credit quality are better placed in both enforcing and rewarding resilience. Ahead of such market adjustment, investors and actors across relevant user groups should explore opportunities to improve asset valuations.

[3] IPCC, 2022, 'Climate Change 2022: Impacts, Adaptation, and Vulnerability'

1.3 — Asset Management, Engineering and Climate

At the early stages of an infrastructure project, there is a tendency to focus on risk prevention from an insurance lens which tends to be restricted to loss and damage. Thus, impacts of other (non-loss related) risks are not always considered, despite being material to the asset.

Infrastructure projects have historically faced and continue to face serious challenges in design, delivery and operations. Cost overruns, delivery delays, procurement failures and issues in securing private financing are common. Many of these problems arise due to the lack of a structured, forward-looking approach to risk management across all stages of the value chain and throughout the project life cycle. The Institute of Asset Management outlines key elements for effective risk management, including processes and procedures, strong linkages to planning and budgetary cycles, good reporting and performance management, risk assessment frameworks, risk registers and audit programmes. In particular, poor risk assessment and risk allocation during the early phases of design and procurement can lead to higher materialised risks later on.

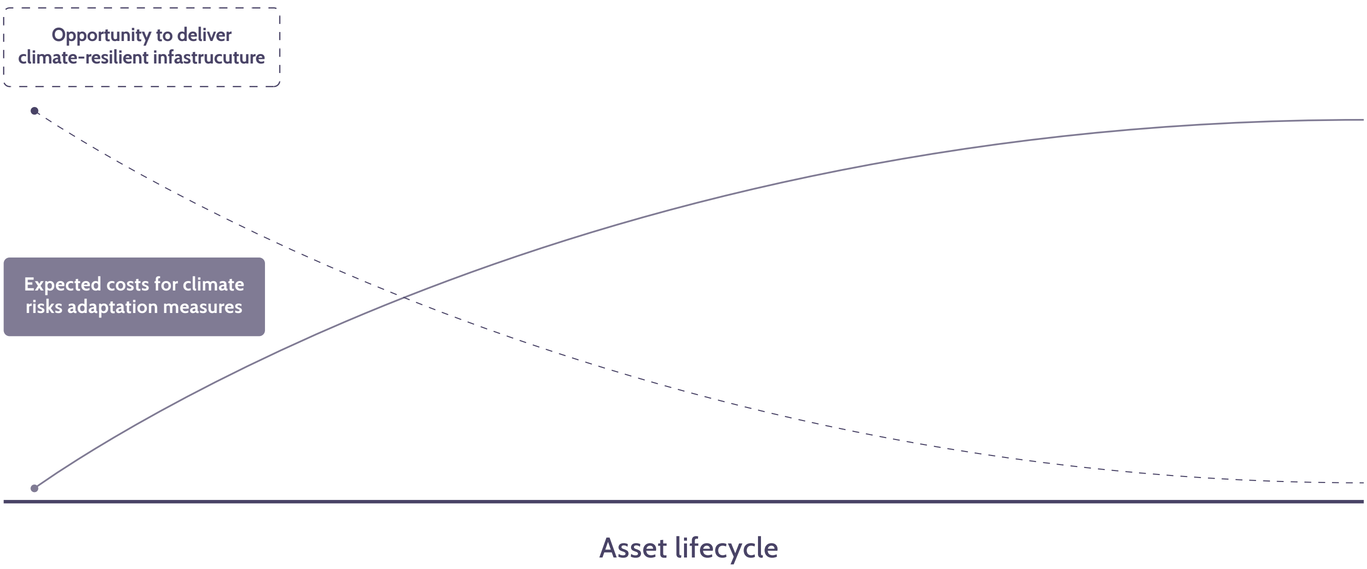
The aforementioned is especially true for PCRs. Decisions made in regard to asset delivery and management, especially in the design and procurement phases, are not often informed by climate projections and a robust understanding of future PCRs under various scenarios in the relevant geographies. Historic climate data is often used in the design of climate-specific thresholds (e.g. temperature, humidity level, wind speed etc.) for infrastructure assets and individual components. Factors of safety in design are used to account for any future variability in climate scenarios; however, these factors are applied in a blanket approach and do not necessarily equate to the severity, frequency and type of possible climate risks under various scenarios. Factors of safety in design are the engineer's version of discount rates in finance.

Rather, infrastructure asset delivery and management decisions are driven by a handful of key parameters that decision makers attempt to optimise against. Firstly, decisions are usually influenced by the desire to minimise CAPEX, OPEX and schedule, while delivering infrastructure assets that do not pose a risk on the lives and wellbeing of the communities that they are designed to serve, and the wider surroundings. Secondly, any decisions or suggested changes ought not to compromise the serviceability of infrastructure assets (i.e. asset functionality and durability).

Lastly, as infrastructure assets tend to exist in regulated environments, decisions need to respond to and comply with regulatory frameworks and design codes. Regulators such as Ofgem, UK (Office of Gas and Electricity Markets), present stringent requirements in industry codes and standards to ensure fair treatment of end users and compliance with legislation. In addition, design codes (e.g. British Standards and Eurocodes) and asset management standards (e.g. ISO 55000) provide guidance and often dictate how infrastructure assets are to be designed, procured and managed.

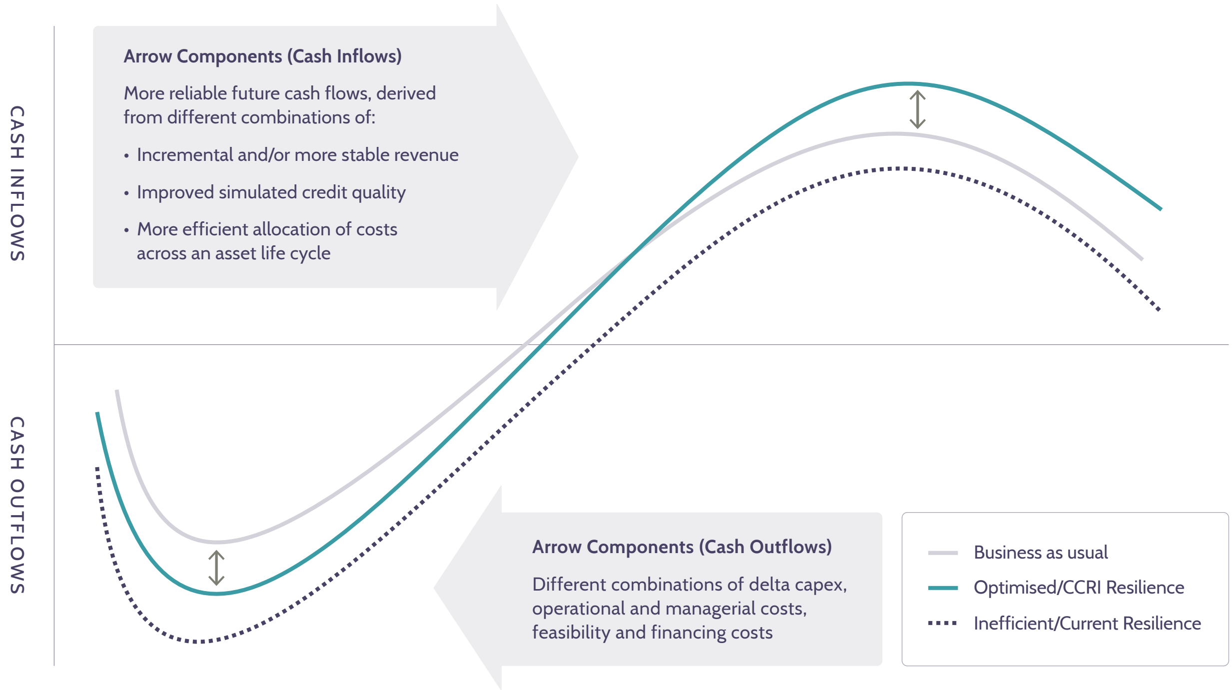
The focus the infrastructure sector places on the above parameters (e.g. minimisation of cost and schedule, prevention of loss of life, serviceability, current regulation and code compliance) means that future climate projections and associated climate risks are often overlooked from the private sector perspective in design and delivery. They are generally transferred outwards to the insurers or the public sector, with little attention paid to the potential value destruction in the long term and inefficient recognition and reward of associated improvements. This should not be the case as integrating climate risk assessment to adapt infrastructure assets from the outset, including through adjustments to operations, can lead to both significant reductions in the costs of climate adaptation measures later on and improvement in the quality of revenue streams. This is further illustrated in Figure 1, below. In other words, investing in resilience is perceived to increase costs and schedules, which is viewed as irrational. The private sector is rarely incentivised to make decisions that optimise costs throughout an asset life while incorporating climate risks.

Figure 1: Diagram highlighting the importance of early adaptation of climate resilient infrastructure



The resilient investment perception problem is depicted in Figure 2 below.

Figure 2: The resilient investment perception problem



The Business as usual (BAU) J-curve describes cash inflows and outflows based on current investment practices, standards, regulation, and credit quality assessments. There is no integration of PCRs, other than through risk transfer when and if applicable. The "Current Resilience" J-curve draws on current perceptions regarding resilient investing. In this curve we observe both a significant additional investment upfront (the so-called "delta capex") which is not optimised over the asset life cycle, and an inefficient if not inexistant recognition of the value of such delta capex in terms of the long-term financial and structural performance of the asset.

By contrast, in the "Optimised / CCRI Resilience" J-curve we recognise the gains in terms of the size and composition of the delta capex. The adjusted capex level has been derived from an analysis of multiple resilience options and their impact on the value of the asset. The rigorous integration of PCRs in the definition of the structural and operational configurations of an asset is recognised through incremental and more predictable future cash flows. The differences between the optimised and the current J-curves constitutes an expression of market inefficiencies that are linked to inconsistent scientific data, a lack of standardised approaches for the integration of PCRs in investment appraisal, and the difficulties experienced by standard setters, regulators, and credit rating agencies to adequately enforce and reward the integration of PCRs.

Figure 2 highlights the different benefits of integrating PCRs, which in addition to more predictable cashflows include improved credit quality simulations, or/and a more efficient allocation of costs across an assert life cycle. Other costs that may be associated with improved managerial and opex solutions, as well as feasibility, due diligence and financing costs are reflected in the cash outflows.

A crucial take-away from PCRAM is that, in a counter-intuitive way, it may lead to a reduced cost of resilience based on a proper integration of PCRs. As PCRAM and other CCRI analytics gain further momentum and inspire key market forces, it is expected that considerable efficiency gains will be harnessed through the implementation of this methodology.

1.4 — PCRAM Guidelines Overview

PCRAM guidelines have been prepared for infrastructure asset developers, managers and providers of capital. They outline a methodology for the combination of three distinct fields to incorporate PCRs into the appraisal of infrastructure assets, namely (a) climate science, (b) infrastructure asset management and engineering, and (c) infrastructure finance.

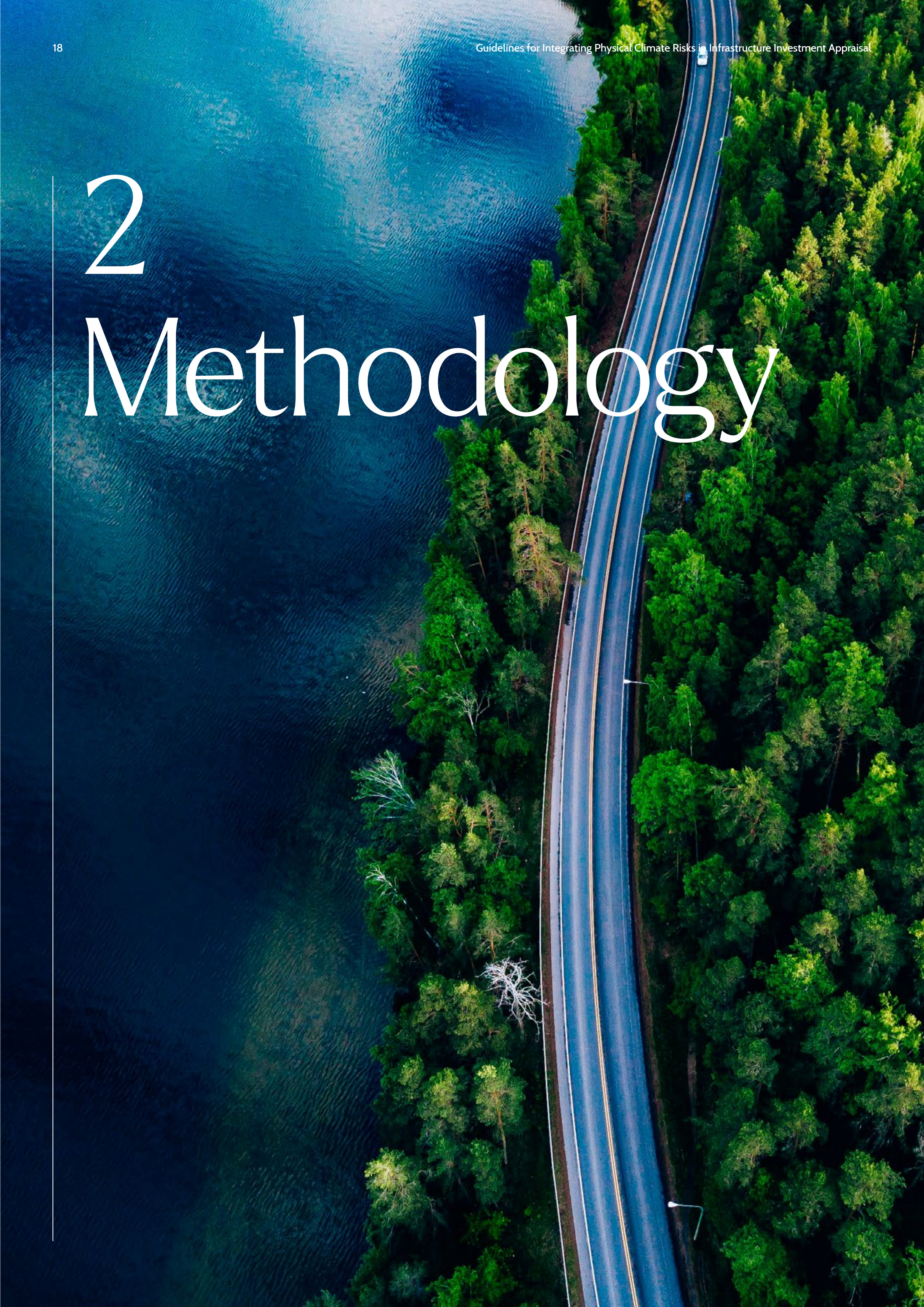
The document builds on good practice from each of these fields, including the IPCC models with AR6 Synthesis Report, ISO Standards on Climate Adaptation and the Asset Management Institute ASCE MPE 140.

The guidelines form a practical and effective (i.e. systematic, objective, auditable, and repeatable) framework for the effective integration of PCRs in investment decision-making.

Key PCRAM Features

- This is a multidisciplinary exercise requiring climate data scientists, engineers, asset owners, managers, including operators, and finance practitioners to collaborate equally and closely from the outset.
- The assessment process relies upon professional judgement and requires inputs from multiple stakeholders to quantify the impact of climate change PCRs on critical component(s) of an asset.
- The process requires the practitioners to make and communicate pragmatic assumptions where information may not be available and to accept and highlight uncertainty.
- The assessment is agnostic to the nature of value (economic vs. social vs. environmental) and can be applied by public or private sector entities and is applicable to all types of financial ownership set up structures and infrastructure sectors.
- The methodology should not be seen as a one-off exercise but as a live, iterative process that is regularly updated as new information on climate hazards and risk (exposure, vulnerability and consequence), damage costs etc. become available.

2 Methodology



2.1 — Introduction

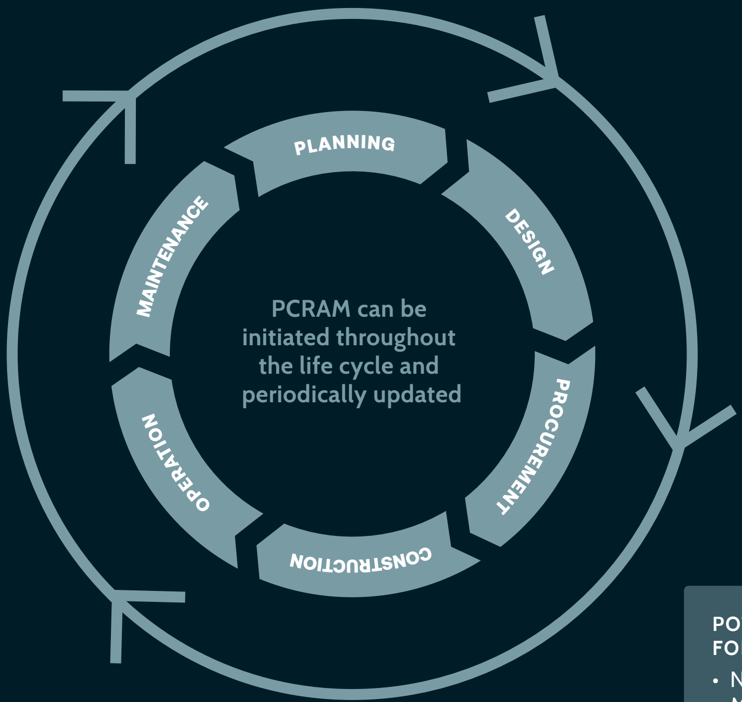
PCRAM is a methodology for assessing physical climate risks (PCRs) and integrating them in infrastructure investment decision-making by incorporating climate science into financial analysis. It builds upon the principles of ISO 31000 Risk Management – plan, do, check, act, process – and ISO 14091 – Adaptation to climate change, a risk-orientated framework.

The intent of the methodology is to allow infrastructure asset operators, managers, investors, lenders and regulators to quantify the impact of PCRs on asset performance (e.g. in relation to physical, operational, economic and financial performance parameters or broader ESG performance). The methodology will aid infrastructure stakeholders to identify, quantify and disclose their exposure to PCRs relative to asset performance, as well as make informed decisions on how best to adapt infrastructure assets to reduce the material impacts of such PCRs.

The methodology is applicable to new and existing assets or groups of assets and is intended to be used throughout the asset life cycle. It is focused on impacts to the infrastructure asset and not on broader systemic impacts. Importantly, PCRAM is an iterative process and should be regularly revisited throughout the project life cycle. Potential triggers are found in Figure 3.

PCRAM delivers a resilience snapshot and reflects the information available at the time of the assessment. As a result, there is a need to revise and update any risk assessment periodically to appropriately manage PCRs.

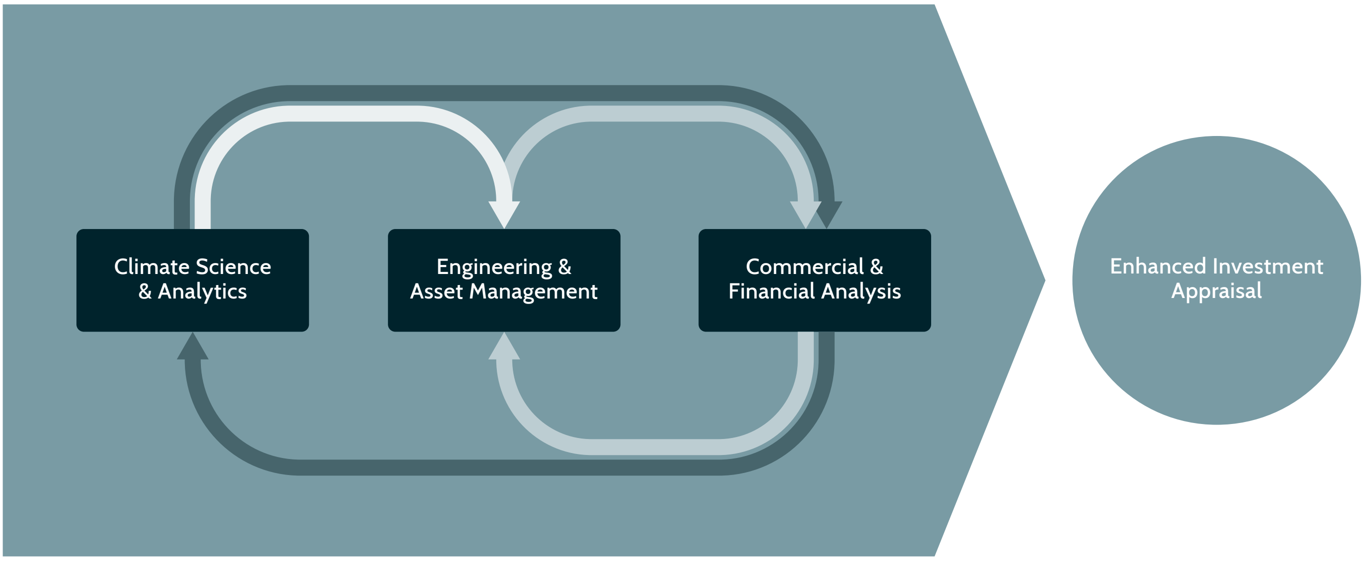
Figure 3: PCRAM throughout the project life cycle



POTENTIAL TRIGGERS FOR PCRAM

- New climate data or events
- Major milestones
- Regulatory changes
- Change in ownership or refinancing

Figure 4: Feedback Loops for PCRAM Workstreams



The methodology brings together three distinct workstreams working together through an iterative process, as shown in Figure 4 above.

The methodology has four key steps and three gates as shown in the diagram on the following page (Figure 5).

In Step 1 the project team defines the objectives, identifies the scope of the assessment, and collects essential information about the climate, the infrastructure asset(s) and the associated critical components, as well the key performance indicators (KPIs). This data collection is used to develop the Base Case performance of the asset.

At the end of Step 1, the project team arrives at a Decision Gate (A) and decides if the data is robust, complete and sufficient to proceed to the detailed materiality assessment. If not, the project team would return to Step 1 in order to collect further information or modify the scope of the assessment to better reflect data availability.

In Step 2, the project team develops the inputs for the Climate Case(s) by taking the data and assessing the severity of impact to the infrastructure stemming from relevant climate hazard(s) using the KPIs to quantify the risk.

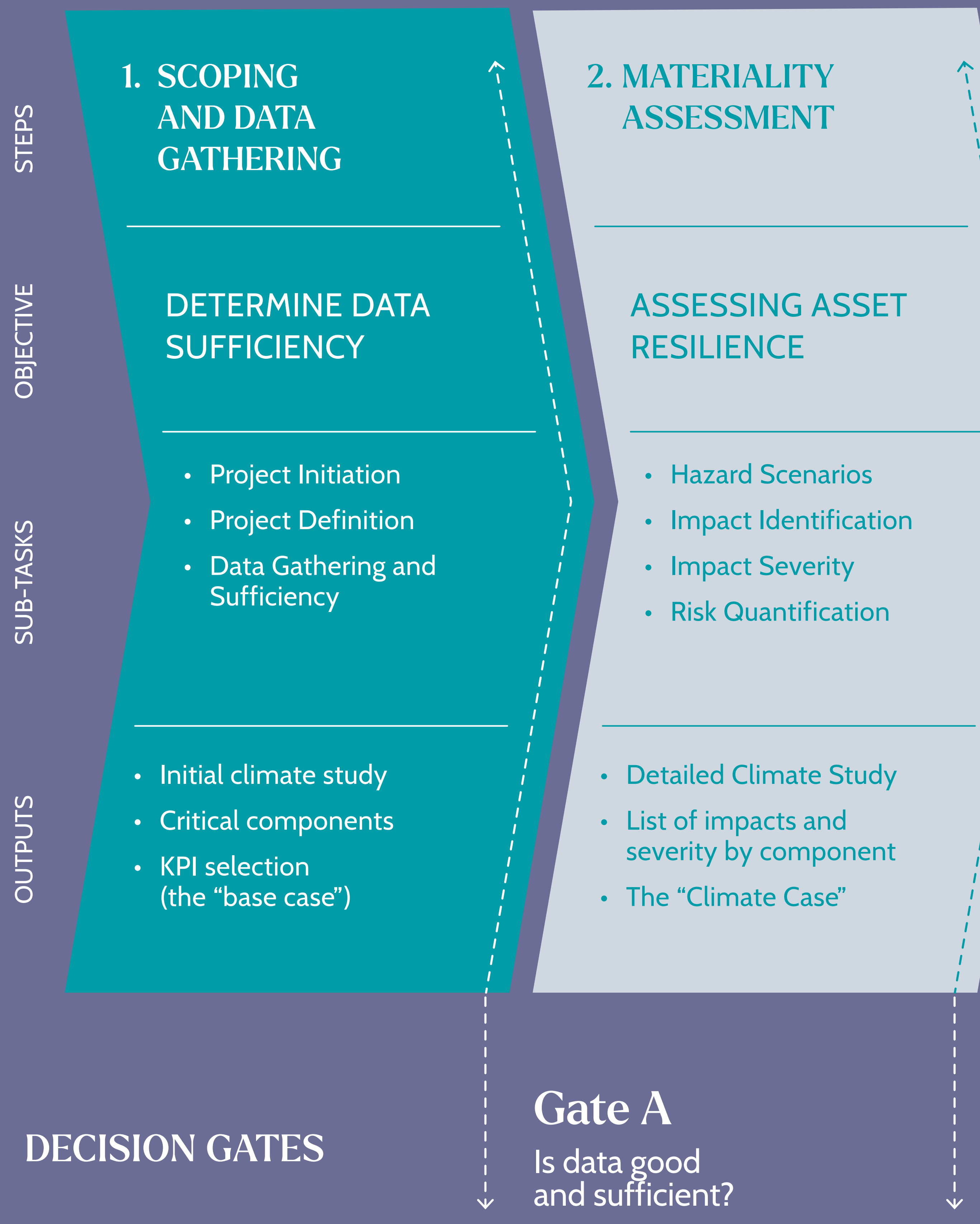
At the end of Step 2, the project team arrives at Decision Gate (B) and decides if the PCRs are material to the asset(s) given the KPIs. In the event the PCRs are not material, the assessment is complete.

In Step 3, the project team develops the Resilience Case(s). Initially, a list of options to improve resilience of the asset to material PCRs is generated through discussion between the climate practitioner, engineers and asset managers. Resilience Case(s) are composed of feasible resilience options that may reduce the severity of impact of material climate hazards. These resilience options (effectively an improved infrastructure asset) are re-run through the Step 2 Materiality Assessment to measure projected benefits against the cost of the options (CAPEX and OPEX).

At the end of Step 3, the project team arrives at Decision Gate (C) and decides if there are resilience options available to reduce the severity of impact.

In Step 4, the project team undertakes an economic and financial analysis to de-risk an asset exposure to PCRs and recommends resilience options.

Figure 5: PCRAM methodology



3. RESILIENCE BUILDING

IDENTIFYING RESILIENCE OPTIONS

- Resilience Options:
  - Hard (structural / capex)
  - Soft (operational / systems
- Repeat Materiality Assessment

- Revised climate study for new elements
- The "Resilience Case"

4. ECONOMIC AND FINANCIAL ANALYSIS

DE-RISK ASSET EXPOSURE TO PCRS

- Cost / benefit analysis
- IRR comparison

- Recommendations
- Value implications

Gate B

Are PCRs material to this asset?

Gate C

What resilience options are available for this asset?

2.2 — Step 1: Scoping and Data Gathering

Objective: Define the scope and determine data sufficiency and quality.

Purpose

1. Define the motivation for and desired outputs of the assessment with respect to the various drivers that may initiate PCRAM (e.g. regulation, financial or operational milestones, change in ownership, etc.). The objectives for an organisation may include the following:
    - Safeguarding longer-term value of investments.
    - Obtaining and maintaining internal and external credit ratings.
    - Compliance with regulatory or other third-party requirements.
    - Improving longer-term asset performance.
    - Achieving environmental and social outcomes.
2. Define the scope of the risk assessment, including:
    - The climate hazards to be assessed.
    - The asset(s) and components included and excluded.
    - The commercial/financial elements for consideration.
3. Confirm the scope of work and determine if there is sufficient information available to complete the scope.

Sub-tasks

Step 1a) Project Initiation

The organisation(s) collaborating on the assessment should define the objectives and expected outcomes which should fundamentally seek to address one simple question:

Is the infrastructure asset at risk due to changes in the climate?

At this time a project team should be appointed to carry out the risk assessment. The makeup of the project team is critical to the success of the assessment and it is recommended that many of the key specialists typically involved with infrastructure development and management be assembled, including:

- Asset developers, managers and operators with detailed operational knowledge of the infrastructure / type of infrastructure.
- Asset owners with their understanding of how the asset performance impacts economic and financial KPIs (as reflected in a financial model).
- Engineering team that understands how the design of an asset is affected by the relevant climate thresholds; this could be the Lender Technical Adviser appointed in the context of a project financing.
- Climate risk data specialists that can use historical climate data and spatial and temporal scales, select appropriate climate models (global and downscaling, regional or at local scale); and that are experienced at processing data, bias adjustment, downscaling, computation of climate indices and estimation of uncertainty. Specific climate hazard models might be required depending on the asset (e.g. hydrological model, coastal dynamics).

- Project finance and financial modellers capable of adjusting an asset cash flow forecast to include the possible impacts of PCRs and assess resilience options.
- Other potential key stakeholders as relevant, such as financial experts that are able to identify economic and financial materiality thresholds linked to a climate impact (e.g. financial advisers, lenders, regulatory bodies, insurance providers).

It is also important for the organisations leading the assessment to assemble a data room of relevant information for the exercise, including climatic, engineering, commercial and financial information related to the asset. Additional data will also be required after completion of Step 1b).

Output

The outputs of Step 1a) Project Initiation should be:

- A clear formulation of the objective and motivation for the assessment.
- A list of expected outcomes of the assessment.
- Mobilisation of a project team.

Step 1b) Project Definition

The project definition step should aim to define the scope of the assessment considering the three workstreams: (1) climate science,

Climate Science

The climate scope of the assessment should be defined with respect to the following:

Climate hazards – Global warming will result in changes to a range of climate variables and hazards that result from these changes. The team should identify a list of potential climate hazards to consider in the assessment, based on known sensitivities of the asset type, coupled with climate projections of those hazards.

Time period for analysis – Climate projections are available for a range of time periods up to the end of the 21st century and PCRs should be considered for multiple time periods. The choice of time periods should be relevant to the asset and/or investment being assessed (e.g. linked to maintenance or replacement cycles or re-financing or concession terms).

Type of projection – Climate projections can be probabilistic or deterministic. Probabilistic projections are based on multiple simulations from an ensemble of climate models and are commonly used to explore a set of plausible future climates. It is advisable that deterministic values be avoided and that a range of probabilistic values (e.g. 10^{th}, 50^{th} and 90^{th} centile values) be considered in any climate threshold analysis.

Emissions scenarios – Climate projections are available for a range of emissions scenarios. A range of emissions scenarios should be considered and the choice of emissions scenarios guided by the sensitivity of the asset to climate change, taking account of the degree of flexibility to add resilience measures over the life of the asset. In most cases, the assessment should consider projected change in climate variables under medium and high/very high emissions scenarios. This allows for exploration and understanding of risk under a worst-case scenario, based on the precautionary principle.

See appendix 1 for further information about the use of climate data.

Asset Management & Engineering

The asset management and engineering scope of the assessment should be defined in consideration of the following:

Selection of the asset elements to be assessed – Infrastructure assets can contain many systems and sub-assets of varying function and relative importance. It is important for the project team to identify both a list of what aspects of the asset are in scope, as well as the level of detail with which these aspects are to be assessed. Will the assessment examine down to the individual component level or will it remain at a system level? At this stage, a long list of asset systems and components will be identified to scope into the assessment.

Identification of the relevant asset management key performance indicators (KPIs) – Or thresholds to be used to measure impact (e.g. targets related to downtime or availability requirements, production, safety, environmental, CAPEX, OPEX, etc.).

Identification of key technical documents and information sources – Need to be identified at this stage and requested by the project team. This information could include (depending on where the asset is within its asset life cycle):

- Physical location and surroundings.
- Engineering Drawings.
- Specifications (including operational thresholds).
- CAPEX.
- Operations and Maintenance plans, manuals and records.
- Condition Assessments.
- OPEX.
- Historic climatic information (e.g. past events).

(2) asset management and engineering, and (3) commercial and financial perspective.

Financial & Commercial	Output
The financial and commercial scope of the assessment should be defined with respect to the following: **Definition of the financial and commercial assessment –** Infrastructure assets have a variety of potential financial and commercial drivers, and at this stage the project team should define what financial and commercial factors will be analysed as part of the assessment. This could include impacts related to contractual obligations, debt service obligation, credit ratings, financial return targets, broader socio-economic goals, and other potential factors. **Selection of financial/commercial/ESG KPIs –** In line with the financial and commercial scope of the assessment, the KPIs that will be used to measure impact of PCRs from a financial and commercial perspective should be selected. This could include: • Financial metrics such as DSCR, IRR, NPV, ROI and related debt covenants (stemming from changes to CAPEX and OPEX and revenues). • Commercial penalties or liquidated damages. • Socio-environmental metrics such as CO_2. emissions and other greenhouse gases. • Socio-economic metrics such as job creation/loss. **Identification of key documents and information sources –** At this stage, financial and commercial documentation will need to be identified and requested by the project team. This information could include: • Concession, transportation and/or off-take agreements. • Regulatory requirements. • Policies and guidelines. • Construction and O&M contracts with relevant warrantees/ guarantees. • Insurance considerations. • Tax regimes. • Financial information (e.g. finance plan). • Loan agreements. • Financial models including historic and forecasted cash flows.	• Climate hazards to be considered, time period for analysis, type of climate projections and emissions scenarios to be used. • Asset components/systems to be analysed. • KPIs which will be used to measure impact. • Documentation needed to complete the assessment.

Step 1c) Data Gathering and Sufficiency

Once the scope of the assessment has been defined, the project team will determine whether or not the necessary information

Climate Science Data Sufficiency & Gathering

This step involves collecting data on historic climate and projected climate change, relevant to the climate hazards scoped in during Step 1 b), including:

- **Identify thresholds –** Understand any climatic thresholds critical to successful delivery of the asset management objectives and/or financial objectives. Any climatic factors or thresholds included in the basis of design, asset management objectives or standards used in asset design should also be identified.
- **Understand performance of the asset –** Or similar assets under historic climate. Data to analyse include:
  - Historic records of temperature, rainfall and wind patterns as well as sea level (if relevant) in the vicinity of the asset. Records should cover a minimum of 30 years (where possible)
  - Records of extreme events, such as floods, droughts, or heatwaves, and how the asset was impacted (e.g. loss of service, down time, repair or early replacement)
- **Understand how climate is projected to change –** Data to collect includes climate projection data relevant to the hazards, time periods and emission scenarios scoped in
Step 1b). See also Table 2.
- **Threshold exceedance analysis –** Once the projected climate data has been collected, it should be analysed to understand the frequency and timing of threshold exceedance. It should seek to answer the following questions (these can be tailored depending on the nature of the asset and/or threshold):
  - How frequently is the threshold exceeded in the future? The metric for this will depend on the nature of the asset (e.g. number of days per year, or number of occurrences over a defined period). What is the duration of threshold exceedance? When does threshold exceedance occur – near, medium or long term? If an asset is typically designed to a specific return period, what is the expected change in that return period?

Engineering & Asset Management Data Sufficiency & Gathering

This step involves analysis of the data collected and provided, including:

- Review the key functions and components of the asset and how they relate to the asset management KPIs.
- Highlight key interdependencies that could lead to cascading failures.
- Review of the asset life cycle and design life and provide this data to climate science workstream.
- Review in detail the CAPEX and OPEX and their relationship to the asset management KPIs and broader financial model.

Engineering, asset management and climate practitioners must collaborate with the commercial and financial teams in order to:

- Confirm the boundary of the assessment, including what systems and asset components can and should be analysed.
- Identify and confirm relevant asset management KPIs (e.g. downtime or availability requirements production targets, safety, environmental, CAPEX, OPEX, etc.) and ensure that the necessary linkages between asset performance and design are quantifiable.
- Identify critical asset components and screen asset components based on exposure to hazards.
- Identify climate thresholds used in design of critical components and in the operations and maintenance plan (e.g. schedule/unscheduled downtime, response to extreme events).

It is also important to identify limitations to the assessment.

is available to complete the assessment.

Commercial & Financial Data	Output
In this step, financial and commercial practitioners should analyse the data collected and provided, including: • Confirm the boundary of the assessment, including what commercial and financial elements will be included in the assessment. • Review regulatory compliance and contractual requirements impacted by climate change. • Review how asset management information is reflected into the financial models. • Review detailed CAPEX and OPEX assumptions. • Review duration of the concession agreement or investment. • Confirm financial/commercial KPIs (DSCR, IRR, NPV, penalties/LDs, ROI, etc.) by performing sensitivity analysis or by other means on key inputs into the financial model. • Other KPIs such as ESG indicators can also be considered. It is also important to identify limitations to the assessment in terms of the asset, climate and financial data and any assumptions made. The limitations should be expressed at a minimum as a function of uncertainty (range) in the results.	The output of Step 1 c) Data Sufficiency and Gathering should include the following: • A climate study with probability of exceedance of specific thresholds as identified by the asset management and engineering team. • A clear understanding of the availability of information and limitations that this may have on the assessment. • A short list of asset components that are expected to be carried forward into the detailed assessment. • Confirmation of the scope of work. Note: The climate Study should set out the following: • Climatic thresholds or factors critical to the successful delivery of the asset management objectives and/or financial objectives of the project. • The historic climate context used to determine the asset management objectives, asset design or financial objectives of the project. • The projected change in climate and associated hazards over the defined timescale of the assessment. • Results of the threshold exceedance analysis, including frequency, duration and timing of threshold exceedance. • Discussion on the adequacy of the climate context used to determine the asset management objectives, asset design or financial objectives of the project with respect to projected climate and threshold exceedance. • It is also important to identify limitations to the assessment.

Table 1: Sample climate hazards

Hazard	Potential variables (proxies in italics)	Notes
Acute		
Coastal flooding	Extent, depth	Consider a range of return periods
Storm surge	Height, full curve of height over time, astronomical tide, sea level rise, extent, depth	Consider a range of return periods
Fluvial flooding	Extent, depth, velocity (if available)	Consider a range of return periods
Surface water flooding	Extent, depth, *daily max rainfall, 5-day rainfall total*	Consider a range of return periods, consider a range of probabilities, including the 90% probability (where possible)
Heatwave	*Heatwave index, daily max temperature, tropical days/nights,* sea-surface temperature	It may be possible to gather data on exceedance of temperature threshold (if known)
Wildfire	*Wildfire index*	Wildfire hazard depends on changes in temperature and rainfall
Cold events	Daily min temperature	Consider a range of probabilities, including the 10% probability (where possible)
Snowfall	*Daily min temperature, winter precipitation*	Snowfall hazard depends on changes in temperature and precipitation
Storms	Wind speed and direction	There is generally low confidence in projections of changes in wind in downscaled climate projections
Chronic		
Drought	*Drought index* *Seasonal average* rainfall	Consider a range of drought index durations (3, 6 and 12 months) Consider a range of probabilities, including the 10% probability (where possible)
Low/high river flow	River flow or discharge rate *Seasonal average rainfall*	Consider a range of probabilities, including the 90% probability (where possible)
Change in soil moisture content	Soil moisture content *Seasonal average rainfall* *Seasonal temperature*	
Change in length/timing of growing season	*Seasonal average rainfall* *Seasonal temperature*	Consider change in timing of seasons

Challenges and lessons learned

- When mobilising the team, it can be difficult to identify the correct technical, commercial and financial needs of the project. In many cases the data needed is sensitive, therefore confidentiality and non-disclosure agreements, and secure online storage, including provisions for external access, may be required.
- The objectives and expected outcomes of assessment will likely evolve as the assignment progresses, and the organisation leading the assessment must be ready to face these changes in scope.
- Close collaboration between the three specialist teams is critical in this early step to ensure the assessment scope is appropriate and relevant to the asset/investment being assessed. Getting the scoping right saves time and avoids repeat work at later stages.
- The timescale for the assessment should be limited to 2100 due to availability of detailed climate projections, even if the asset has a design life beyond 2100.
- At this stage of the project, scoping decisions are made without a fulsome understanding of the asset and its potential vulnerabilities to climate change. As a result, there is the risk of the scoping impacting the quality of the results.
- PCRAM may be seen as an unnecessary burden. However, analysis of PCRs can result in long-term value creation and predictable gains in efficiency at the asset level. Regulatory pressure combined with a shift in financial markets' perception about PCRs may also change the dynamics.
- Records of historic climate data may not be available at a local (asset scale) level in all parts of the world or records may be incomplete. National and regional scale information about observed climate can be obtained from sources such as the World Bank Climate Change Knowledge Portal[4].
- Involve climate data providers at an early stage in discussions about potential climate variables to include in the assessment. Not all climate data providers have data on all climate variables, different providers use different metrics and proxy indicators for climate hazards, and uncertainty is almost assuredly treated differently between providers, if treated at all. Early discussion with data providers to understand what data and metrics are available is crucial.
- Ideally, climate projection data should be obtained for the site or asset location, based on latitude-longitude coordinates. However, this is not always appropriate, particularly for linear assets. Where this is not possible (e.g. where an asset has not yet been built or is in early planning stages), an alternative approach can be discussed with climate data providers, recognising the limitations of data. For example, flood hazards can be highly localised and an approach which looks at flooding across a wider area may underestimate risk. For linear assets, gridded climate projections may be more appropriate.
- Climate thresholds may not exist or be well understood for all asset types. In this case, the climate practitioner should work with the asset managers and engineers to identify relevant thresholds, based on professional knowledge.

[4] World Bank Climate Change Knowledge Portal Homepage | World Bank Climate Change Knowledge Portal

Decision Gate A

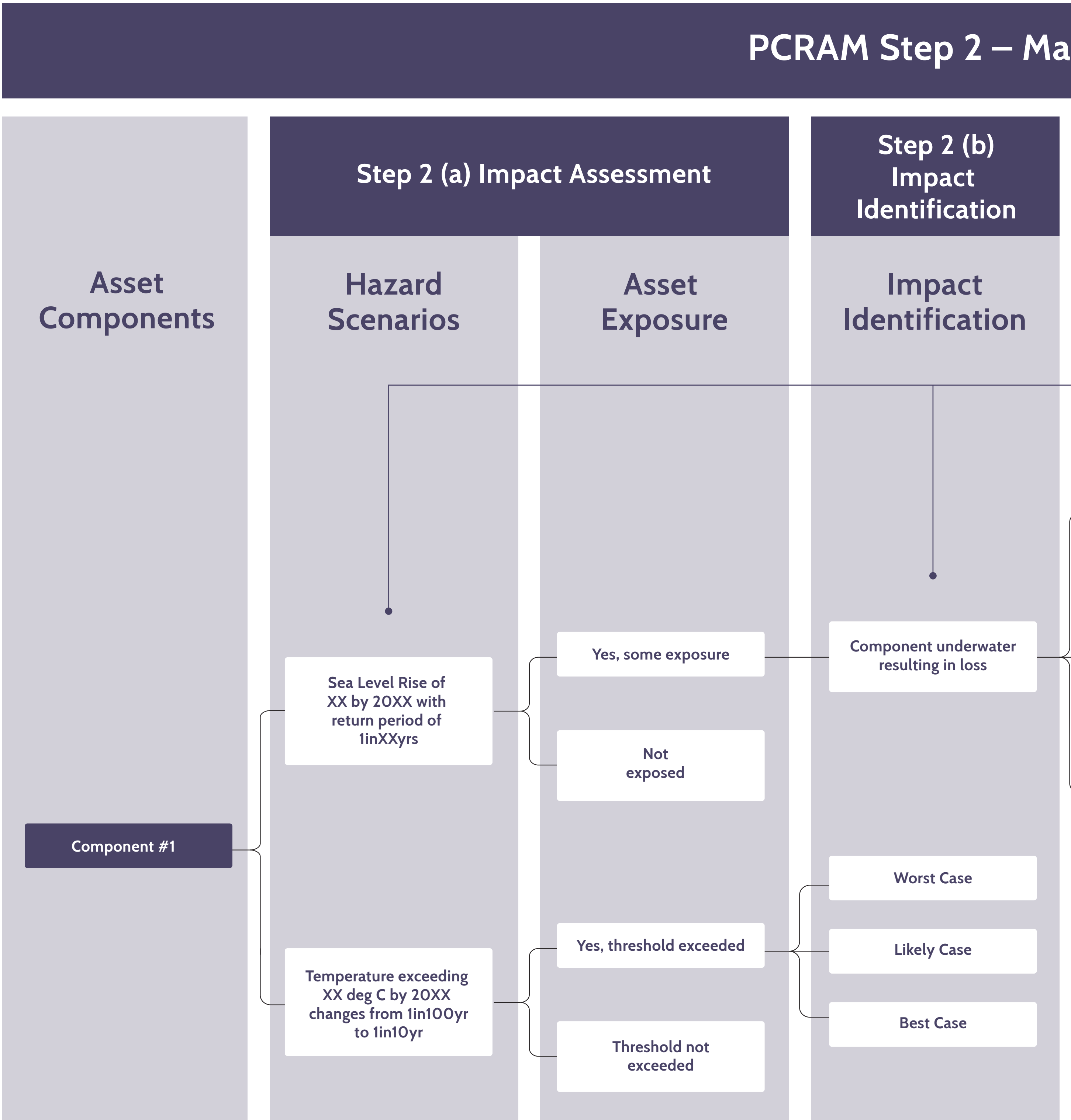
Is data robust, complete and sufficient?

If not: return to the start of Step 1.
Does the scope or objectives need to be revised?
Can additional information be obtained?

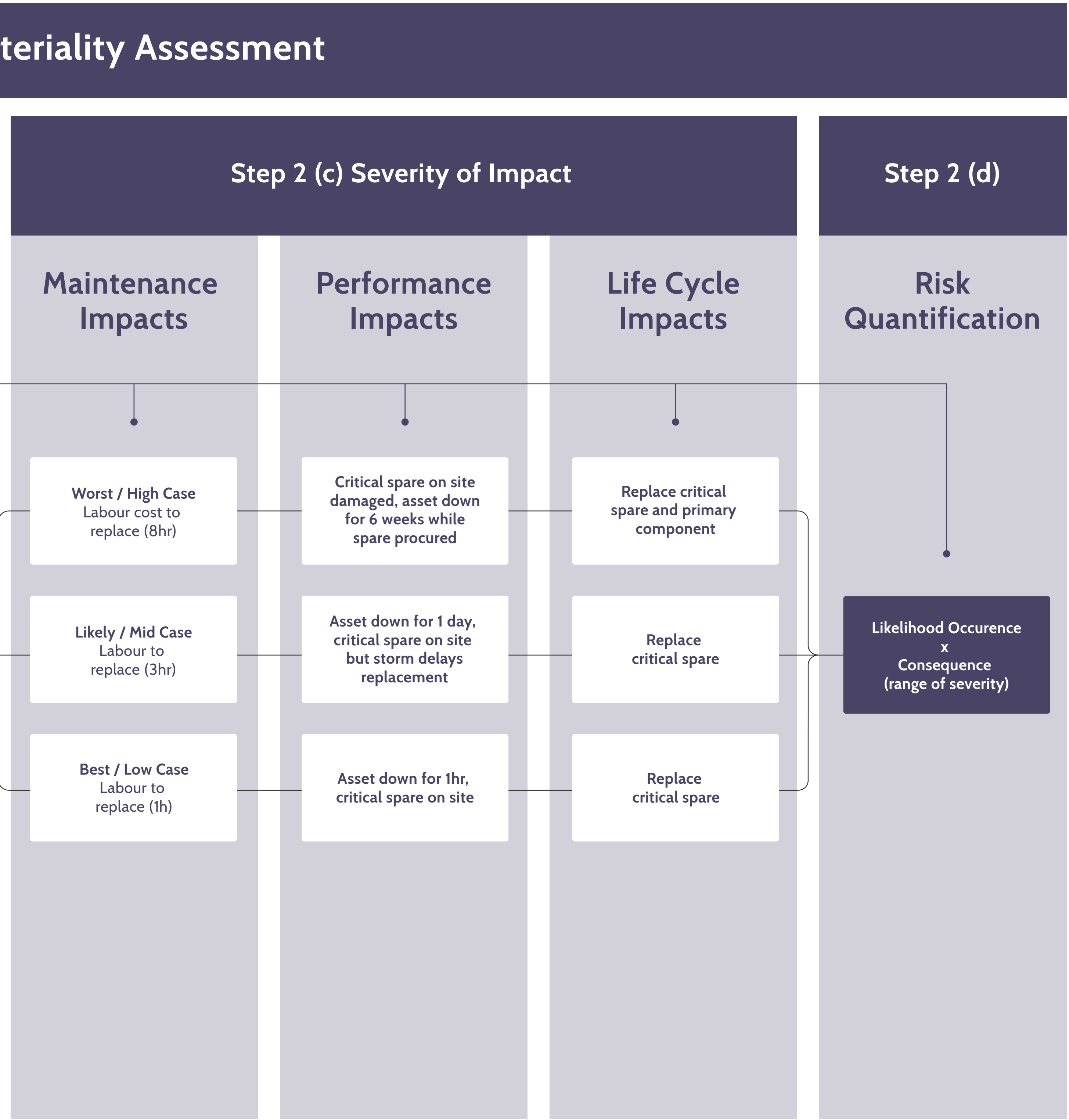
2.3 — Step 2: Materiality Assessment

Objective: Assessing relevant materiality thresholds to quantify vulnerability to

Figure 6: Materiality assessment process



climate change.



Purpose

To determine if the PCRs are material to the asset based on the previously identified KPIs and to develop the so-called "Climate Cases".

Description

In this step, a risk assessment is performed in order to develop a range of scenarios so as to link the cause (climate change hazard) with an effect (loss, increased maintenance, temporary or permanent downtime or a reduction in productivity). The effect is then quantified as a function of the project KPIs. Refer to Figure 6 for additional information.

Step 2a) Exposure to Climate Hazards

The goal of this step is to determine the exposure of different critical asset components to climate hazards at a range of return periods under the chosen Representative Concentration Pathways (RCP) scenario (the various possible future greenhouse gas concentration trajectories).

First the project team must develop hazard scenarios that link climate hazards to asset components or systems. In order to do so, the following questions must be answered for each climate hazard and asset component or system:

Drawing from climate risk assessment, describe the scenarios under which the climatic event will pose a hazard to an asset:

Under each hazard scenario, is that asset component or system likely to be exposed to a hazard?

If No, then the assessment stops for this hazard and component/system, **if Yes**, then proceed to the next step:

Is the asset component deemed critical to the function of the asset? How is this asset component linked to the KPIs defined in the scope of the assessment?

Output

A list of exposed asset components and systems affected by climate hazard. A singular component or system can be exposed to several hazards (e.g. coastal drainage can be affected by both sea level rise and extreme precipitation independently).

Step 2b) Identify Impacts on Assets

If an asset component or system is likely to be exposed, it is also likely that there will be some kind of impact, this step is intended to determine the potential impact(s) to the asset component or system.

For each infrastructure component or system that is deemed to be exposed to a climate hazard, the following questions should be answered:

Is the asset component or system designed to a specific climate exposure threshold?

Is that asset component or system's design threshold expected to be exceeded or modified through exposure to a climate hazard during the timescales defined in scoping of this assessment? [Yes or No]

If No, then the assessment stops for this system or component.

If Yes, then proceed to the next step.

If a threshold is exceeded, classify impacts into three main categories:

- **Maintenance** (e.g. increase in cleaning or repairs)
- **Performance** (e.g. increase non-availability of the asset, reduction in efficiency, unexpected temporary/ permanent shutdown)
- **Life cycle** (e.g. damage that requires early replacement of a component or total loss)

Identification of these impacts is typically done through multi-disciplinary consultation with engineers, operators, maintainers, suppliers and manufacturers. There are several well-known industry methods for impact identification, including fault tree analysis or failure mode and effects analysis, among many others. This exercise can take the form of a risk workshop or other forms of organised engagement.

To build understanding of physical climate-related risks over time, it is recommended that a set of practical steps (ground rules) are followed to facilitate the risk assessment, such as:

- Quantify and assess one failure mode at a time (these PCRs can be combined in later steps); and
- All other systems/components (that are not impacted by the same hazard) are operational.

In some cases, cascading failures can cause independencies between seemingly independent systems, leading to larger impacts. It is important at the outset of the assessment to define the boundary of PCRAM.

Output

A range of potential impacts for each asset component affected (e.g. impacts ranging from change in serviceability to loss of function to catastrophic damage).

Step 2c) Assess Severity of Impact(s) on Assets

Once the list of expected impacts resulting from a climate hazard is determined, the severity of the impact should be quantified. This step is intended to determine what happens if the design and operating thresholds are exceeded or otherwise modified by the climate hazard.

While occasionally the relationship between climate hazard and asset function can be simple or well understood, the relationship can often be better represented by a range of probabilities, just like the occurrence of climate hazards is a function of probability. There can be a range of impacts from "best case" to "most likely" to "worst case". It is incumbent on the engineering and asset management team to define a range of expected outcomes for all relevant and affected asset components, and sensitivity test these where possible. For some asset classes climate stressor damage functions can be implemented where they exist. Practitioners utilising these damage functions should exercise caution when applying them in complex assets and should pay special attention to the asset location. These damage functions are primarily utilised to assess chronic risks.

The severity of the impact can be evaluated under the same three categories and used to evaluate the potential OPEX cost impacts (Table 2):

In some instances, the range of potential impacts will be difficult to quantify and it may not be possible to determine the severity of the impact. If this is not possible, best efforts should be made to conduct sensitivity testing to evaluate the potential range of a specific risk.

These maintenance, performance and life cycle costs impacts should then be evaluated in such a way to fit into the financial model in order to quantify the impact to the Financial/commercial KPIs. For example, OPEX and life cycle costs are typically inserted into financial models on a quarterly or yearly basis. Therefore, identifying the relevant time period of the impact is of utmost importance. A simplified example is shown in Figure 4.

Output

A range of impact severity – from worst case to most likely to best case – for each asset component affected.

Table 2: Classifying severity of impact related to acute and chronic hazards

Type of Impact	Acute Hazard	Chronic Hazards
Maintenance	Immediate repair or replacement costs. Typically represented as a function of asset downtime (which can be associated with a cost) and cost to perform maintenance activities.	Manifests as increases in maintenance activities or new/different maintenance activities not previously required.
Performance	Immediate decrease in performance (efficiency) or loss of availability. This can be negatively impacted which in turn affects the ability of the asset to generate benefits. Recovery time should also be considered.	Long-term change in performance (efficiency) or repetitive decrease in availability. Recovery time may also be gradually reduced over time.
Life cycle	Immediate replacement which would modify life cycle costs.	Increase in replacement frequency which would increase life cycle cost.

Step 2d) Quantify Impacts on KPIs

The KPIs are defined as commercial, financial and operational. In this step, the range of impact severity is then converted into a cost to enable insertion into the financial model. The "severity of impact cost" associated with each hazard and infrastructure component or system pairing can again be organised into the three cost groups, as shown below:

- **Maintenance costs** – typically represented as a function of downtime of the asset (which can be associated with a cost) and cost to perform maintenance activities.
- **Performance costs** – typically represented as a function of availability and efficiency both of which can be negatively impacted (e.g. decrease in revenue or penalties).
- **Life cycle costs** – typically the function of an increase in replacement frequency which would increase costs.

These severity of impact costs may be adjusted to account for risk using stochastic analysis (e.g. Monte Carlo analysis), where the probability of occurrence, sourced from the climate practitioner in Step 2, in any given year is multiplied by a range of potential impact severities expressed as a function of cost or other relevant KPIs.

Risk = Probability * Severity

This risk-adjusted severity of impact cost would then be inserted into the financial model as a change in OPEX, change in revenue, application of penalties or other adjustments as appropriate for the project.

Alternatively, the range of best case to worst case impact could be inserted directly into the financial model in order to gauge the range of potential impacts to the asset KPIs.

Output

The Step 2 – Materiality Assessment baseline resilience outcomes should include the following:

- A list of assets systems or components exposed to a climate hazard.
- A list of impacts to asset systems or components.
- A range of severity for each impact expressed as a cost (or such as is required for the project).
- Optional stochastic analysis for each hazard to generate a risk-adjusted severity of impact cost for each hazard and asset component.
- A list of materiality assessments with identification of key risks and focus areas.

Collectively, the materiality assessment results comprise the quantified impacts of PCRs and can be referred to as the Climate Case(s). There can be multiple Climate Cases reflecting different time horizons or stemming from different RCPs.

Challenges and lessons learned

- In some instances, the range of potential impacts will be difficult to quantify and it may not be possible to determine the severity of the impact. If this is not possible, best efforts should be made to conduct sensitivity testing to evaluate the potential range of risk.
- Combining multiple climate risks can cause difficulties for over or underestimating specific risks. This is also an issue when addressing risks that may or may not be independent, e.g. high winds and flooding can be both dependent and independent.

Long-term risks are unlikely to affect Net Present Values in a material way due to the time value of money, but they may lead to a significant value dislocation during the life of an asset, thus confirming the importance of establishing adequate KPIs and repeating the PCRAM process regularly.

Decision Gate B

Are PCRs material to the asset?

At Gate B, the project team must determine whether PCRs are material to the asset. If PCRs are deemed to be material, the project team would then proceed to the next step and identify potential resilience interventions.

As a reminder, materiality is a function of what was determined at the onset of the assessment process in Step 1, and subsequently confirmed in Step 2.

2.4 — Step 3: Resilience Building

Objective: Identifying resilience interventions

Purpose

To identify resilience interventions for material climate risks affecting the infrastructure assets and quantify the benefit, or disbenefit as the case may determine, as a function of the KPIs. Collectively, these options can be referred to as the Resilience Cases.

Description

In this step, the specialist teams work together to identify potential resilience options (typically in the form of structural and non-structural interventions) which can be taken to build resilience to *material* risks identified in Step 2. It is important that only PCRs with impacts deemed to be material by the project team are analysed in Step 3.

At this stage, the resilience options should be screened for cost, schedule and other impacts (such as environmental impact) in order to identify a realistic list of interventions for further study.

Infrastructure resilience measures can focus on the structure, management, operations or maintenance, and can be split into engineering and nature-based solutions, as described below. Different climate hazard scenarios may require different resilience options.

Sub-tasks

Step 3a) Resilience Options

In this step, potential measures for building resilience to the physical risks assessed in Steps 1 and 2 should be identified. There are several types of infrastructure resilience options that should be considered: measures that focus on the structure, management, operations or maintenance of the asset.

Structural measures

In terms of structural measures, both engineering and nature-based measures should be considered:

- Engineering solutions – traditional, engineered systems providing resilience benefits to water, drainage, or transportation systems through built structures. Includes enhancements to water systems and treatment plants, storm drains, sewers, shoreline levees, wave attenuation devices, sea walls or tidal gates.
- Nature-based solutions – projects that mimic natural cycles to enhance natural systems or provide other climate risk mitigation. Includes living shorelines, tree preservation/planting, green roofs, rainwater harvesting, bioswales, bio retention ponds, open space preservation, wetland restoration, coral reef restoration, oyster reef restoration, barrier island restoration.

Non-structural measures

- Maintenance interventions – measures and activities which reduce the incidence or duration of downtime of the asset.
- Performance interventions – measures that avoid negative impacts on availability and function.
- Life cycle interventions – measures related to repair and replacement cycles.
- Other interventions as determined through the assessment.

Collaboration between the specialist teams is required to consider the full range of potential resilience measures.

A literature review can also be undertaken to identify potential resilience measures, including reviewing best practice from around the world. It can be useful to look at regions of the world that currently experience climate conditions similar to those which are projected for the asset under assessment (climate proxies) to identify potential resilience measures.

Once a long list of potential resilience options has been identified, this should be screened for cost, benefits, schedule and other impacts (such as environmental or social) in order to identify a realistic short list of interventions for further study. The specialists and functions listed above should be consulted as part of this screening exercise.

Step 3b) Repeat materiality assessment

Once a list of preferred resilience interventions is established, the Step 2 – process must be repeated in consideration of the "improved" infrastructure asset for the material risks as follows:

- Reassess exposure to climate hazards.
- Redefine potential impacts.
- Re-assess severity of impact.
- Assess cost of the interventions in the financial model as additional CAPEX or OPEX.
- Re-quantify impacts on KPIs for each intervention.

Output

The Step 3 – Resilience Building outcomes should include the following:

- An updated list of assets systems or components exposed to a hazard.
- An updated list of impacts to asset systems or components.
- A list of climate resilience interventions/resilience measures identified with associated costs.
- A revised range of severity for each impact expressed as a cost or other KPI.
- A re-run of the optional stochastic analysis for each hazard to generate a new risk-adjusted severity of impact cost for each hazard and component.
- A list of materiality assessment with identification of key risks and focus areas.

The result of this step is a set of Resilience Cases for investment that materially reduce the exposure and impact of PCRs on the asset(s).

Challenges and lessons learned

Quantifying the impact of a modified asset component or system can present challenges to technical staff and highlights the importance of focusing on a range of outcomes as opposed to defining one single value.

When re-quantifying impacts on the KPIs, it is important to consider that interventions may reduce potential impacts associated with multiple hazards. Similarly, multiple interventions together might have non-linear effects on impact severity. Teams might also consider combining two or more interventions and running simulations for those scenarios. This could require many scenario iterations requiring additional budget and schedule.

To address these issues, it is recommended that following concepts be used to aid in prioritising scenarios:

- **Focus on higher probability hazard scenarios that result in largest severity of impact:**
  - All hazard scenarios that are virtually certain (>99%) to occur over the life of the asset should be considered.
  - All impact severities resulting in complete loss of the asset should be considered, regardless of the probability of occurrence.
- **Avoid in-depth analysis of scenarios where there is a very low confidence (very high uncertainty) associated with the climate hazard or the severity of impact:**
  - When climate hazard projection data shows no strong signal or data is not readily available.
  - When the range of severity of impact cannot reasonably be predicted.

Decision Gate C

Do suitable resilience options exist?

At Gate C, the project team will determine what resilience interventions exist and whether these interventions can materially reduce PCRs to the asset.

2.5 — Step 4: Economic and Financial Analysis

Objective: Determine whether there is a case for investment in resilience.

Purpose

In this step, the benefits of the interventions are compared with the cost of implementing the various options and the disbenefit of doing nothing to determine whether there is a case for investing in resilience. A comparison with risk transfer through insurance should also be considered.

Description

A comparison of the commercial and financial KPIs from the Base Case (pre-integration of PCRs) and the resultant KPIs from Step 2 will have been conducted previously to quantify the impact of climate change. This exercise results in the creation of the “Climate Case(s)” that incorporates the impacts of PCRs on forecasted cash flows. Multiple Climate Cases are possible as the materiality assessment can be done for multiple time horizons and RCP scenarios. Such Climate Cases should incorporate the costs associated with commercial penalties, decrease in performance and other impacts of “doing nothing" to assess the climate resilience of the asset.

The Climate Cases are then compared against a set of Resilience Cases which capture the costs and benefits of each resilience options quantified in Step 3, including any incremental capital expenditures and operating costs. The benefits may relate to incremental revenues, expected reductions in specific costs such as insurance or maintenance costs, as well as reduced variability in operating cash flows.

The Climate Cases and Resilience Cases are compared by analysing changes in project Internal Rate of Return and other KPIs including total life cycle costs. Sensitivity analyses should be undertaken before making a final recommendation.

In practice, each Climate Case will likely require several Resilience Cases (with various resilience options that can be shown to materially reduce the impacts of PCRs). The comparison between the various Climate Cases and the Resilience Cases can be expressed as a function of the commercial and financial KPIs. A sample summary results table is shown below.

Resilience Case 1 corresponds to an incremental investment in resilience in the short term, which results in lower operating and maintenance costs (caused by physical climate risks) over the medium to longer terms and improved revenues as compared to the Climate Case. Note that the overall life cycle costs can be lower or higher than under the Climate Case depending on the type of resilience option.

Resilience Case 2 corresponds to a delayed and larger incremental investment in resilience, with similar adjustments to operating and maintenance costs and improvement in revenues post the investment as compared to the Climate Case. This Case would likely lead to significant increases in life cycle costs. Note that the Project IRR under Resilience Case 2 may be higher or lower than that under Resilience Case 1.

Table 3: Example Base, Climate and Resilience Cases summary table

BASE CASE (PROJECT IRR)	CLIMATE SCENARIO REFERENCE	CLIMATE CASE (PROJECT IRR)	RESILIENCE CASE 1 (PROJECT IRR)	RESILIENCE CASE 2 (PROJECT IRR)	CHANGE IN LIFE CYCLE COSTS FOR RESILIENCE CASE 1 (AS COMPARED TO CLIMATE CASE)	CHANGE IN LIFE CYCLE COSTS FOR RESILIENCE CASE 2 (AS COMPARED TO CLIMATE CASE)
9%	RCP 4.5 (mid case)	7%	8%	10%	-2%	+15%
	RCP 8.5 (high case)	4%	9%	6%	+3%	+20%

Life cycle costs include all capital expenditures and operating expenditures associated with an asset during its construction, operating and decommissioning phases.

Once this cost benefit analysis has been completed, the project team should present the results of PCRAM assessment to the asset manager / operator. The assessment highlights risks in a standardised format but purposefully does not prescribe an acceptable level of risk tolerance for asset operators and investors. This is the subject of ongoing development of good practice and will be addressed in further iterations of the methodology.

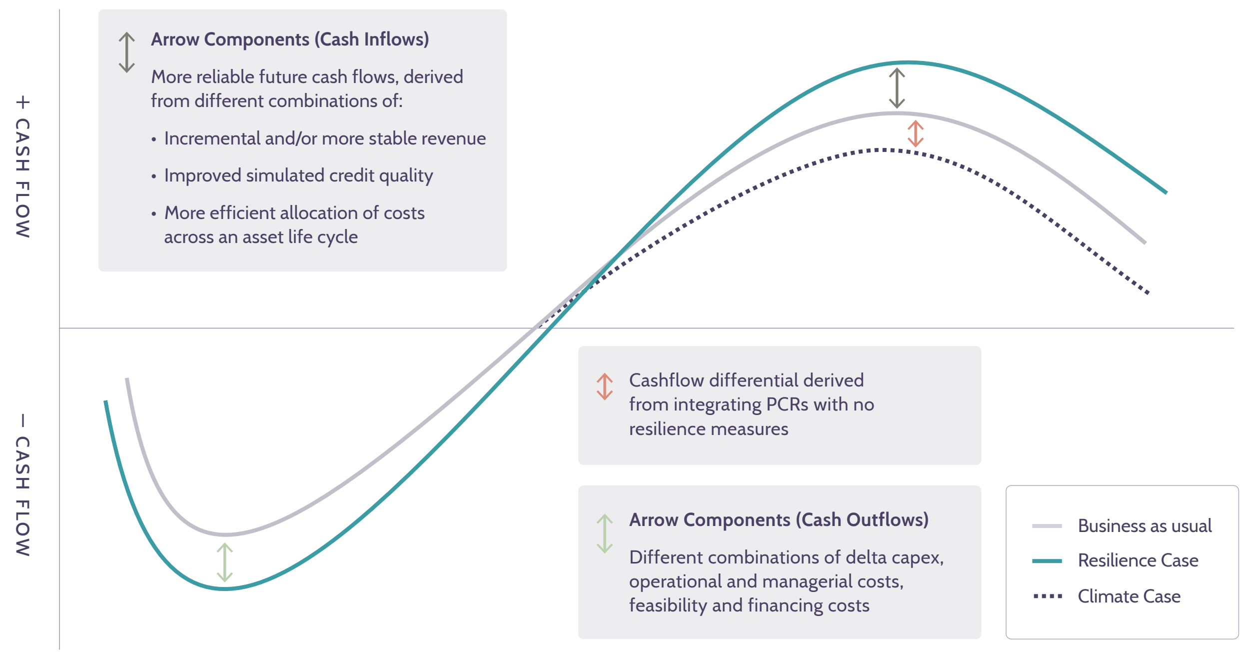
In a CCRI 'real world' case study, resilience was embedded into the design of the project. Implementing this resilience option increased initial CAPEX by approximately 2% and decreased the project IRR by 0.1%. The project avoided future potential losses, which using PCRAM were projected to decrease the Project IRR by 2%. A conceptual depiction of a resilience J-curve is found below.

Figure 7 depicts changes expected to cash flow forecasts in a sample Climate Case and Resilience Case. Cash outflows in the Climate Case are likely to be similar to the Base Case, with lower cash inflows to take into account the impacts of PCRs. In the Resilience Case an optimised life cycle cost analysis leads to greater cash outflows and inflows as compared to the Climate Case and would likely require additional upfront CAPEX. The extent to which cash inflows may also greater than in the Base Case depends on the characteristics of the project, including the nature of its exposure to PCRs and of resilience options that may be available.

Risk Transfer

At this stage, it is also important for the asset manager to explore risk transfer instruments capable of further enhancing the benefits associated with incremental investments in resilience, for example via reduced insurance premia. There may be situations where a combination of both engineering and risk transfer may be best suited to address the challenges of climate resilience. The asset manager should be aware of the potential mismatch between the availability of an insurance policy and an investment holding period, as well as the fact that specific climate hazards may not be covered through risk transfer solutions. The evolution of insurance premia for a specific hazard can indeed be seen as an indicator of a change in risk perception.

Figure 7: Preliminary representation of key PCRAM outputs



Output

The step should lead to a ranking of resilience options.

There could also be combinations of resilience interventions that may achieve a better outcome than single options.

The extent to which risk transfer is an alternative to resilience options will have been addressed, as well as a possible combination with structural and non-structural interventions.

Challenges and lessons learned

There are a number of challenges with this exercise, such as:

- The fact that it is difficult to determine both the quantum and the timing of changes to revenues and costs associated with each resilience options, as these may be untested and could also depend on the timing of occurrence and/or severity of a specific climate hazard. One way to alleviate this is to undertake a Monte Carlo-type analysis.

  Another way would be to utilise climate damage curves, which are a simplified expression of impacts and damages (e.g. monetary or downtime impacts) as a function of climate hazard severity.
- The impact of changes to cash flow forecasts in the long run are reduced by the time value of money, which makes changes to IRRs more sensitive to shorter-term events and adjustments.

There still is a debate on adjustment to discount rates in relation to climate risks. As an asset becomes more resilient through incremental investments and/or the implementation of non-structural measures, its cost of equity should theoretically be reduced. The methodology for adjusting a project discount rate is however still under development, which is the reason why we have not focused on changes in Net Present Values to compare resilience options.

Envisaged PCRAM Improvements

PCRAM is expected to be reviewed and expanded as the methodology starts being applied by asset managers. Future areas to be covered will likely include:

1. **Insurability function:** covering innovative risk transfer methodologies capable of further enhancing an asset's net present value
2. **Multi-hazard function:** enabling an assessment of materiality to measure the impact of multiple hazards occurring simultaneously
3. **Streamlining:** improving the overall process and timing of delivery

3 Conclusion

PCRAM provides a robust four-step process that translates PCRs into quantifiable impacts to asset performance.

PCRAM allows asset managers to make informed decisions on how best to build resilience into infrastructure assets to reduce the material impacts of such PCRs. It is sufficiently flexible to fit any asset type, at any stage in development, in any ownership model (e.g. public, private, PPPs, concessions) and incorporates a variety of KPIs (e.g. economic, financial, social, and environmental). It can be applied to any type of PCRs (e.g. acute vs. chronic). PCRAM provides practical guidance to overcome the common pitfalls of assessing PCRs in the context of infrastructure assets.

Whilst PCRAM is a comprehensive methodology, there is a recognition that it will undergo continuous improvement as the industry continues to mature and evolve. Areas for future improvements include the combination of multiple hazards occurring concurrently, a more rigorous combination of probabilistic and deterministic assessments of climate hazards, and adjustments to discount rates linked to the implementation of resilience options (or a decoupling of Net Present Value calculation and discount factors). It is also important to recognise that PCRAM is not a one-off assessment but part of the process of building an understanding of the impact PCRs have on an infrastructure asset throughout its life cycle. It should be revisited regularly as part of a broader approach to managing risks.

As PCRAM evolves into future versions, incorporating lessons learned from practitioners in the implementation of the methodology, CCRI is considering the development of a set of Principles for Climate Resilient Investment to guide and encourage institutional investors to monitor and disclose PCR exposure in their portfolios. Other stakeholders such as regulators and rating agencies may find the Principles of interest. Adoption of the Principles would validate the inclusion of PCRs in the investment appraisal methods undertaken by an investor. CCRI's ultimate ambition in promoting the Principles is to encourage the identification of sound valuation practices to unlock investment in climate resilience.

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5 — Appendix

Further considerations to take into account when selecting and using climate data.

Spatial and temporal scale

A crucial element in providing not only reliable but also useful climate risk assessments is the use of climate projections with appropriate temporal and spatial scales able to reproduce acute climate hazards (such as extreme precipitation events) which occur within scales of several hours and few kilometres. This implies that global projections (such as CMIP6) with resolving spatial scales above 100km cannot be directly used in climate risk assessments. Two approaches are commonly followed in order to generate the climate projection at the asset scale; high-resolution regional models (10km) or statistical methods which require long-term observational datasets from the area of study.

Representation of uncertainty

The representation of the unpredictability inherent to the natural evolution of the climate system is an essential element that should be included in any climate assessment. It is important that projection data can be linked to the thresholds required by the engineering and asset management team for each relevant asset component or system (where they are known) and the climate data package chosen should be fit for this purpose. For an example of how this can be done using an exceedance curve, please refer to the Uganda case study.

Model validation

To evidence trust in the future climate projections, validation of the reproduction of the historical climate by the different models might be considered; the better the past climate is replicated by a model, the more confidence we might have in the reliability of its future projections. However, this task is not straightforward. There is no general rule to understand which past climate features guarantee a general higher predictive skill of the future climate change signal. Without a general rule to apply, another important consideration should also be taken into account: the larger the number of climate simulations used, the more robust the uncertainty estimation would be. It is crucial in the case of low-frequency, high-impact extreme events where the agreement between models may greatly vary and having a large ensemble provides a better confidence estimation. With this idea in mind, we prioritise having a large multi-model ensemble and for each domain we aim to include the largest number of climate projections available.

Range of probabilistic values

We recommend using probabilistic projections wherever possible and a range of values from a probabilistic data set should be used, for example the 10th, 50th and 90th centile values.

For more information please visit
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