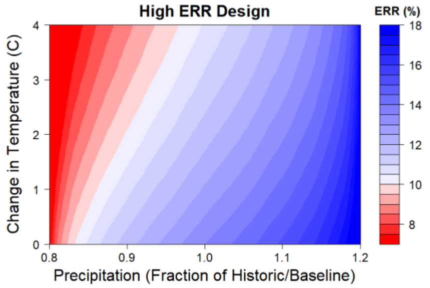
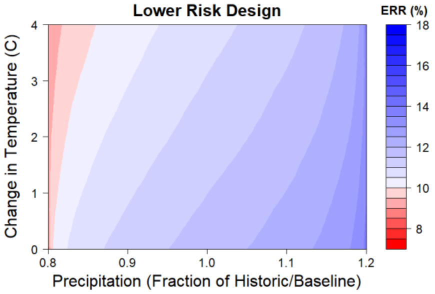
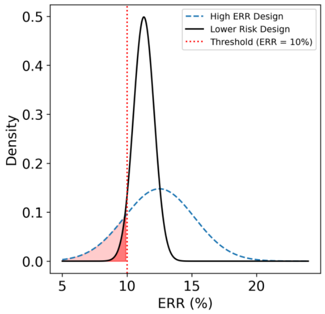
Achieving robust project design

Through iterative climate-informed performance assessment







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The graphical images above illustrate comparison of two hypothetical designs with different expected benefits and different levels of robustness to climate impacts. The upper right image is a road on Samar Island constructed under MCCs first Compact in the Philippines, for which climate hazards were considered as part of design. The road later withstood Typhoon Haiyan, one of the strongest typhoons on record.

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GLOSSARY

(Climate) Adaptation. The process of adjustment of human systems to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities.[*] In the context of this guidance, adaptation typically takes the form of adjustments to project design, implementation, and operation.

Climate. The average weather, or more rigorously, the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The relevant quantities are most often surface variables such as temperature, precipitation and wind.[*] In the context of MCC projects, climate is typically referring to behavior over approximately a few decades, that is, the lifetime of the project under consideration.

Climate Future. As used in this guidance, a single possible version of the future climate, typically described in terms of the long-term increase in average temperature, and the percent change in average annual precipitation. Climate futures are associated with, but distinct from, more granular climate scenarios or "realizations" that serve as inputs to models of project performance (providing, for example, representative monthly rainfall over 30 years). (Contrast with *climate projection* and *climate scenario*).

Climate Hazard. The potential occurrence of a climate-related physical event or trend (including negative impacts from long-term climate change) that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. For awareness, not all sources include long-term impacts under the umbrella of "hazards" (preferring to restrict hazards to shorter time-scale "events") -- however this guidance considers both events and long-term impacts, and uses hazard as an overarching term to avoid repeated cumbersome language.

Climate-Informed Robustness Index. When performing a climate stress test, the likelihood-weighted fraction of the uncertainty space (as described by different climate futures) in which a project performs acceptably. (Contrast with *robustness index*. See also *uncertainty space*).

Climate Model. A numerical representation of the climate system based on the physical, chemical and biological properties of its components and their interactions and feedback processes. Climate models are applied as a research tool to study and simulate the climate and for operational purposes, including monthly, seasonal and interannual climate projections.[*] (Contrast with *climate-responsive model of project performance.*)

Climate Projection. Simulated response of the climate system to a scenario of future emissions or concentrations of greenhouse gases and aerosols, and changes in land use, generally derived using climate models.[*] A climate projection is the output of a climate model run. (Contrast with *climate future* and *climate scenario*).

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[*] Indicates descriptions are based on widely-accepted definitions developed by the Intergovernmental Panel on Climate Change.

Climate Resilience [of a project]. The ability of a project to withstand a hazardous climatic event, trend or disturbance, responding or reorganizing in ways that maintain its essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.[*]

Climate-Responsive Model (of project performance). A numerical representation of the project that links project design variables and climate conditions to outcomes of interest, such as project benefit streams or other performance metrics (energy served, water delivered, etc).

Climate Risk. The potential for adverse consequences to human or ecological systems from climate variability and change. Risks can arise from potential impacts of climate change as well as human responses to climate change.[*]

Climate Scenario. The output of a weather generator (or other finer-time/spatial scale results) as applied to an individual climate future (as defined by a change in temperature and precipitation). (Contrast with *climate future* and *climate projection*).

Climate Stress Test. Evaluation of the performance of a project design of interest under a wide range of possible climate futures, with the end goal of identifying the climate conditions under which project performance becomes unacceptable on one or more metrics. (See Step 3.)

Climate Uncertainty. A state of incomplete knowledge regarding climate that can result from a lack of information or from disagreement about what is known or even knowable. It can be represented by quantitative measures (i.e., a probability density function) or by qualitative statements (i.e., reflecting the judgment of a team of experts). [*]

Cost-Benefit Analysis. The process of comparing the projected or estimated costs and benefits associated with a project decision, where both are expressed in monetary units, allowing an assessment of whether total benefits outweigh total costs, and ideally how both vary in response to design changes.

Deep Uncertainty. Uncertainty cases in which experts and stakeholders do not know or cannot agree upon: (1) appropriate conceptual models that describe relationships among key driving forces in a system; (2) the probability distributions used to represent uncertainty about key variables and parameters; and/or (3) how to weigh and value desirable alternative outcomes (Lempert *et al.,* 2003). Climate-affected systems, as well as the climate itself, are often considered to be characterized by deep uncertainty.

Downscaling. A method to derive local- to regional-scale (up to 100 km) information from larger-scale climate models or data analyses.[*]

Economic Rate of Return. A single metric, produced from a cost-benefit analysis, that compares the economic costs and benefits of a project. The Economic Rate of Return (ERR) is typically expressed as a percentage and represents the discount rate at which benefits equal costs after discounting. Many organizations, including MCC, utilize a minimum ERR hurdle rate as one (among several) filters informing project approval.

Ecosystem-Based Adaptation. The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. It aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change.[*]

Ecosystem Services. Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or biodiversity maintenance, (2) provisioning services such as food or fiber, (3) regulating services such as climate regulation or carbon sequestration, and (4) cultural services such as tourism or spiritual and aesthetic appreciation.*

Exposure. The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected by (climate) hazards. *

Extreme Weather Event. An event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than occurring on average once in 10 years. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season). *

Frequency. The number of occurrences of a periodic process within a unit of time, such as the occurrence of floods of equal magnitude in a year.

Model. A simplified, conceptual, representation of a system that relates inputs to outputs of interest, such as physical variables, economic variables. Unless otherwise noted, "model" as used in this document refers to mathematical models, where the relationships are specified with equations and (typically) computer code. Climate models and economic models (including cost-benefit analysis models) are both special cases of models.

Nature-Based Solutions. Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits. Nature-based solutions are often considered in the context of ecosystem-based adaptation, which describes the use of nature-based solutions to increase climate resilience.

Parsimony. The complexity of a mathematical model, often characterized by the number of model parameters.

Predictive Error. The difference between a model's prediction of a variable and the true value of that same variable. It is a measure of the predictive uncertainty of the model.

Probability Distribution. A statistical function that describes all the possible values and likelihoods that a random variable can take.

Project Assessment. A systematic process for ex-ante evaluation of expected project performance and risks, in terms of monetary and non-monetary benefits and costs. At MCC this includes cost-benefit analysis, but can also include assessment of other "engineering" or "social" outcomes – both in terms of expectations and risks.

Robustness. The extent to which a project or system delivers an acceptable outcome under a wide range of uncertain states. Robustness can be quantified in different ways, some of which are discussed in Step 5.

Robustness Conditions. The climate conditions (typically described in terms of climate futures) under which a project performs acceptably. (Contrast with *vulnerability conditions*.)

Robustness Index. When performing a climate stress test, the fraction of the uncertainty space (as described by different climate futures) in which a project performs acceptably. (Contrast with *climate-informed robustness index*. See also *uncertainty space*).

Strategy (for Adaptation). A roadmap for the process of adjustment to actual or expected climate and its effects, often including steps to take as new information is gained.

S**ystem.** In this guidance intended to serve MCC needs and those of other development actors, *system* typically refers to a civil infrastructure system, such as a road, irrigation network, school, electricity generation or transmission element, or dam/levee, and potentially the economic activities it supports, or capital it protects. In some instances, the "system" being modeled could include policy or educational initiatives.

Uncertainty Space. The space or range of all possible realizations of a random variable (or multiple random variables). For instance, the uncertainty space could cover temperature changes from 0 to 3 degrees and average annual precipitation changes from -25 to +50%.

Vulnerability. The potential to be adversely affected by a hazard. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Vulnerability Conditions. The climate conditions under which a project performs unacceptably. In this guidance they are typically framed in terms of ranges within the space of potential climate futures. (Contrast with *robustness conditions*.)

Weather. The state of the atmosphere at a given time and location. i.e. weather is local climate, at any given moment. Weather is driven by a diverse set of naturally occurring phenomena, especially air pressure, temperature, and moisture differences between one place and another.

Weather Generator. A modeling tool that randomly generates local climate variables consistent with certain specified mean climate characteristics. In this guidance, a weather generator is developed to translate climate futures into specific inputs to a climate-responsive model. For instance, under a climate future that expects an increase in mean temperature of two degrees and a 25% increase in mean annual precipitation by 2050, a weather generator can statistically representative daily climatological variables of interest for a specific location that are consistent with these long-term changes to the mean.

EXECUTIVE SUMMARY

ITERATIVE CLIMATE-INFORMED PERFORMANCE ASSESSMENT: WHAT IS IT, AND WHY DO IT?

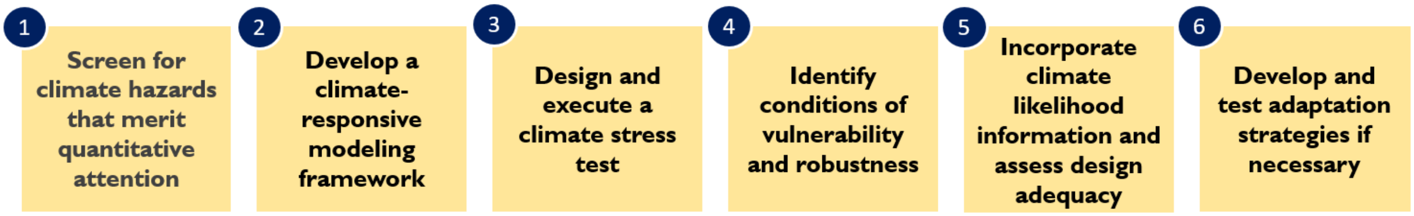
The connections between climate change and development are now clear, just as it is clear that climate change impacts are already being felt today. It is therefore critical that development agencies such as MCC incorporate fulsome consideration of climate hazards -- and opportunities to protect against them -- into the project design process. Omitting such consideration can lead to failure to achieve project objectives and millions of dollars in reduced benefits to partner country populations. While MCC does routinely give some consideration to climate issues during project development, the guidance described here advocates for a particular approach: one that thoroughly explores the space of possible climate futures, and allows for transparent assessment of the costs and benefits of measures to reduce vulnerabilities associated with those different futures.

More specifically, the approach described in this document addresses potential pitfalls of some other approaches (see Section 1.2) by recommending a project development process that:

- Connects climate conditions to *project performance*, not just exposure to hazards;
- Explores project performance under a *wide range* of climate futures, not just specific pre-packaged climate projections;
- Utilizes the performance-oriented nature of the assessment to characterize *project vulnerabilities* by identifying those *specific climate conditions* where project performance is unacceptable;[1]
- Allows for the *evaluation of design adaptations to reduce vulnerability* and enhance robustness, including the conditions and assumptions under which potential adaptations are cost-effective.

This approach supports the identification of robust project designs and is comprised of six steps, summarized in Figure ES 1 (and discussed more fully in Chapter 2 of this guidance).

FIGURE ES 1. HIGH-LEVEL WORKFLOW FOR CLIMATE-INFORMED PROJECT ASSESSMENT



Note: To assist project teams and consultants, Chapter 2 contains more detailed guidance for 2-3 sub-steps within each step.

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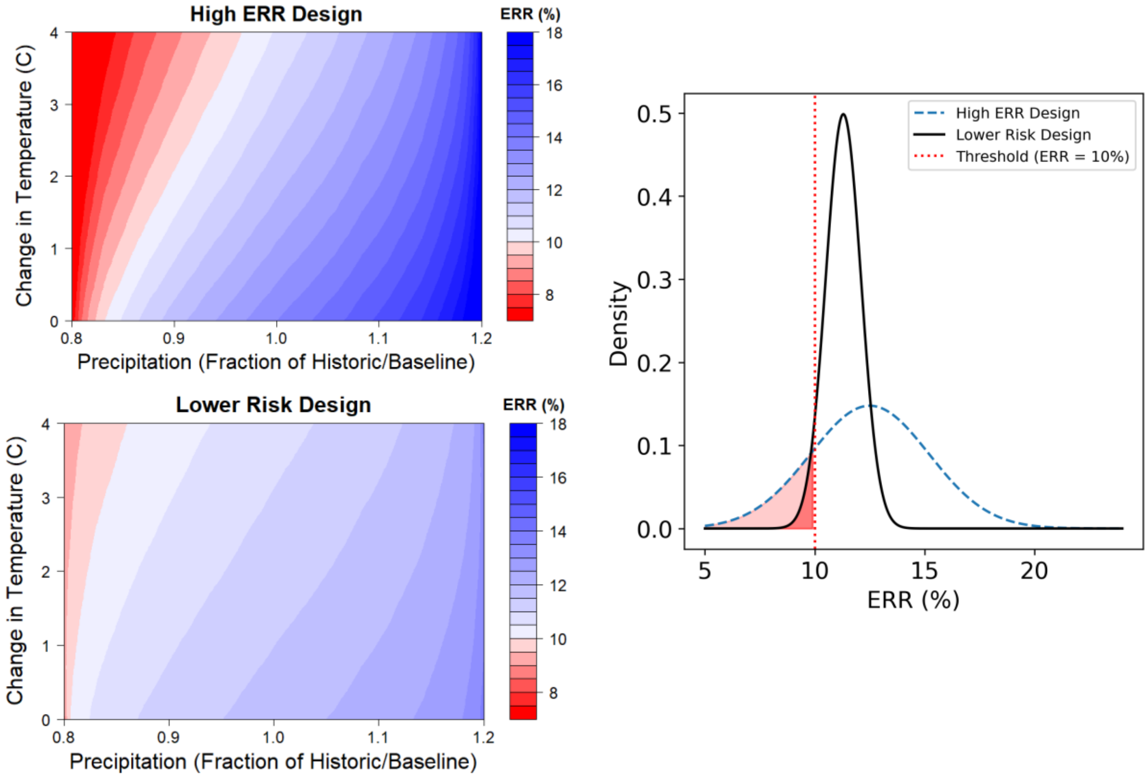
[1] This is sometimes known as a “bottom-up approach” to risk assessment. Such approaches, often associated with “Decision Making Under Deep Uncertainty,” are characterized by their focus on understanding how project performance varies across the full range of possible uncertain conditions, rather than only under those conditions defined by existing climate projections. Bottom-up approaches focus on questions of probability and values assigned to uncertain variables only to the extent that these factors would change project decisions.

An illustrative example of a key output of this process is shown in Figure ES 2. It compares two different potential project designs and shows how they perform under different assumptions about future climate. The color in the heatmaps on the left indicate the estimated project economic rate of return for any given combination of long-term temperature change (the y-axis) and change in annual precipitation (the x-axis) – e.g., .9 means that future precipitation would be 90% of historical precipitation. When combined with assumptions about probabilities of different climate futures (supported by Step 5 of the process), these heatmaps also correspond to a *distribution* of potential economic returns, shown at right for the two illustrative projects. While Economic Rate of Return (ERR) is shown in these plots, they can also be generated for other metrics that may be modeled during the compact development process, such as the magnitude of benefits going to disadvantaged groups or environmental outcomes such as carbon sequestration.

FIGURE ES 2. AN ILLUSTRATIVE EXAMPLE OF A DESIGN WITH CLIMATE VULNERABILITIES (UPPER) AND A DESIGN ADAPTATION THAT REDUCES THE CHANCE OF A LOW ERR WHILE REDUCING THE AVERAGE ERR (LOWER). THE RIGHTHAND FIGURE SHOWS THE ASSOCIATED DISTRIBUTIONS.



How can these plots be used usefully inform the development process? First, they highlight climate vulnerabilities, which are framed as climate conditions that lead to unacceptable project performance. In the illustration shown here, these are the red regions, which indicate the project ERR falls below 10% in situations where precipitation reduction and temperature increase occur at the same time (the upper left corner). The figure illustrates a case where these vulnerabilities were revealed in a higher-ERR default design (upper heatmap), and then a design adaptation was made to reduce risk under the conditions of vulnerability (lower heatmap) – however since it had additional costs, the adaptation brought the average ERR down. This trade-off is captured in the sub-figure at right, which shows the distribution of ERR under the two designs – the modified design has much fewer cases falling below 10% hurdle, but the center of the distribution is also lower. In other cases, the process of searching for new design adaptations may yield creative solutions that achieve win-wins, where vulnerabilities decrease and the average ERR improves (see Figure 7 in the main body text for an example). In others, the analysis may reveal that the design adaptations are too expensive for the level of performance risk reduction they bring (the new distribution shifts too far left overall).

The outputs of this process can therefore change decisions in three possible ways: First, the initial assessment may identify climate risk as significant, and prompt a search for design modifications that will address the climate risk. In some cases, it could cause a design or project element to be abandoned in favor of projects that are less exposed to climate risk. When a new design adaptation is identified, it can facilitate assessment of whether the new design elements are likely to be worth the cost. This can help justify "rightsizing" climate adaptations: avoiding gold-plating on the one hand, and avoiding underdesign that leaves large residual risk, on the other. In some cases, low vulnerability of the initial design may also present an opportunity for *scaling up* a project to deliver *more* benefits: A case study following a similar methodology as proposed here gave the World Bank confidence in the economic rationale to nearly triple the size of a planned hydropower investment in Nepal – which of course increased cost, but also delivered a commensurate increase in benefits to the country (Ray *et al*, 2018).

APPLYING THE APPROACH AT MCC: WHO AND HOW?

Following the first screening step in Figure ES 1 (to be conducted by MCC country team members or due diligence consultants**), the guidance within this document will ideally be carried out by consultants as part of pre-feasibility study workstreams, and subsequently refined in feasibility and detailed design studies as relevant**.[2] While some steps may be unfamiliar to certain contractors, the firms which MCC has historically engaged to deliver such studies generally hold the expertise needed to apply the approach documented in this guidance. (First applications of the approach by an individual firm may require augmenting resources, or involve sub-awards to groups that are more familiar with the modes of analysis.) To facilitate the adoption of this approach, future versions of this document will provide template language and guidance in drafting terms of reference. Additionally, to reduce the calendar time and resources required by feasibility and design consultants, MCC is also exploring utilizing divisional due diligence funds to streamline certain elements of the workflow, such as the connection of climate outputs to weather-based model inputs (Step 3) and the characterization of climate probabilities (Step 5).

While implementation of the approach recommended here is envisioned to largely fall to consultants, **at least three members of an MCC country team would be expected to familiarize themselves with the guidance approaches** sufficiently to be able to direct and integrate the consultant work: The project technical lead, economist, and environment and social performance lead. The economist in particular will need to ensure the ability of "biophysical" or "engineering" model outputs to link into the economic

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[2] If the approach has not been applied starting at the pre-feasibility study stage, there can still be value in applying it at later stages.

analysis framework in a manner that reflects climate impacts.[3] Beyond that, it will be helpful for the broader team and country counterparts to appreciate the nature and outputs of the approach, since they will be involved in joint decision-making about whether to accept or reject design alternatives with various risk and performance profiles. However, familiarity with the detailed steps is not necessary.[4] **Outside this executive summary, the guidance is a technical document intended for a technical audience.**

The recommended approach does constitute a "new ask" of team members, and a significant analytical task for contractors to integrate within the feasibility and design stages of project development. However, the elements of the approach have been chosen to address shortcomings of lighter engagements, and have been successfully deployed in development contexts, on timelines comparable to MCC's engineering studies. Ultimately, given the value at risk in MCC investments, the relatively small addition of analytic workload within the compact development process is expected to pay dividends in terms of benefits delivered to partner countries.

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[3] In some cases, this may be done through the economist ensuring that consultants engage in transparent *integrated* engineering/economic modeling that is reviewed and defensible by the country economist, and in others the country economist may need to work closely with the consultant to ensure a "handshake" between the biophysical/engineering modeling outputs and the inputs to the MCC-maintained cost-benefit model.

[4] For MCC economists, this guidance document may be considered in the same vein as sector-consistent design patterns (SCDPs). Once the screening step determines that applying the remainder of the steps in this guidance is necessary, the economist would be expected to familiarize themselves with the methods described -- just as review of an SCDP would be expected when assigned to work on a project in that sector.

1. INTRODUCTION

This document presents step-by-step guidance on incorporating decision making under deep uncertainty principles[5] into climate-affected project design and performance assessment[6] for the Millennium Challenge Corporation (MCC). This first chapter establishes the importance of incorporating climate-related uncertainties in project design and assessment, presents the rationale for the enhanced approaches within this guidance, as well practical considerations related to staffing and contracting.

1.1. BACKGROUND: ASSESSING PROJECT COSTS AND BENEFITS IN THE FACE OF CLIMATE CHANGE

Cost Benefit Analysis (CBA) is a well-established and accepted practice within the development community at large, and at MCC in particular,[7] for quantitatively assessing the economic impacts of a development project. Investment decisions are informed by the comparison between benefits and costs over a period of time, summarized by metrics such as the Net Present Value or the Economic Rate of Return (ERR[8]). Investments are also often subject to minimum thresholds of economic viability. For instance, MCC investment criteria require funded projects to have an ERR equal to or greater than 10 percent, a threshold which is referred to as the *hurdle rate*.

Climate change impacts and the fact that future climate may diverge significantly from past conditions pose important challenges for project design and CBA. Many costs and benefits in development projects are sensitive to prevailing climate conditions and weather extremes (e.g., floods, droughts, heat waves), and that sensitivity may vary over the project's lifecycle. Consequently, the estimation of costs and benefits of such projects is contingent on the assumptions made about future climate conditions and the corresponding frequency of extreme event occurrence. Existing evidence of climate change indicates that historically observed frequencies of occurrence are already changing and likely to continue to do so, undermining assumptions of historical consistency that often inform project design and CBA (whether those assumptions are explicit or not). Furthermore, the inherent uncertainty of the climate system and insurmountable limitations of climate modeling preclude the next easiest approach, which is simply to build an analysis around one or a few well-characterized projected climate futures.

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[5] Deep uncertainty is defined as cases in which experts and stakeholders do not know or cannot agree upon: (i) the external context of a system, (ii) how that system works and its boundaries, and/or (iii) the outcomes of interest from that system and/or their relative importance. See the Conclusion and Appendix A for how this guidance is situated relative to prominent methods for handling decisions under deep uncertainty.

[6] Given the central role of cost-benefit analysis at MCC, this document uses CBA metrics (especially the ERR) as a default output in the examples. However, we use the term "performance assessment" and "performance metrics" because the approaches described here apply both to other CBA metrics (such as net present value or disaggregated ouputs for beneficiaries), as well as for other metrics such as environmental outcomes like ecological flows or carbon sequestration.

[7] See MCC's 2021 Cost Benefit Analysis Guidance for more details on approach: https://www.mcc.gov/resources/doc/cost-benefit-analysis-guidelines/

[8] The ERR is simply the "Internal Rate of Return" formula calculated using economic costs and benefits, rather than purely financial costs and benefits. Some other government and development organizations refer to it as the "EIRR".

More specifically, while climate projections from global-scale models are helpful for providing general indications of how mean conditions might change over large regions, they are generally not skilled in providing the range of outcomes or spatially and temporally refined detail needed at the scale of a typical investment (elaborated in 1.2 below). As a result, a typical project development process may face the unfortunate choice between conducting a CBA using a no-longer representative historical climate record or using an unreliable future climate projection. The end result is that a project may be overdesigned, or worse, vulnerable or maladaptive to hazards that could have been cost-effectively protected against, resulting in higher costs and lower benefits delivered to the populations MCC is attempting to help.

In response to these challenges, **analytical methods have been developed that are less dependent on specific assumptions about climate futures** (see Footnote 1 above)**. This guidance presents a specific step-by-step approach tailored to the MCC context**, that follows the principles of these new methods, which generally share the following common features: They utilize the concept of "stress testing," where a large number of plausible climate scenarios are used to model the response of the project to climate variability and change. This project response information can be used to identify the climate changes that cause a project to perform unacceptably, as indicated by performance metrics, such as falling below the hurdle rate. Climate information, including historical trends and climate projections, may be used to assess a level of concern to associate with the vulnerability, without necessarily taking the climate information strictly at face value. If the level of concern is sufficient, the revealed "vulnerability" can then be addressed through thoughtful adaptations of the project design, and the stress test can be repeated to assess the ability of the adaptations to cost-effectively reduce vulnerability and enhance robustness. In so doing they help avoid the problems of overdesign or maladaptation noted above.

1.2. CHALLENGES TO EFFECTIVE CLIMATE-INFORMED PERFORMANCE ASSESSMENT

This guidance recognizes that MCC and many other development agencies already undertake climate vulnerability and climate risk assessments to some degree. While these approaches often provide value to teams developing projects (particularly via rapid assessments), they often do not translate into the ability to quantitatively inform design-level decisions. The approach advocated here does involve a higher level of effort and longer engagement time, but overcomes some potential limitations in default approaches to considering climate risk, and is deemed to be worth the effort given the size of MCC investments.

To appreciate the value-add of the climate-informed performance assessment approach, this section briefly highlights some challenges to effectively assessing the impact of climate variability and change on project performance.

First, many of the existing approaches do not adequately connect changing climatic conditions to the metrics by which project outcomes are measured. Existing screening methods and off-the-shelf tools often quantify potential changes to the climate and evaluate their associated hazards (e.g., "increased flood risk is likely"), but they stop short of connecting these climatic conditions all the way to project performance assessment. Making this connection allows for more refined assessment of whether climate impacts to a particular project's performance are worth mitigating, and whether potential design changes adequately mitigate the anticipated impacts.

More specifically, it is important to bear in mind that climate (and by extension, climate change) is experienced locally and on shorter time-scales as *weather*, and it is the weather characteristics that generally affect project performance. For example, being aware that average annual temperature may rise from between 1.7 to 2.2 degrees Celsius does not provide the information one needs to design an irrigation project to be robust to the climate hazards (droughts, increased evaporation and heat stress) that would be associated with such a world. An irrigation project needs rainfall patterns and streamflow, and other weather characteristics that affect crop water demand such as days of extreme heat). While many climate screening tools will identify general trends in weather-related hazards associated with broad-scale climate change, they often do not provide these outputs at all, and when they do, they often do not provide quantitative descriptions of how these hazards may change. While it is critically important not to place false confidence (and false precision) in descriptions of potential climate change, important information is lost when changes are treated in a purely qualitative manner.

Some climate risk assessments do go further and utilize outputs of global climate models (GCMs[9]) to generate quantitative information. GCMs are powerful tools for consistently representing planet-wide dynamics of the climate and should not be ignored, but approaches that use GCM output alone suffer from two issues that limit their utility when attempting to design robust localized projects.

First, they have a tendency to poorly capture regional weather variability, which is a key driver of the climate hazards that affect project performance. Figure 1 shows GCM projections of rainfall variability from year to year in West Africa, overlaid with a historical trace of an equivalent period of time (the blue line): That is, the grey lines represent projections for the future, while they blue line displays what has already occurred.[10] What is of interest is not whether the long-term trends line up, but the variability: The blue line of historical behavior shows much greater year-to-year variability than any of the climate projections. Climate-sensitive projects designed to operate in a world with a relatively stable climate year to year (the grey lines) would likely be quite vulnerable if the climate turned out to exhibit the variability that has already been demonstrated.

More fundamentally, even when GCM outputs are reliable and used within a project that connects climate impacts all the way to project performance, exploring only across pre-set GCM outputs necessarily only tests project performance under a truncated range of possible climate futures, compared to what we know is possible. Individual GCM outputs represent the future under specific sets of assumptions, making approaches to evaluating climate risk that rely on solely on GCM output akin to looking under a lamppost: They examine futures that have been pre-selected by others, but do not explore the full range of possibility -- even though scenarios that don't correspond to specific GCM runs (i.e., what is outside the lighted area) may have significant consequence.

One reason this is important is because the consequences of climate change may be nonlinear. For example, in an agricultural project, small reductions in average expected rainfall and streamflow may cause a small and predictable contraction in the area farmers cultivate, but larger changes may be associated with increasing drought intervals that cannot be weathered, or might drop overall revenue low enough that net revenue is negative and farming operations shut down, even though they are agronomically still possible.

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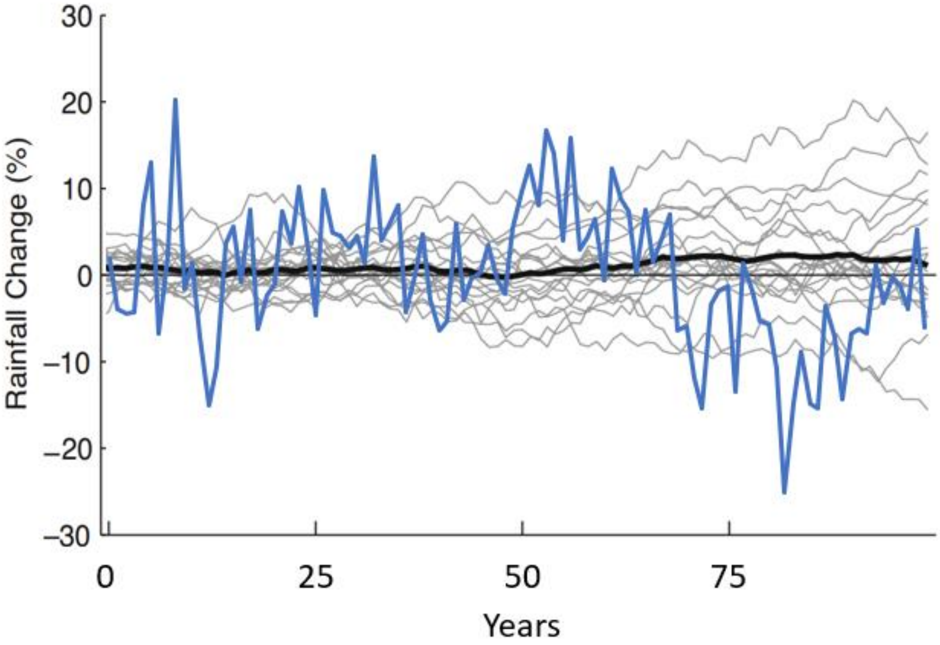
[9] GCM originally referred specifically to "General Circulation Models" though the simpler and more generic reverse acronym "Global Climate Model" has come to be commonly used.

[10] While the figure is generated from an older generation of models (CMIP3), the general point of extreme events and challenges in capturing variability still exists in the latest generation (e.g., Hamed et al 2022).

These issues, taken together, suggest that approaches which connect climate conditions to project performance, and explore project performance under a wide range of climate futures, will be more fruitful for thoroughly understanding and addressing climate vulnerabilities. This is the approach recommended in this guidance.

FIGURE 1. COMPARISON OF HISTORICAL RAINFALL VARIABILITY (BLUE) TO RAINFALL VARIABILITY PROJECTED BY MULTIPLE GLOBAL CLIMATE MODELS (GREY) OVER WEST AFRICA



1.3. OBJECTIVE OF THIS GUIDANCE NOTE AND IMPLEMENTATION ASSUMPTIONS

The objective of this note is to provide MCC and the broader development community with guidance on how to assess climate change uncertainties in project design and performance assessment, and subsequently propose project investments and related policy actions that are more robust to those uncertainties. **The note describes a generally applicable, structured approach to identify uncertainties and incorporate them into the quantification of benefit and cost streams**, thereby informing project design choices as well as the various decision-making stages of a project, from feasibility, to investment approval, to implementation (See Textbox 1 for overview of MCC's development process)**.** This note represents an application of methodological principles grounded in decision making under deep uncertainty methodologies (Marchau et al 2019), building primarily on the Decision Tree Framework from Ray and Brown (2015), and giving attention to MCC's compact development process and CBA needs.

This guidance is intended to be relevant when climate change is potentially a significant factor for the calculation of costs or benefits of a project.[11] Generally, if weather is likely to significantly affect

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[11] Companion guidance is in development that describes the incorporation of additional benefit streams in the decision-making process, with a focus on ecosystem services arising from "ecosystem-based adaptation" interventions, which often both affected by climate-related uncertainties and helpful in adapting to them.

project performance, then this guidance will facilitate the accounting for climate change in these processes. If the role of weather events is uncertain, the framework’s Step 1 is useful to identify and screen for possible indirect and direct factors. Further, this note is intended to be general to all sectors, while also noting that some sectors are more exposed than others and affected in different ways.

Textbox 1: Applicability of this guidance to the existing MCC Compact Development Process

The MCC Compact Development Process involves several steps that are completed by MCC and partner country teams prior to the negotiation and agreement of a compact. This guidance document should be considered relatively early in the process, with the principles being brought in as problem diagnosis leads to concept development, and then considered with increasing formality during the Project Development phase. The Compact Development Process consists of five steps prior to implementation:

1. **Early Analysis including Constraints to Economic Growth.** During this first step, eligible countries name a national coordinator and put together the compact development team (CDT). The team analyzes constraints to economic growth, opportunities for private investment and poverty reduction, and consults with a broad range of stakeholders. During this stage, MCC staffs a country team, provides compact development guidance and advises and assists with the preliminary analyses. The broad climate risks associated with specific investment area opportunities should be qualitatively identified during this stage, especially risks to the sectors identified in the Constraints Analysis.
2. **Problem Diagnosis.** With expanded teams, the MCC country team and partner country CDT conduct analysis to understand the *root causes* of constraints to inclusive growth and define and develop initial project ideas to address these constraints. At this step, the impact of climate change on the root causes of constraints and initial risks associated with the project should be identified and communicated, but technical modeling or detailed analysis is unlikely to be useful.
3. **Project Definition.** During this step, the team defines and scopes specific projects and activities for the compact, building strong logic for the proposed program. Additional stakeholders are consulted and intended beneficiaries are identified. The country team submits a detailed Project Proposal which is reviewed and approved by MCC. As project proposals include initial estimates of costs and benefits, more specific information on climate risk should be discussed at this stage.
4. **Project Development leading to Investment Memo.** Teams conduct feasibility, environmental, climate, and other studies to measure the expected impact of the proposed projects. Risks, including climate risks, are identified , and risk mitigation measures are included. This stage includes high-level design work reflecting decisions informed by this analysis. In addition, MCC and the CDT develops structures to prepare for implementation, such as preparatory studies and procurements. MCC conducts a thorough project appraisal and makes final decisions on projects for inclusion in the Compact. Ideally, the present guidance would be fully deployed to analyze projects and the analysis included in the Investment Memo.
5. **Negotiation and Compact signing.** This step formalizes the technical, legal, and financial terms of the program. MCC notifies Congress of the intent to negotiate and defines the budget to commit funding. Once the project is approved by MCC’s board, the agreements are signed by each country. Compact signing is typically followed by 1-2 years of preparatory activities before the formal start of implementation and the “five-year clock.” This period may also involve activities leading to design refinements where the present guidance may be useful.
6. **Implementation.** Finally, the compact provision enters into force and implementation and associated procurements commence. Progress and performance reports are submitted, along with disbursement requests for MCC approval. The final design and execution may consider further refinements or adjustments based on new information.

As noted, a full version of the analysis described in this guidance note would ideally be completed prior the Investment Memo stage, though in practice studies and significant design enhancements may be undertaken or completed after that step, in which case the guidance here would apply later as well.

With the exception of the very first step (screening),[12] **the guidance within this document will ideally be carried out by consultants as part of pre-feasibility study workstreams, and subsequently refined in feasibility and detailed design studies as relevant.**[13] While some steps may be unfamiliar to certain contractors, the firms which MCC has historically engaged to deliver such studies generally hold the expertise needed to apply the approach documented in this guidance. (First applications of the approach by an individual firm may require augmenting resources, or involve sub-awards to groups that are more familiar with the modes of analysis.) To facilitate the adoption of this approach, future versions of this document will provide template language and guidance in drafting terms of reference. Additionally, to reduce the calendar time and resources required by feasibility and design consultants, MCC is also exploring utilizing divisional due diligence funds to streamline certain elements of the workflow, such as the connection of climate outputs to weather-based model inputs (Step 3) and the characterization of climate probabilities (Step 5).

While implementation of the approach recommended here is envisioned to largely fall to consultants, at least three members of an MCC country team would be expected to familiarize themselves with the guidance approaches sufficiently to be able to direct and integrate the consultant work: The project technical lead, economist, and environment and social performance lead. The economist in particular will need to ensure the ability of "biophysical" or "engineering" model outputs to link into the economic analysis framework in a manner that preserves climate impacts.[14] Beyond that, it will be helpful for the broader team and country counterparts to appreciate the nature and outputs of the approach, since they will be involved in joint decision-making about whether to accept or reject design alternatives with various risk and performance profiles. However, familiarity with the detailed steps is not necessary.[15]

The recommended approach does constitute a "new ask" of team members, and a significant analytical task for contractors to integrate within the feasibility and design stages of project development. However, the elements of the approach have been chosen to address shortcomings of lighter engagements, and have been successfully deployed in development contexts, on timelines comparable to MCC's engineering studies. Ultimately, given the value at risk in MCC investments, the relatively small addition of analytic workload within the compact development process is expected to pay dividends in terms of benefits delivered to partner countries.

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[12] The remainder of this subsection is duplicated from the Executive Summary so may be skipped as relevant.

[13] If the approach has not been applied starting at the pre-feasibility study stage, there can still be value in applying it at later stages.

[14] In some cases, this may be done through the economist ensuring that consultants engage in transparent integrated engineering/economic modeling that is reviewed and defensible by the country economist, and in others the country economist may need to work closely with the consultant to ensure a "handshake" between the biophysical/engineering modeling outputs and the inputs to the MCC-maintained cost-benefit model.

[15] For MCC economists, this guidance document may be considered in the same vein as sector-consistent design patterns (SCDPs). Once the screening step determines that applying the remainder of the steps in this guidance is necessary, the economist would be expected to familiarize themselves with the methods described -- just as review of an SCDP would be expected when assigned to work on a project in that sector.

1.4. STRUCTURE AND STATUS OF THIS GUIDANCE NOTE

Following this introduction, Chapter 2 describes the step-by-step approach discussed above, and provides conceptual illustrations. This chapter is subdivided into six steps, each outlining the different activities necessary to carry out the analysis, and describing objective, approach and outcome at each step, as well as expertise and anticipated level of effort. In the future, this document may be updated to incorporate the results of a forthcoming case study of a real MCC project (the Lesotho II Market-Driven Irrigated Horticulture project) to illustrate the steps more concretely. Depending on demand, future versions may also include an expanded section on nature-based solutions for climate adaptation, which are currently briefly discussed in a textbox in Step 6.

2. A FRAMEWORK FOR ROBUST DECISION-MAKING UNDER CLIMATE UNCERTAINTY

The framework presented in this chapter provides guidance on how to assess climate change uncertainties in project assessment, as well as propose and evaluate design modifications and related policy actions that are more robust to those uncertainties. The note describes a structured process of six steps to identify uncertainties in a way that can be incorporated into the quantification of costs and benefits in cost-benefit analysis (CBA), and to inform the various decision-making stages of a project. Furthermore, the particular methods and processes that comprise the steps of a climate-informed project assessment may be useful in isolation or in combination with other steps without necessarily applying the full framework. Figure 2 illustrates the connection of the six steps and their component sub-steps, with further detail provided in the text. The description of each sub-step provided in this chapter includes an overview of the objective, the approach, and finally the outcome of the sub-step. Textbox 2 presents the ideal timing for carrying out a climate-informed project assessment as well as a summary of the key requirements.

Textbox 2: Ideal timing and key requirements for a climate-informed project assessment

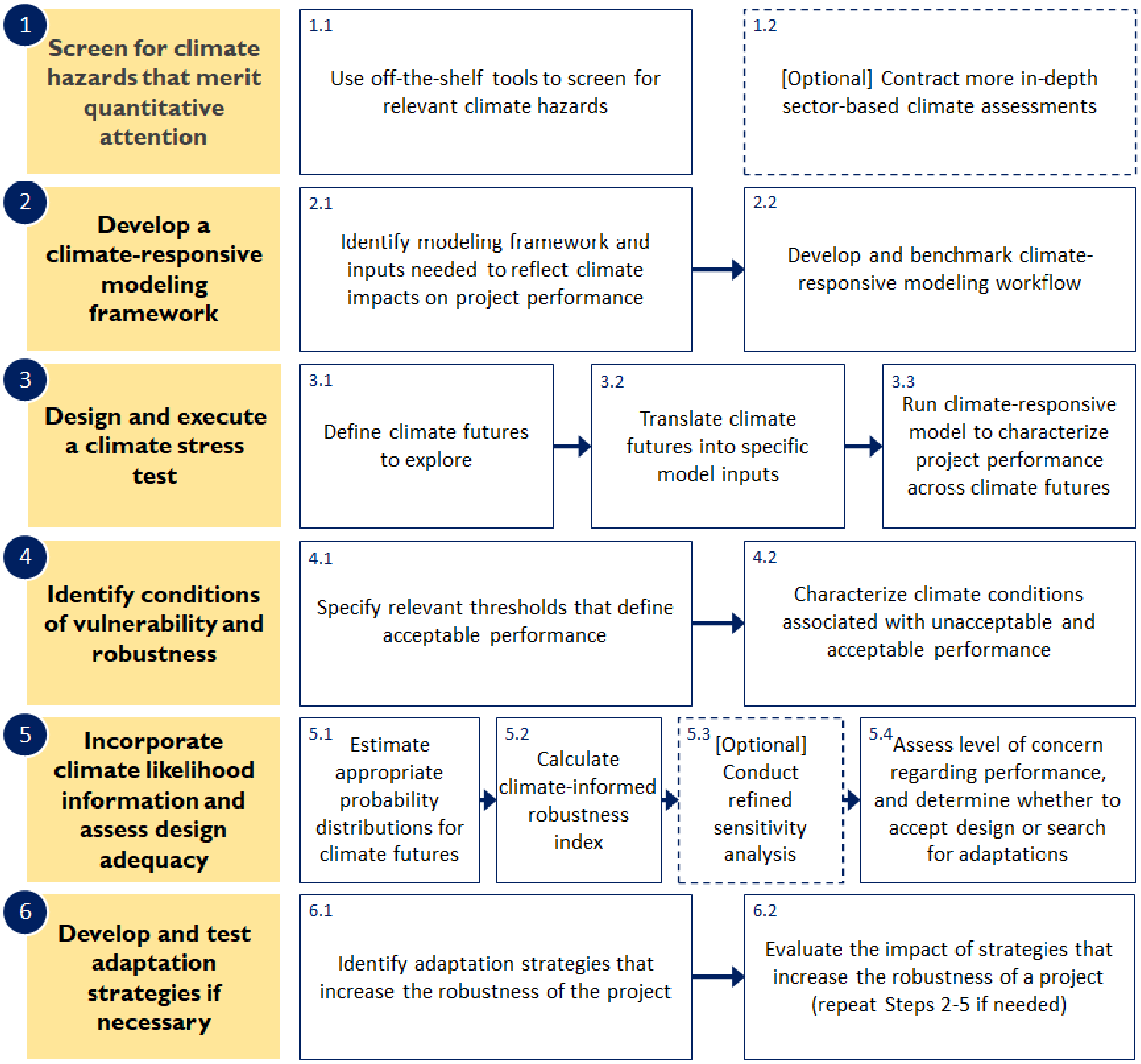
Ideal timing in MCC Compact Development Process (as previously introduced in Textbox 1). Incorporating a robust decision-making approach into project development should ideally begin when project concepts are first being prepared. The six steps to conducting a climate-informed project assessment (as detailed in this chapter) are likely best suited for the project development stage (that is, the lead-up to MCC's Investment Memorandum), when project performance and associated risks are quantified. Nevertheless, a qualitative application of the activities described in Step 1 could be appropriate at a Compact's Preliminary Analysis and Problem Diagnosis stages, particularly for Root Cause Analysis. Additionally, the process may be iterative, with a coarser engagement akin to "pre-feasibility studies" prior to the Investment Memo, and additional refinements examined as the project design itself is refined (e.g., from pre-feasibility study to feasibility study to preliminary designs).

Data needs. In addition to the data already needed for a standard CBA, incorporating climate uncertainties into project assessment requires location-specific historical climate data (e.g., precipitation, temperature, recurrence of extreme events). Though downscaled future climate projections and occurrence probabilities are not essential, some consideration of how climate change is expected to alter historical patterns is also important to incorporate.

Model types or tools. The framework presented in this guidance requires mathematical models of the relationship between climate and the outcomes that are relevant to project design and evaluation. The suitability of different possible models will vary depending on project characteristics, the availability of pre-existing models, and the experience of the project team. Model selection should take into account the parsimony and the predictive error of the model, as laid out in Step 2 of the framework below. In many instances, existing models commonly used by MCC and its consultants can accommodate the inclusion of climate uncertainty.

Necessary expertise. Specific needs are detailed below, but broadly the approach requires expertise in CBA and economic appraisal; biophysical modeling skills (e.g., infrastructure, hydrology); basic understanding of climate change impacts and their impact on biophysical model outputs; and strong stakeholder engagement skills to obtain information and validate proposed solutions.

FIGURE 2. A FRAMEWORK FOR ITERATIVE CLIMATE-INFORMED PROJECT ASSESSMENT



2.1 STEP 1: SCREEN FOR CLIMATE HAZARDS THAT MERIT QUANTITATIVE ATTENTION

The overall purpose of Step 1 is to determine which types of hazards will require formal attention in the project design and will need to be included when modeling project performance. This guidance considers two approaches to screening for climate hazards: the first relies on off-the-shelf accessible screening tools (detailed as Step 1.1 below), while the optional second approach involves contracting more in-depth climate assessments (Step 1.2 below). As MCC staff are well-placed to consider what other analyses are available and feasible to contract at any given time, this guidance focuses mainly on an overview of existing and accessible screening tools.

The level of effort and expertise required to conduct Step 1 depends on which of the two screening approaches is selected. If off-the-shelf tools are used, the screening can be completed with a few days of effort, likely by in-house environmental staff or due diligence consultants, or economists and sector leads that possess familiarity with climate change concepts. The owner of the exercise should coordinate and review the process and results with other team members. Some additional time may be required at the end of this step if subject-matter experts and local stakeholders are consulted to validate and supplement the results obtained from the screening tools. In the second instance where a more in-depth climate assessment is contracted, the level of effort will be greater and will depend on the specifics of the contract.

2.2.1 STEP 1.1: USE OFF-THE-SHELF TOOLS TO SCREEN FOR RELEVANT CLIMATE HAZARDS

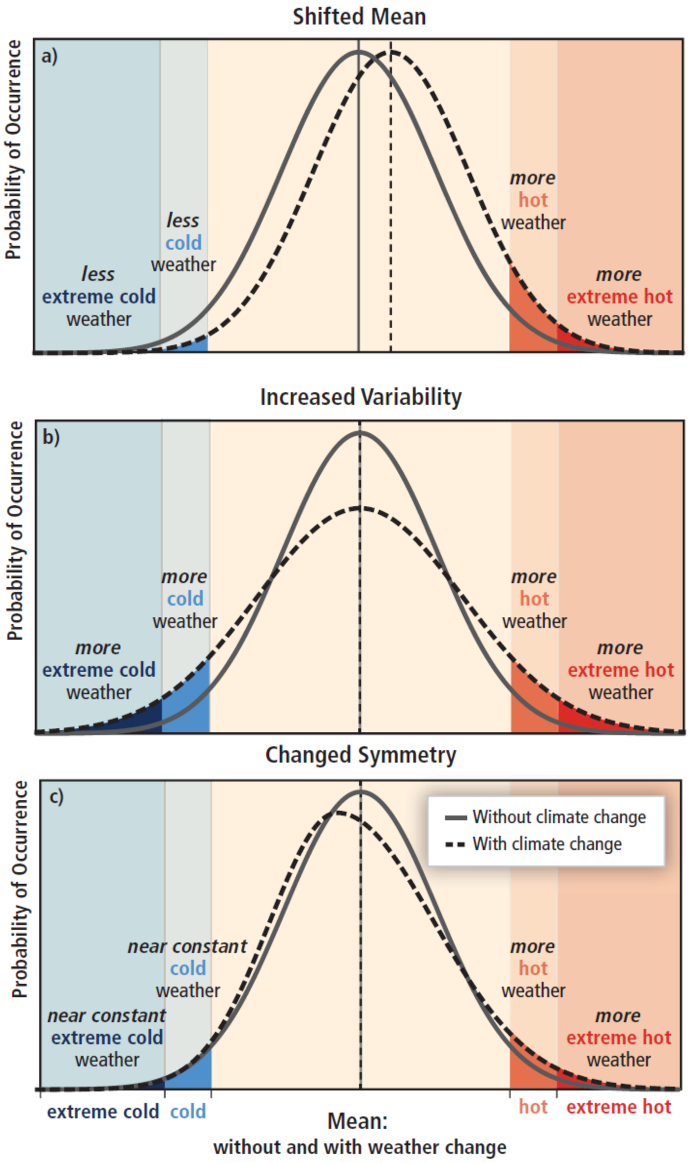
Objective: The objective of this first approach to screening for climate hazards is to use off-the shelf screening tools to gain an understanding of the possible exposure of the project to key hazards and uncertainties. The focus is on climate-related hazards, identifying and characterizing potential threats from current climate variability and future climate change that have potential to affect the project's performance.

Approach: Screening for climate hazards helps the project team identify the types of hazards that threaten the performance of the project, given the project's location and expected useful lifespan. A **climate hazard** is any climate-related threat that may result in damage and loss to the project's physical assets, or a reduction in its level of service delivery. These can be a product of:

- **Extreme weather events:** low-probability but high-impact climatic phenomena such as floods, cyclones, droughts, or heat waves
- **Long-term changes to normal climate conditions:** changes relative to the historic baseline, such as higher average temperatures or increases in average precipitation.

As Figure 3 shows, taken together, climate change can impact both the mean conditions to which a project will be exposed (e.g., higher temperature on average in the future), as well as the frequency and intensity of extreme weather events (e.g., more record hot weather).

FIGURE 3. ILLUSTRATION OF POSSIBLE CLIMATE CHANGE IMPACTS ON TEMPERATURE DISTRIBUTIONS



Source: Intergovernmental Panel on Climate Change (2012).

Typical variables to consider when evaluating exposure to climate hazards are temperature, precipitation, sea level rise, and recurrence interval of extreme weather events. As such, the record of hazards that have occurred historically at a site is a critical source of information. When screening for climate hazards at a given location, analysts should first build an understanding of the frequency and severity of historic events, before then considering future exposure over the course of the project's useful lifespan. While climate change is often important, natural (historical) climate variability informs the range of plausible climate futures and is often under-analyzed, even when long-term climate change is considered (Koutsoyiannis *et al.*, 2009).

Generally, projects with a short (e.g., less than 20 year) useful lifespan may only need to focus on the impact of extreme weather events consistent with those experienced historically, provided historical variability is adequately captured in the existing recorded data (Hawkins and Sutton, 2009; Schlef *et al.*, 2018). That said, **the kinds of projects that MCC typically considers have sufficiently long lifespans to justify the need to also assess the increased frequency and severity of existing climate hazards, as well as identify any new hazards that may arise over the project's lifetime**. Given the significant degree of uncertainty about future conditions, this guide recommends considering the broadest possible range of climate hazards, including those considered less likely, rating the severity of each threat to identify those most relevant for the project.

Various tools exist that can be used to screen a project's exposure to climate hazards. Some MCC country teams have begun initial screening for hazards using existing country risk profiles from the United States Agency for International Development (USAID) or the World Bank's Climate Change Knowledge Portal and working with due diligence consultants to undertake specific sector-level analyses. **Table 1 shows a list of free tools generally used by development agencies that could be used for more systematic and comprehensive screening of climate hazards by MCC.** These tools are ordered based on complexity and depth, ranging from quick and simple high-level information to more comprehensive participatory tools. This information is complemented by Textbox 3, which provides a step-by-step description of how to use one of the tools from Table 1, namely the World Bank's Climate and Disaster Risk Screening Tool.

TABLE 1. AN OVERVIEW OF CLIMATE RISK SCREENING TOOLS

Screening Tool	Description	Advantages
THINKHAZARD! **Global Facility for Disaster Risk Reduction** *https://thinkhazard.org/en/*	Web tool that provides a general assessment of climate hazards and other extreme events at a sub-national, specific region level. The tool presents 12 different hazards based on a qualitative assessment of the level of threat (i.e., low to high), describing the high-level impacts of the hazard along with generic recommendations for planning and evaluation. Climate-related hazards include flooding (river, urban, and coastal), extreme heat, water scarcity, and cyclones. The tool also includes additional local and/or regional online resources when available. **Requirements:** region of project location.	Very quick and simple to use. Useful for obtaining a list of the relevant hazards to consider in the selected area and does not require project specific information. Relevant hazards are provided in downloadable report format. Output can help to put climate hazards in context with other non-climate threats.
Resilience Booster Tool **World Bank** *https://resiliencetool.worldbank.org/*	Web tool for enhancing the climate resilience of a project at any stage, from early design to implementation. Focuses on adaptation and equity through identifying gaps and opportunities in nine resilience attributes. Not a climate screening tool *per se*, but it can identify shortcomings in the project's features that increase its vulnerability to climate hazards. **Requirements:** project concept and subject matter expertise of country or project context.	Quick (about 30 min to 1 hour), self-guided tool. Provides a pathway map to enhance the resilience of the project as well as an optional monitoring system to track progress.

Screening Tool	Description	Advantages
Climate Change Knowledge Portal **World Bank** *https://climateknowledgeportal.worldbank.org/*	Web portal that provides processed and synthesized historical and projected climate information from the Intergovernmental Panel on Climate Change. It includes auto-generated plots, maps, and raw data for temperature and precipitation as well as main indicators (e.g., number of days > 35°C), for sub-national entities, watersheds, and ½ degree grid cells. Country profiles provide a light assessment of historical trends, vulnerabilities, and risks. However, it does not guide the assessment of hazards. **Requirements:** project location and basic knowledge of climate variables and projections.	Provides global processed climate indicators and pre-generated visualizations to inform screening and communicate hazards, as well as quantitative data that can be used in the analysis.
Climate Risk Screening and Management Tools & Risk Profiles **USAID** *https://www.climatelinks.org/resources*	The USAID ClimateLinks portal includes a Climate Risk Screening and Management Tool as well as Risk Profiles, which can be used during the screening stage. The screening and management tool provides a sectoral toolkit for self-screening of climate risks in the early stages of project design. The tool helps to identify and rate risks, as well as identify opportunities. The risk profiles consist of short briefs for countries and regions that assess the potential impacts of climate change on key economic sectors, including an overview of historical and future climate trends, the policy context, and existing adaptation projects. **Requirements:** project location and concept.	The tool provides a guided questionnaire to perform the screening that is tailored by sector. It also includes illustrative examples and an output matrix for reporting the results. The risk profiles provide comprehensive assessments that contextualize climate change to the socioeconomic context of the location. In addition, the USAID ClimateLinks portal contains additional tools within it that can be used later in the evaluation process, such as carbon emissions calculators, waste management estimators, an ecosystem service tool, etc.
Climate and Disaster Risk Screening Tool **World Bank** *https://climatescreeningtools.worldbank.org/*	Tool that provides a guided and systematic method to identify climate hazards and levels of risk at an early stage in the project design process. It focuses on physical and non-physical components of the project, and ranks the threat from low to high, including a no risk and insufficient understanding category. It has a "rapid" (about 30 min) and "in-depth" (about 2 hours) version for multiple sectors, the latter being highly recommended unless the evaluator is familiar with climate science and the particular context of the project. Considers extreme temperatures, extreme precipitation, flooding, drought, winds, sea level rise, and storm surge. **Requirements:** project concept or design and subject matter expertise in country or project context.	Structured process that guides the user to perform the screening and how to use data from other tools presented (e.g., Climate Change Knowledge Portal). Provides an assessment that includes the hazards at the project location as well as the potential impacts on the project's infrastructure and service delivery. Considers how institutional and contextual factors interact with hazards and project physical components.

Screening Tool	Description	Advantages
CRiSTAL Tool **International Institute for Sustainable Development** *https://www.iisd.org/cristaltool/*	Project planning tool for identifying climate risks and design activities to enhance adaptation that incorporates community-based stakeholder consultation and expert interviews. The tool includes an initial screening step that can be used to understand the potential impacts of climate hazards on the project and local livelihoods in the area. It expands beyond a cursory screening tool, offering guidance for project design and evaluation through a participatory process. The tool does not prescribe which climate hazards to analyze. **Requirements:** project concept or design.	Guides the user to perform a screening following a questionnaire. Provides a community-based perspective of the project, as opposed to the perspective of funders only, and puts climate hazards in context with social, political, and cultural conditions. Provides a framework for incorporating local and expert knowledge through consultation.

Textbox 3 -- Deeper dive on illustrative screening method:

World Bank Climate and Disaster Risk Screening Tool

The World Bank tool is a free, online, tool that guides the screening of climate risks to projects and policy at an early stage of their design process. The tool relies on the World Bank Climate Change Knowledge Portal, which (as of 2022) provides climate variables for countries and watersheds at a ½-degree latitude/longitude grid scale.

This tool offers two levels of screening: a rapid assessment, requiring about 30 minutes, for projects in 11 different sectors, and an in-depth assessment, of about 2 hours, for projects in agriculture, energy, health, transportation, and water. The in-depth assessment is recommended, particularly for cases when the project team does not have a strong pre-existing understanding of the climate threats. The in-depth assessment is comprised of five steps, as laid out below. Within each step, a set of questions guide the evaluator, resulting in a final assessment (categorized from low to high risk) based on the responses and a supporting rubric.

1. **Characterize the project:** select the sector and subcomponent that will be included in the project.
2. **Identify exposure:** evaluate the extent to which a project or location is exposed to each of the climate hazards included in the tool.
3. **Determine potential impacts:** qualitatively assess the potential impacts from each hazard to the subcomponents of the project.
4. **Assess adaptive capacity:** analyze how relevant non-physical factors (e.g., institutional capacity, macroeconomic environment) impact the project.
5. **Determine risk:** rate the risk to the project's performance. A summary report with generic recommendations is auto-generated after completing the last step.

The screening exercise should focus on identifying the list of hazards the project is exposed to along with a high-level, preliminary assessment of the degree of uncertainty in how severely these hazards can impact the performance of the project. Tools such as ThinkHazard! or the Climate Change Knowledge Portal, which present general risks which occur in a specified location (i.e., not specific to a particular project), can be used to identify hazards even before the development of a project concept. While none of these tools require the analyst to have compiled specific data other than project concept or early design, some rely on climate information from external sources to guide the assessment. Subject-matter experts and local stakeholders should further supplement the climate risk screening results from these tools, as a mechanism to both validate the identified threats and reduce the risk of omitting relevant hazards.

The outcome of the project screening exercise conducted as Step 1.1 may indicate that climate change is not a primary concern for the investment under consideration. In such case, the analyst may find it unnecessary (or inefficient) to continue on with a detailed assessment of the project's climate change risks (i.e., Steps 2 through 6, detailed in the remainder of this chapter). This could be because: 1) climate change is highly unlikely (according to the screening tools) to occur in a way that is problematic for the project; or 2) the project's climate change vulnerabilities appear with high confidence to be small compared to project vulnerabilities of other kinds. Examples of (1) include a water treatment plant investment in a location that is already water rich and projected to get wetter in the future, or a roadway investment in a location without flood concerns. Examples of (2) include investments with such large vulnerabilities to geopolitical threats, market forces, or earthquake damages that climate change hazards are negligible by comparison. Importantly, conclusions that climate change risks are small compared to vulnerabilities of other kinds are much more credible for projects with a majority of benefits accruing within the first decade or so of post-compact functioning (which may still be 6-7 years away).

Outcome: At the end of this step, the project team should have acquired, at a minimum, a high-level understanding of the climate hazards the project is exposed to, and whether climate hazards have the potential to exert significant influence on the project's expected performance. These are critical to informing the required features of the modeling framework to be developed in Step 2, but may also be useful even if the full guidance described herein is not followed.

2.2.2 STEP 1.2 [OPTIONAL]: CONTRACT MORE IN-DEPTH SECTOR-BASED CLIMATE ASSESSMENTS

Objective: The objective of this optional second approach to screening for climate hazards is also to gain an understanding of the possible exposure of the project to key hazards and uncertainties, but to do so by contracting in-depth climate assessments.

Approach: The off-the-shelf products referenced in Step 1.1 above generally allow users with expertise likely to be held by MCC or its due diligence consultants to ascertain key climate risks with a relatively low level of effort (on the order of a few days). Other "medium-depth" off-the-shelf products are available as rapidly-deployable consulting products such as ERM's Climate Risk Impact and Solutions Platform, or relatively standardized contracted climate vulnerability assessments that bring value by connecting more detailed project context to the implications of available climate information, including screening for potential adaptation considerations (as was done for MCC's engagement on the Sierra Leone compact preparation). Depending on the timing of country engagement and project development, these types of studies may bring value to the overall project development process, but if the detailed project-specific assessment approach described in this guidance is likely to be followed, there may not be a need to contract these other options. However, they are referenced here for completeness, as the timing, content, and utility of this rapidly evolving ecosystem of products remain an active area of learning for MCC.

Outcome: At the end of this step, the project team should have acquired a detailed understanding of the sector-specific climate hazards the project is exposed to, and whether climate hazards have the potential to exert significant influence on the project's expected performance.

2.2 STEP 2: DEVELOP A CLIMATE-RESPONSIVE MODELING FRAMEWORK

The overall purpose of Step 2 is to identify system modeling needs and then ensure they are met, either through in-house expertise, or (more likely) as part of contracts managed in the process of developing projects. At the end of the step, MCC or its consultants should hold an integrated model, or set of linked models, that accepts climate-affected variables (relevant to the climate hazards identified in Step 1) as inputs and quantifies how they change key project performance metrics, including the Economic Rate of Return.

In terms of level of effort and required expertise, this step requires a mix of sectoral knowledge and knowledge of climate change. Step 2.1 would therefore likely benefit from the use of sector-specific due diligence consultants, while Step 2.2 is expected to be included in the scope of work for (pre-)feasibility or design studies. The overall level of effort for a consultant with pre-existing familiarity with relevant models and potential climate data sources would be two to three person weeks for Step 2.1 (essentially preparing terms of reference) and on the order of one to two person months for Step 2.2, though this can be shorter or longer depending on the availability of pre-existing models and familiarity of the consultant.

2.2.1 STEP 2.1 IDENTIFY MODELING FRAMEWORK AND INPUTS NEEDED TO REFLECT CLIMATE IMPACTS ON PROJECT PERFORMANCE

Objective: The objective of this step is to identify the models and workflow needed to simulate the project's impact. The models associated with designing and assessing project performance are typically run by external consultants under prefeasibility, feasibility, or design level studies, and linked to economic models held by consultants or by MCC. Hence, from MCC's perspective, the objective of this section is to specify the desired abilities of the modeling framework described in the contract terms of reference such that the performance assessment is responsive to different climate inputs, and either includes or integrates with the CBA modeling work.

Approach: Assessing the impacts of climate hazards on a specific project can be a complex, data-intensive process. This section provides an overview of the analytical requirements and good modeling practices for incorporating changing climatic conditions into the modeling process, and discusses the attributes of models that are appropriate for simulating the effects of climate change on project performance.

For the purposes of climate change risk assessment, a **model** is a simplified, conceptual, representation of a system that relates inputs (like design variables and climate conditions) to outputs of interest, such as physical variables, engineering reliability metrics, or economic benefits. Unless otherwise noted, "model" as used in this document refers to mathematical models, where the relationships are specified with equations and (typically) computer code. By **system**, we will nearly always mean a civil infrastructure system, such as a road, irrigation network, school, factory, electricity generation/transmission element, or dam/levee. However, it is possible that the "system" being modeled would be something other than a constructed piece of infrastructure, such as a public policy or educational initiative.[16]

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[16] For non-infrastructure cases, the general principles associated with Decision Making Under Deep Uncertainty approaches may still be useful, though it is likely to be more challenging to find or develop models with clear quantitative connections between climate conditions and project performance.

The selection of a model appropriate for simulating of the system under consideration should be considered early in the project development process. Knowledge regarding the strengths and weaknesses of available modeling tools (and more fundamentally, the limits of our understanding of system dynamics) can inform and improve the design of a project. Model selection early in the development process includes explicit planning for how models that relate project design to project performance will link to (or, ideally, be integrated with) the cost-benefit model. In these early stages, it is important to gather information on available*, especially those which have already been vetted and have local or governmental buy-in*.

At MCC, models associated with designing and assessing project performance are typically identified and run by consultants under prefeasibility, feasibility, or design level studies, and linked to economic models also held by consultants, or sometimes by MCC economists.[17] Therefore, **the content in this section is about specifying (as might be done in contract terms of reference) the abilities of the modeling framework to ensure that MCC benefits from a performance assessment that is responsive to different climate inputs, and either includes or integrates with the CBA modeling work**.[18]

Whatever the model output (e.g., simulated energy production costs or flood damages), the selected models should be able to accommodate inputs that correspond to major climate uncertainties (e.g., uncertain future precipitation and temperature), and that will be varied or manipulated in the process of evaluating project performance. For instance, hydrologic models simulate the response of river streamflow to changes in such variables as precipitation, temperature, and land cover. By systematically varying the precipitation or temperature inputs, for example, the analyst can discern the impact that climate change might have on river streamflow. This in turn can be used to estimate the climate sensitivity of watershed-dependent investments, such as hydropower production, water supply, or flood protection.

A key element of the framework presented in this guidance (called a climate stress test, presented in more detail in Step 3) involves the identification of the climate conditions under which project performance becomes unacceptable on one or more metrics.[19] Therefore **the model used must incorporate a mathematical relationship (likely, a series of mathematical relationships) between the climate variables and project performance metrics of interest, including benefits and costs.**

In the case of a flood levee investment, for example, this would be done with the following: 1) a hydrologic model to translate climate variables into streamflow variables; 2) a hydraulic model and spatially-explicit flood inundation model to translate streamflow and levee design parameters into a flooded area; and 3) an economic model to translate flooded area into flood damages. The cost of flood levee construction would be traded off against the benefits offered by levee performance, namely avoided damages (as shown in Figure 4). As a part of a climate stress test, this model chain would be run many

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[17] The universe of relevant models is very large, but some examples include HDM-4 in the transport sector, energy systems models like PLEXOS and LEAP, and the CEIWR-HEC suite for projects with significant hydrologic/hydraulic concerns.

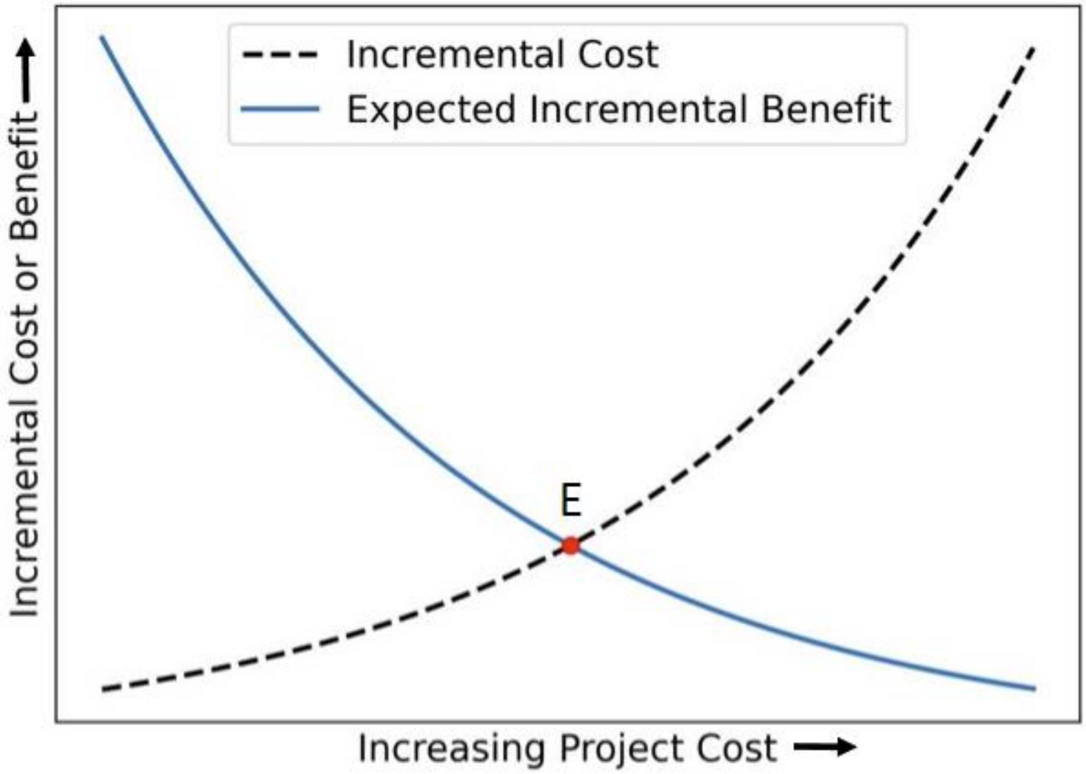
[18] In some cases, MCC may call for specific modeling platforms to be used by contractors, such as if there is a compelling case for integrating with a pre-existing system used by officials in the partner country (such as an energy modeling or water resources planning model). However, most studies should specify performance requirements and be agnostic to the modeling platform used, allowing contractors to demonstrate that needs can be met.

[19] The most prominent institutional threshold at MCC is the ERR hurdle rate, but the project development team and other stakeholders will often define additional metrics, such as avoiding negative impacts to vulnerable groups.

times with climate inputs systematically varied to simulate the performance of the flood levee investment across a range of possible future climate changes.

In many cases where climate change is a relevant factor for consideration in project development, the existing models used for project design and evaluation will already have weather inputs of some kind. In cases where existing models do not yet include weather inputs, but should (as informed by Step 1 of this framework), it may make sense to select a new model that is better able to incorporate climate variables. In other cases, it may be possible to make post-hoc modifications to an existing model. For example, a road design model may not include flooding hazards by default, but the (climate-dependent) frequency of road-damaging flood events and associated rebuilding costs could be combined with the main model outputs, and used to estimate cost as a function of climate conditions.[20]

FIGURE 4. COST BENEFIT CURVES ILLUSTRATING DIMINISHING RETURNS TO INVESTMENT IN CLIMATE-PROTECTIVE DESIGN



Notes: Cost-benefit curves illustrate the diminishing returns to investment in climate-protective design: beyond point E, additional investment offers protection, but costs are more than the benefits achieved. Climate-protective measures sized less than point E are under-sized.

During this model selection phase, it is important not just that the model relates climate variables to outcomes of interest, but also to consider **which individual climate variables the model uses.** Models vary in terms of their ability to translate particular climate-related inputs (of many possible inputs) into changes in project performance. For example, common hydrologic models have meteorological variables such as precipitation and temperature as input, but do not necessarily incorporate sensitivities to other

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[20] An approach along these lines was taken in evaluating MCC's road investments as part of the Malawi II compact.

variables such as wind speed and relative humidity, which could be important for an agriculture project. In the context of another sector, this could mean selecting an appropriate model that is able to evaluate the response of the power sector's physical assets to changes in wind and diurnal (variation within the day) temperature patterns.

The need to identify the variables of interest does require sector-specific expertise. When selecting a model chain for a climate stress test, the analyst will need to map out, incrementally, the connection between changing climate variables and changes in the performance of the investment under consideration. Likely, as in the case of the flood levee investment, the connection between climate conditions and system performance will involve a number of sequential steps. A hydrologist could inform the project evaluator that, in the case of flood damages, relative humidity is not an important model input, but in the case of the design of an irrigation network to improve agricultural productivity, for example, relative humidity is an important factor. It would be important that the model chain chosen for an irrigation investment accommodate relative humidity, but such a capability would not be important in the case of flood damage modeling.

Furthermore, if the project team would like the capability to evaluate the potential benefit of the ecosystem services offered by a variety of nature-based solutions (see the textbox included in Step 6 below), this may require a model that includes a range of biophysical inputs (some of them climate-impacted, and some less so). In addition to temperature and precipitation, this may require a hydrologic model that includes adjustable parameters for land use change, soil infiltration, crop-based evapotranspiration, and potentially water quality parameters such as water temperature and turbidity.

Outcome: At the end of this step, the project team should have specified the modeling features necessary to support a climate-informed project assessment, likely for incorporation into a contract terms of reference.

2.2.2 STEP 2.2: DEVELOP AND BENCHMARK CLIMATE-RESPONSIVE MODELING WORKFLOW

Objective: The objective of this second portion of Step 2 is to incorporate inputs from Step 2.1 to link all the identified model components into an integrated model chain that produces the desired project performance parameters of interest (e.g., ERR).

Approach: The key steps are to 1) bring together various data sources, models, assumptions, and software (as discussed in Step 2.1) into a functioning model chain, and 2) ensure the model outputs are able to provide insights about whether project goals are met under different climate conditions. This may require an iterative approach as the development of the models clarifies their ability to capture critical design variables and project performance. For example, a bridge project may have a hydrological model that estimates the frequency and intensity of potentially damaging high flows. The output of this hydrological model would then be input into an economic model that estimates monetary loss from bridge damage due to flooding. However, during this process, the project team may realize they also want to quantify the monetary loss due to impaired bridge access for the duration of the repairs. If not already included, this type of economic model would have to be developed. Identification of multi-pronged modeling needs will be helpfully informed by reference to the links in the program logic.

Other model selection considerations include the existence of models already calibrated for the task or accepted by stakeholders, the availability of data, and the experience and preference of the analysts and/or consultants. Finally, while difficult to do at this early stage of the framework, it is also important for the project team to give at least some initial thought to ensuring the model will be able to represent project design parameters that the project team may want the ability to adjust later on in the process (specifically in Step 6, described below) when seeking to improve project performance under uncertain conditions.

With these general considerations in mind, there are two specific factors that the analyst should bear in mind when evaluating possible modeling tools:

(1) **Parsimony** – this refers to the complexity of the model and in particular the number of model parameters. The goal for the analyst is to find the least complicated model that adequately represents the relationship between inputs and outputs. In addition to compounding uncertainty that each new parameter introduces, more complex models require more computational effort, and this quickly becomes burdensome when conducting a climate stress test since many model runs are typically required. A model with a long run time can make it infeasible to fully explore the consequences of climate on project performance. Reducing complexity and computation cost can often be achieved by decreasing the spatial and temporal resolution of the model to only what is needed,[21] for example, conducting analysis at the watershed scale in lieu of the sub-watershed scale, or on a monthly time step in lieu of a daily time step. The analytical team should in general seek the simplest model that provides the abilities needed for the analysis.

(2) Predictive Error of the Model – this refers to the difference between the model's prediction of a variable and the true value of that same variable and informs assessment of the model adequacy as decisions about parsimony or complexity are being assessed. The predictive error can be quantified in several ways.[22] The model must be able to adequately simulate the response of the system to variations in uncertain climate variables, meaning that the modeled response must be consistent with physical expectations. Unfortunately, models often embed assumptions derived from historical climate observations. The use of new values of climate variables that exceed the range of the historical climate observations may make it problematic to apply the model beyond its intended range. Additionally, if the predictive error (i.e., the uncertainty in the model) is similar in magnitude to the effects of the uncertain external variables, it may be difficult to convincingly conclude very much about the impact of those uncertain variables, although the relative direction of change may still be informative.

Outcome: The output of this step is an integrated model, or set of linked models, that accepts climate-affected variables (relevant to the climate hazards identified in Step 1) as inputs and quantifies how they change key project performance metrics. In the MCC context, this model will most likely be held by a consultant, or collaboratively owned by a consultant and MCC economist.

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[21] "What is needed" is of course not objectively defined but can be assessed by considering which model outcomes are ultimately used, and conducting early stage sensitivity analysis to meta-parameters like resolution or numerical tolerance.

[22] Common metrics included root mean squared error, mean absolute percentage error and mean absolute scaled error.

2.3 STEP 3: DESIGN AND EXECUTE A CLIMATE STRESS TEST

A climate stress test uses a range of possible climate futures as inputs to the model chain developed in Step 2 to explore the project's performance response to uncertain climate conditions. In this way, **the models are used to simulate the effects of different climate futures on the project's key metrics** (e.g., ERR and related cost-benefit statistics, as well as other performance metrics of interest to the country team), **thereby quantitatively evaluating the conditions to which the project is robust, and to which it is vulnerable.** A climate stress test alone does not require up-front judgments about the probability or relevance of individual climate futures, but these can be brought in later (Step 5) to the extent they are decision-relevant. Project performance is simulated for a set of climate futures that are chosen to comprehensively explore possible future conditions. This comprehensive exploration achieves a more complete understanding of the project's sensitivity to climate change than is possible using a small set of GCM outputs or "best guess" climate projections (see Section 1.2). Using a small set of climate model projections (or worst of all, projections from a single climate model) only reveals the effects of those particular projections on the project performance, and may lead to false confidence in the performance of a design, along with missed opportunities to reduce vulnerabilities (Brown and Wilby, 2012).

In terms of the level of effort and required expertise, this step primarily requires very solid familiarity with climate change modeling and statistical processing. The overall level of effort for a consultant with pre-existing familiarity with relevant models and potential climate data sources would be less than one person week for Step 3.1, 4-6 person-weeks of effort for Step 3.2 (a bit longer for those with expertise but less experience), and a relatively low (order of one week) effort for Step 3.3, though the last step could be longer to the extent that some revisiting of Step 2 is required to finalize workflows. Ultimately the overall process will be iterative and so may blend across Steps 2 and 3, so their LoE and calendar time considerations should be considered jointly. These two steps are also the most significant of the entire workflow in terms of effort and expertise required, with most of the steps that remain being closer to analysis and communication of the information produced here.

2.3.1 STEP 3.1: DEFINE CLIMATE FUTURES TO EXPLORE

Objective: The objective of this step is to specify a set of high-level climate futures to explore in the climate stress test, which will then be translated into model inputs in Step 3.2.

Approach: By a climate future, we are referring to a single possible version of the future climate, as altered by long-term climate change. For the methodology recommended here, a climate future is typically described in terms of the degree increase in average temperature, and the percent change in average annual precipitation. In Step 3.2, these are translated into more locally relevant, finer scale outputs that serve as inputs to the climate-responsive model. This second step of translating changes in long-term average conditions into more local outputs is necessary because climate models have been shown to produce estimates of certain key variables (such as the frequency of extreme precipitation) that contain much greater bias and uncertainty relative to the same model's estimates of other variables (Farnham, Doss-Gollin, and Lall, 2018).

Step 3.1 requires assessment of two issues, namely the plausible ranges of high-level climate futures to be explored, and the number of climate futures to be considered. That is, the analyst must:

- Define the range of climate changes to be explored in the analysis. The range is selected so as to ensure all plausible climate changes are included. This judgment can be grounded in the available climate projections for the region of interest, but should extend beyond them. For context, when looking 30-40 years into the future, varying precipitation from -30% to +30% of the average annual value is often adequate, while for temperature, the range is typically 0 °C to +5 °C.[23]
- Define the intervals at which each climate variable is to be sampled within the selected range. For example, typical increments are changes of 5% for annual average precipitation and .5 or 1 °C for temperature. A well-designed set of climate futures will include the range of plausible changes in mean climate that capture both the uncertainty introduced by unknown future anthropogenic activities (i.e., how will emissions change in the future) as well as several realizations of natural variability (i.e., will year 5 of the project be a particularly wet one or a rather dry one). Climate futures should be sampled in small enough increments to determine those conditions under which a project does or does not achieve project outcomes (see Groves and Lempert, 2007). The desired output is to have sufficient points to understand how temperature and precipitation interact (skip ahead to Figure 5 for a preview), but not so many that time and effort is wasted on needless computation. For two-dimensional descriptions of climate futures (one temperature and one precipitation statistic), sampling with 5 points on each dimension is likely a sufficient starting point. If there appears to be very fine-scale variation in the results of later steps (particularly if decision-relevant), more fine-scale sampling can be conducted in iterative rounds of subsequent analysis.

Outcome: The output of this step is a set of climate futures that comprehensively explore current climate variability as well as future climate change, essentially providing a grid of points to sample. These climate futures are typically defined in terms of long-run changes in temperature and precipitation e.g., from -1 to +4 degrees C change in average temperature, sampled at 1-degree intervals; and from -30% to + 30% change in average precipitation, sampled at 10% intervals.

2.3.2 STEP 3.2: TRANSLATE CLIMATE FUTURES INTO SPECIFIC MODEL INPUTS

Objective: The objective of this step is to develop a computational workflow to translate the set of high-level climate futures defined in Step 3.1 into detailed, locally-relevant inputs to the climate-responsive modeling chain (previously produced in Step 2.2).

Approach: This step takes the high-level climate futures defined in Step 3.1 and derives a large number of finer-scale climate scenarios by using a tool called a weather generator. A *weather generator* produces local climate variables (model inputs) *consistent with the mean climate characteristics that define the climate future being considered*. For instance, under a climate future defined by an increase in mean temperature of two degrees and a 25% increase in mean annual precipitation by 2050, a weather generator can generate daily or monthly climatological variables (e.g., temperature, precipitation, wind speed, etc.) needed to drive a model of project performance for a specific location that are consistent with these long-term change. In this way, a weather generator generates new time series of weather variables while preserving the observed statistics, thus creating realistic short-term variability: Even under a 25% increase

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[23] While five degrees Celsius of global average warming is deemed very implausible for a 30-50-year timescale, local variations can be significantly higher than the global average change.

in mean annual precipitation (i.e. the climate is getting wetter), a certain location will still experience dry days and wet days, as well as dry years and wet years.

There are multiple approaches to creating or obtaining the finer-scale local climate variables that underpin a climate stress test, which vary in their complexity and, relatedly, level of effort.

- **"Delta shifts" and climate re-samplers:** These tools are most suited to cases where the primary concern is shifts in long-term average climate characteristics, keeping historical variability constant. Applying "delta shifts" is a relatively simple way to generate finer-scale climate variables from the historical climate record, either in its entirety, or as shuffled output from a stochastic climate re-sampler. A Delta shift approach involves simply taking historical time series and shifting them by adding the expected temperature change, or multiplying by the expected percentage precipitation change. A slightly more complex approach is a stochastic climate re-sampler, which would apply the same shifting approach but to randomly reshuffled years of the historical climate record. A climate realization from a stochastic climate re-sampler might be a sequence of 30 re-ordered historical years, such as 1978, 2004, 1987, …, 2013, 1996, 1982. Because the years are re-sampled whole, internal variability (seasonality, transition probabilities from dry days to wet days, etc.) is preserved. Note that this approach assumes that climate variability is essentially unchanged from the historical values which means it does not identify the vulnerability of the project to different manifestations of climate variability. Thus, it is not recommended in cases where changing variability is an important consideration, such as in systems that are sensitive to multiple sequential years of wet or dry conditions.
- **Full-capability weather generators:** If potential future changes in daily (e.g., changing precipitation extremes), seasonal (e.g., shifts in monsoonal arrival time and duration), or inter-annual variability (e.g., trends in drought intensity and duration) are of concern, then a full-capability weather generator is recommended. Wilks and Wilby (1999) provide a review of the development and application of weather generators throughout the 20th century, and Steinschneider and Brown (2013) provide a standard-form weather generator appropriate for many climate stress test applications. The primary difference between the Delta Shift approach and full-capability weather generators is the ability to represent and tweak climate change on multiple time scales as well as consider more subtle changes in distributions. The main components of the Steinschneider and Brown weather generator are a model to account for low-frequency, inter-annual climate oscillations, such as the El Niño Southern Oscillation; a resampling scheme to simulate weather variables over a region; and a mapping procedure to enforce long-term distributional shifts in weather variables that result from prescribed climate changes. Alternatives to the standard weather generator form provided by Steinschneider and Brown are available, including even more advanced weather generators that reproduce the statistics of the ocean-centered pressure clusters (i.e., weather regimes) that drive land-based precipitation conditions (e.g., Steinschneider *et al*., 2019). Once a general weather generator form is selected, it is trained on (i.e., calibrated to) a dataset of local historical climate variables. Once calibrated, the weather generator can be used to generate a large set of possible future climate realizations across a range of climate futures.

Consultation with an analyst experienced in the development and application of weather generators is advised. This guidance recommends that a weather generator is selected or developed that is able to generate a large set of fine-scale climate scenarios that comprehensively explore both current climate variability and future climate change (i.e., a full-capability weather generator).

Outcome: The output of this step is a procedure (and its output) that accepts high-level descriptions of climate futures (from Step 3.1) as input, and returns time series or other parameters that serve as inputs to the climate-responsive model developed in Step 2.2.

2.3.3 STEP 3.3: RUN THE CLIMATE-RESPONSIVE PROJECT MODEL TO CHARACTERIZE PROJECT PERFORMANCE ACROSS CLIMATE FUTURES

Objective: The objective of this step is to simulate the effects of changes to the climate to calculate performance metrics under plausible climate futures.

Approach: The finer-scale local climate variables generated from the previous Step 3.2 (that is, climate futures translated into specific model inputs such as time series of precipitation) are used as inputs to the models that simulate the project performance (developed in Step 2.2). These finer-scale climate scenarios may be combined with scenarios that explore the effects of other uncertain variables for a fuller assessment of the vulnerabilities of a project and needed adaptations. Monte Carlo approaches can be used to draw from the non-climate and climate uncertainties to generate a probability distribution of outcomes. Tools such as Crystal Ball provide a framework for conducting this sampling with probability distributions.

Outcome: The output of this step is a database of model outputs (performance metrics) associated with each climate future. Depending on the approach used and how variability is assessed, there can be more than one individual set of outputs for a given climate future, or the variation within a climate future might be summarized by one or two metrics.

2.4 STEP 4: IDENTIFY CONDITIONS OF VULNERABILITY AND ROBUSTNESS

The overall purpose of this step is to characterize, without concern for probabilities, the climate conditions under which the project performs acceptably and unacceptably.

In terms of the level of effort and required expertise, this step involves a mix of team input and some expertise, though much less expertise than Step 3. Practically, it will typically be most efficient for the same consultant conducting the climate stress test to also identify the conditions of vulnerability and robustness, and they will likely have the required expertise. However, given the results of a stress test are in hand as a database of model runs, the skills required involve relatively straightforward data analysis and visualization, and so could also be undertaken by MCC team members or due diligence consultants with data analysis skills. The overall level of effort for a consultant with pre-existing familiarity with relevant models and potential climate data sources is relatively low assuming the previous steps have been completed: likely less than one to two person-weeks for both steps together in terms of technical work. However, consultation and communicating the results may add some weeks of calendar time.

2.4.1 STEP 4.1: SPECIFY RELEVANT THRESHOLDS THAT DEFINE ACCEPTABLE PERFORMANCE

Objective: The objective of this step is to set threshold(s) of "acceptable" performance on each key performance metric to designate each combination of uncertain variables as "acceptable" or "unacceptable" outcomes (e.g. project outcomes below a 10% ERR threshold are considered unacceptable.)

Approach: Specifying a threshold that separates acceptable versus unacceptable performance helps crystallize the focus on the identification of conditions under which a project is vulnerable (see Step 4.2), interpreted as the climate (or other) conditions under which the project does not achieve acceptable performance. The threshold for a particular project and metric is specific to the project and is a choice of the team, and potentially stakeholders. Additionally, a given project may have more than one performance metric. At MCC, the hurdle rate of 10% provides an institutional criteria for unacceptable performance on the ERR metric, but others may be relevant as well.

Beyond the ERR, the project could be stress tested for additional non-monetized indicators, such as ecological metrics or equity metrics. The project team might, for example, assign a threshold water flow necessary to maintain aquatic populations. When considering equity, a distributional equity threshold could be established to ensure that lower income populations capture at least a population-proportional share of benefits.[24] For greenhouse gas emissions, the threshold might be carbon neutrality or alignment with a country's Nationally Determined Contributions under the Paris Agreement. For an example of using thresholds on multiple metrics, see Poff *et al.* (2016).

While exact thresholds are often arbitrary, a primary benefit of the organization of sampled system conditions into "acceptable" and "unacceptable" is the clarity that it brings to discussions of project vulnerabilities and which conditions result in acceptable versus unacceptable project outcomes. In a more in-depth analysis, the conclusions drawn through the stress testing process can also be assessed for sensitivity to the thresholds themselves, and to what metrics are included – essentially a sort of "meta-

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[24] For instance, if those in poverty comprise 60% of a country's population, at least 60% of the total benefits should accrue to those in poverty.

sensitivity analysis." This may be particularly important if stakeholders disagree on what characterizes acceptable performance.

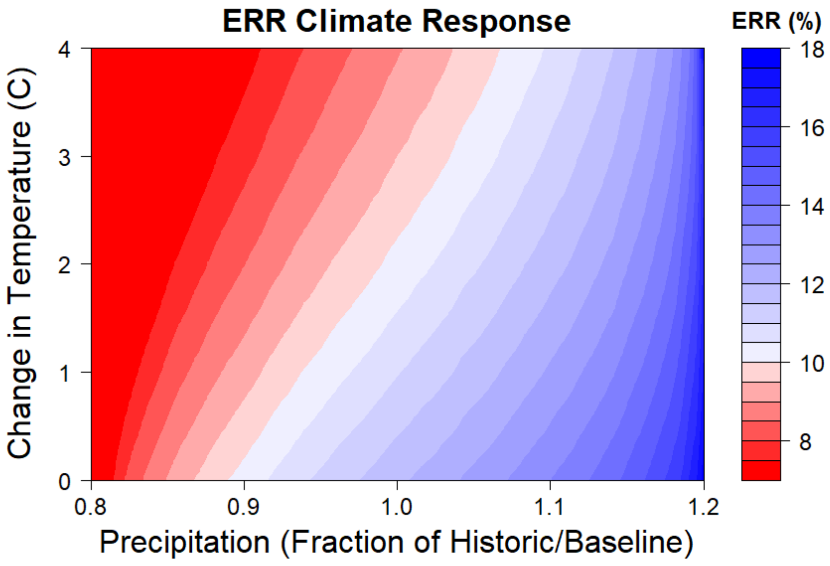
Outcome: The output of this step is one or more relevant performance thresholds per performance metric of interest. For example, falling below the 10% ERR threshold would be defined as unacceptable, though evaluating the vulnerability under a lower discount rate might also be of interest as part of a sensitivity analysis perspective. Alternatively, one might impose criteria on additional performance metrics, so that a project is not deemed acceptable unless it has both a 10% ERR *and* meets an equity metric.

2.4.2 STEP 4.2: CHARACTERIZE CLIMATE CONDITIONS ASSOCIATED WITH UNACCEPTABLE AND ACCEPTABLE PERFORMANCE

Objective: The objective of this step is to examine the stress test outcomes (from Step 3.3) to determine, visualize (or otherwise communicate) the conditions leading to unacceptable performance. These constitute the **vulnerability conditions** (i.e., the climate conditions under which a project performs unacceptably), which will inform the development of mitigating strategies if they are determined to be necessary.

Approach: The previous steps have produced a range of project performance outcomes and set thresholds for unacceptable project performance. This step illustrates the connection between changing climate and project performance, to identify the cause of climate vulnerabilities – ideally visually, and likely augmented by a quantitative description. When there are a small number (two to four) of primary climate variables driving outcomes, this can be simply done with response surface plots (essentially heatmaps). Figure 5 provides an illustration of how precipitation and temperature interact to produce vulnerability (the upper left region). Overall, the figure reveals precipitation change as stronger driver of outcomes, as moving across precipitation holding temperature constant results in a much greater variation in the ERR than moving vertically (increasing temperature while precipitation remains constant). With precipitation identified as the primary driver of negative performance, vulnerability-mitigating design adaptations can focus first on strategies that improve robustness in the face of reduced precipitation, though given the interaction, temperature considerations should not be ignored.

FIGURE 5. RESPONSE SURFACE PLOT SHOWING ERR RESPONSE UNDER DIFFERENT CLIMATE FUTURES



Notes: This figure shows the response of a textile project in terms of ERR as a function of climate changes. Blue shades are responses that meet or exceed the designed performance threshold (here equal to 10% ERR) and red shades indicate responses that do not meet the threshold. The red shades define the climate vulnerability of the project. Overall they figure reveals that the project can retain an above-hurdle ERR with some reduction in precipation or temperature, but simultaneous changes in both quickly put the project in the red, and the project is also vulnerable to large increases in temperature even with no change in average precipitation.

In addition to these kinds of response surface plots, a number of alternative visual and analytic techniques that may be useful for characterizing climate vulnerability are introduced in Textbox 4.

Outcome: The outcome of this step is the identification of the ranges of input variables (e.g., low precipitation) or input variable combinations (e.g., a decrease in precipitation of more than 10% paired with an increase in temperature of more than 1.5 degrees) that are causing the project to perform unacceptably, as well as an indication of the level of influence from each input variable.

Textbox 4: Additional visual and analytic techniques to characterize vulnerabilities

The approach of plotting response surfaces as shown in Figure 5 can be considered a graphical form of sensitivity analysis, which has close connections to what is often termed "**factor mapping**", which attempts to understand what input combinations produce outputs of interest. When it is already known what the two key factors to examine are, the response surface plots used above constitute a succinct way to convey both the boundary between acceptable and unacceptable cases (where the color changes) and the gradient of the response (depth of color). However, in some cases, it may not be obvious which two variables should be considered as the primary ones to plot, or there may be other important variables that need to be included in the mapping. In these cases, modifications to the graphical display approach, or bringing in additional sensitivity analysis methods may be useful. A number of these methods are discussed below.

Multiple Response Surfaces: The effect of a third or fourth variable can be visualized by combining multiple response surfaces into one graphic. In the example on the right, each individual plot represents a different reservoir size. The larger reservoir designs (bottom rows) show wasted investment (greater "regret") if precipitation decreases and/or temperatures increase. The small reservoirs (top rows) show a high regret under precipitation increases and/or temperature decreases, due to lost opportunity. From this graphic, it can be quickly communicated that designs in the 35 m3/s range will perform well under many climate-driven deviations from present conditions, and that the level of regret is low for these designs across all cases (there is no deep red, unlike in the lower right plot). This panel plot changes along a single dimension, but such plots can also be created for one variable changing along the columns and one variable changing along the rows.

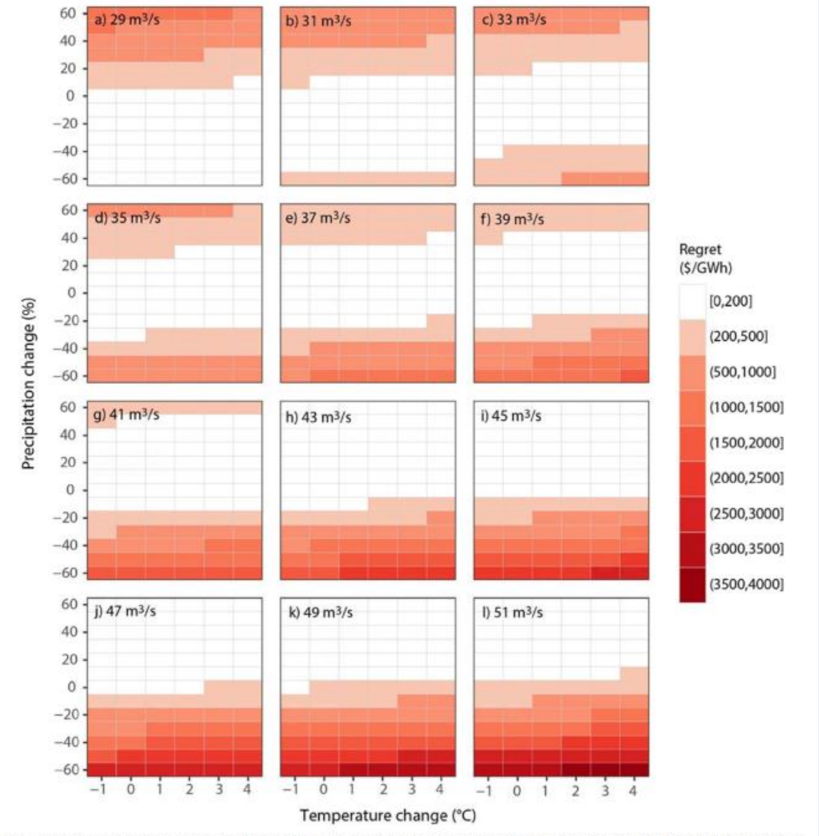


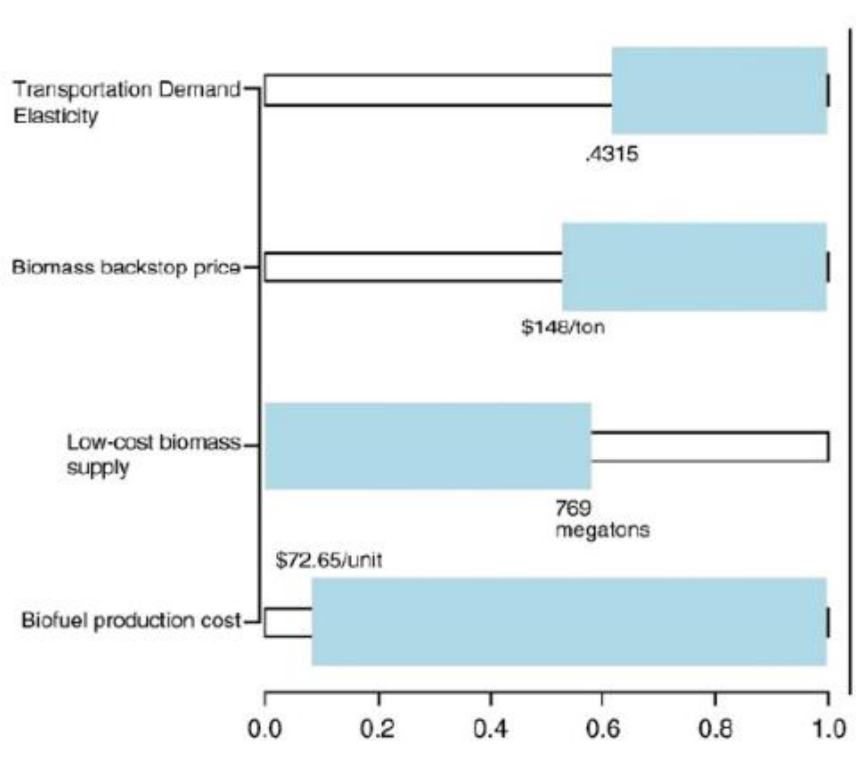
Fig. 3. Computed range of LCE regret across the domain of climate changes ($/GWh) under each design alternative. The cells shaded with white color mark the climate conditions that lead to a low (acceptable) level of regret.

Source: Taner *et al*. (2017)

[continued on next page]

Textbox 4 (cont.): Additional visual and analytic techniques to characterize vulnerabilities

Algorithmic Scenario Discovery: When there are a potentially large number of dimensions that may be important, "scenario discovery" can be helpful for identifying key dimensions (and restrictions on those dimensions) associated with climate vulnerabilities. The term often connotes the description of scenarios of interest as ranges on key uncertainties (effectively creating "boxes" - see Groves and Lempert 2007, and Bryant and Lempert 2010 for examples) but more broadly implies using statistics or other approaches to find and describe the regions of interest. In the example on the right, nine uncertainties were originally sampled, but the algorithm found that restrictions on four specific uncertainties could capture the vast majority (nearly 80%) of all vulnerability cases.



Source: Bryant and Lempert (2010)

Unlike response surfaces with diverging color gradients (which capture both binary information of acceptability, as well intensity), Scenario Discovery does have the drawback that it is typically framed purely around binary outcomes, so some information is lost. That said, response surface plots can still be created using the two most important dimensions.

These tools are of course in addition to more standard methods of sensitivity analysis which can help identify important dimensions and drivers of results, but may not be readily interpretable as scenarios. Some resources for this include introductory CBA textbooks such as Boardman *et al.* (2018) Chapter 11, for implementation software guidance designed to support uncertainty assessment such as Crystal Ball or more specialized packages in languages like R and Python. More in-depth treatment on methods can be found in Saltelli *et al.* (2007).

2.5 STEP 5: INCORPORATE CLIMATE LIKELIHOOD INFORMATION AND ASSESS DESIGN ADEQUACY

The overall purpose of this step is to transparently explore the likelihood of different vulnerability conditions and for the team to identify their level of concern associated with the vulnerability, in order to inform whether to pursue adaptation strategies that improve project robustness. This outcome is achieved by considering the implications of assigning probability distributions to the range of potential climate futures, without necessarily claiming (or requiring stakeholders to agree) that one particular probability distribution is "correct." Often, the implications for whether a project is sufficiently robust are not sensitive to disagreements on assumptions of probability (i.e., a vulnerability either should be mitigated, or is clearly not worth mitigating, across a wide range of assumptions).

The end of this step involves assessing whether the design is considered adequate, considering everything that is known about the nature of the vulnerabilities, the probabilities and overall risk/return profile, and any other context-relevant information. If it is not considered adequate, then a process of identifying adaptations is begun in Step 6, and these adaptation options undergo the same evaluation described in Steps 3 and 4.

In terms of the level of effort and required expertise, it will typically be most efficient for the same consultant conducting the climate stress test to also complete this step. For estimating a distribution in Step 5.1, unless a simple uniform probability distribution is used, specialized experience with the use of climate modeling products (i.e., GCM outputs) is required to undertake this step, and therefore it will likely need to be undertaken by a dedicated consultant familiar with statistical climate modeling. The step is also relatively simple if all context and data are fully understood, but ensuring full context understanding and quality assurance will still require 1-2 weeks. Step 5.2 (calculating robustness index) is a relatively trivial calculation if the same "if all steps above are completed" caveat is applied, in which case it should take less than a week. If required, Step 5.3 would take around two person-weeks to complete. Finally, Step 5.4 requires a mix of context knowledge, sectoral knowledge and knowledge of climate change, and would therefore likely benefit from the use of sector-specific due diligence consultants, or be included in the scope of work for the level of study under consideration.

This important decision about the direction to take project development should also be informed by the country team, and potentially management. The overall technical effort required is relatively low as Step 5.4 mainly involves bringing team judgment to pre-existing technical results (and possibly some additional forms of communicating those results). Therefore, the technical level of effort for Step 5.4 may be less than one person-week, but the administrative level of effort for the team and consultants may be higher, up to a person-month. Depending on feedback received in Step 5.4, some iteration may be helpful.

2.5.1 STEP 5.1: ESTIMATE APPROPRIATE PROBABILITY DISTRIBUTIONS FOR CLIMATE FUTURES

Objective: The objective of this step is to estimate one or more defensible probability distributions for the climate futures sampled in Step 3, for use in generating distributions of key project performance metrics (in Step 5.2).

Approach: Step 4 identifies the conditions under which a project achieves acceptable performance outcomes, but does not take into account the differential likelihood of possible future climate conditions. While it may not be prudent to assume *equal* weights associated with different climate futures, *ignoring the distribution of GCM runs entirely loses important information about relative likelihoods*. This guidance therefore recommends that analysts consider a uniform distribution of climate futures as one limiting case (that will "upweight" extremes), and also use a relatively simple procedure to fit multivariate normal distributions to one or more sets of GCM outputs. However, in the event that the uniform distribution approach does not indicate significant weight on any failure scenarios, fitting a more sophisticated distribution may not be necessary.

There is not a single consensus approach to developing probability distributions for climate variables undergoing anthropogenic climate change, and approaches range from simple to complex in terms of how many nuances are considered. The key challenges are unknown future biases in climate projections, the unknown future greenhouse gas emissions that emissions scenarios (such as Representative Concentration Pathways) attempt to delineate, and integration of multiple models. However, for the purposes of project evaluation under climate uncertainty, a straightforward way to develop probability distributions from climate projections can be employed, which is to calculate the parameters of a multivariate normal probability distribution from an ensemble of GCM projections. An approach to doing so is described in Steinschneider *et al*. (2015) and Textbox 5 provides an overview with specific recommendations when assembling and processing GCM projection data to fit a bivariate normal distribution.

Generally, decision-making under deep uncertainty methods attempt to consider uncertainty in the probability distributions themselves, by considering multiple probability distributions.[25] The use of multiple probability density functions may also be helpful to address concerns of different stakeholders or team members who may find different futures more or less plausible. For example, team members may have equal trust in climate models, but different perspectives on which of humanity's emissions pathways are more plausible. In such a case, one can use separate probability density functions derived for different emissions scenarios (e.g., Representative Concentration Pathways) – see Ray *et al.* (2020) for an application of this approach.

Outcome: The outcome of this step is in the form of one or more relevant probability distributions that can be used to weight the outcomes of the climate stress test. By default, these would include a uniform distribution (which will put extra weight on extreme scenarios and therefore be conservative), and potentially include a multi-variate normal distribution fit to GCM runs. (See right portion of Figure 6 below).

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[25] Some methods also use "imprecise" probabilities, for instance Cosman (2017).

Textbox 5: Calculating project performance distribution using GCMs

To calculate the GCM-weighted performance of a project, as opposed to the uniform approach, there are 4 steps.

- **Step 1:** Acquire the downscaled bias-corrected climate projection data. As of late 2023, the authors were not aware of any stable and user-friendly public interface to acquire the latest (CMIP6) climate projections. Acquiring and formatting the data from scratch therefore requires specialized data-handling skills. Given these requirements, it is recommended to hire a professional consultant to acquire the downscaled bias-corrected climate projections for the project site. Several consultancies have also curated the data for their own use in-house, and can often pull the required project data with relatively low effort.

- **Step 2:** Fit a distribution to the climate projections. A default approach for the "standard" stress test space of average temperature and precipitation is to fit a bivariate normal distribution to the mean change in both variables for the future time period of interest (e.g., 2040-2060), relative to the historical baseline period (e.g., 2000-2020). It is often helpful to plot these shifts onto the stress test/vulnerability assessment, as shown in Figure 6: ERR Climate Response (GCM Overlay). Then these shifts in temperature and precipitation are used to calculate the mean and correlation matrix of a bivariate normal distribution.

- **Step 3:** Create contours of the distribution for visual assessment: The fitted GCM distribution parameters can be used to create contours of the probability space, visually indicating regions of higher and lower probability (with wide contours serving to bound the space of plausible outcomes that merit attention). In Figure 6: ERR Climate Response (GCM Overlay) a 95% confidence ellipse is shown to be a relatively small part of the original vulnerability space. With this information the analyst may consider adjusting the bounds of the vulnerability assessment in the "uniform" case, and also make initial inferences about how much weight to give to unacceptable cases in the red zone. It may still be useful to consider the distribution of outcomes with a uniform distribution, but having a better sense of the relevant bounds will focus attention and avoid a presentation that gives unhelpful weight to extremes that have near-zero probability of occuring.

- **Step 4:** A final step is to estimate the probability-weighted distribution of outcomes, with and without climate weighting. This can be done by assigning a probability mass to each point in the climate stress test space drawn from the fitted multivariate distribution and sampling using standard Monte Carlo techniques.The resulting distribution can be used to calculate the robustness metric for the GCM case and to approximate the probability density function with histograms, as shown in Figure 6. The robustness metric will simply be the number of simulations that fall above the threshold. Similarly, in Figure 6, about 86% of the points fall above a 10% ERR. Full examples and more details are provided in the skill assessment appendix.

The final consideration, mentioned above, is a skill assessment on the individual GCM models. The rationale for a skill assessment is that some GCM models are a poor fit for a specific project location. Although it is perhaps more accurate to say that some GCM models are a "less good" fit, as there is rarely a "good" fitting raw GCM model. A skill assessment is not strictly necessary and should be considered within the context of available resources and technical skill in acquiring and processing raw GCM data.

2.5.2 STEP 5.2: CALCULATE CLIMATE-INFORMED ROBUSTNESS INDEX

Objective: The objective of this step is to assess and quantify the robustness of the project in order to make a decision regarding whether adaptation is required.

Approach: As a complement to identifying vulnerability conditions for attention (Step 4), this guidance recommends numerically summarizing the overall relationship between conditions of acceptable performance and unacceptable performance with a ***robustness index***, along with more traditional graphical output. The **climate-informed robustness index** quantifies the (likelihood-weighted) proportion of conditions under which the project performs acceptably (i.e., relative likelihood of

robustness conditions occurring), and implicitly indicates the proportion of climate conditions under which the project performs unacceptably (i.e., relative likelihood of **vulnerability conditions** occurring). Conditional on a fitted distribution of climate futures from Step 5.1, the climate-informed robustness index of the project can then be defined as the probability of climate change conditions under which the performance metric meets or exceeds the acceptability threshold.[26]

Figure 6 below illustrates the importance of incorporating GCM information compared to a uniform weighting in the space of climate futures. In the top left plot (a reduced version of Figure 5), project vulnerability is shown under all climate changes considered. Assuming a uniform distribution for temperature and precipitation changes, the fraction of cases for which the ERR is greater than the threshold value (10%) is 0.56. Thus, the robustness index is 0.56, with 56% of climate futures falling above the 10% ERR threshold, as shown on the plot on the right. The lower left plot shows the same vulnerability map, but superimposes the output from an ensemble of GCMs. This GCM output suggests that, while a significant temperature increase is likely, major reductions in average precipitation are not. When this information is accounted for by fitting a distribution, the project is robust to 86% of the GCM-based probability-weighted climate futures, and therefore has a climate-informed robustness index of 0.84. To the extent that regional experts and stakeholders accept the GCM outputs, the project appears to be largely robust to most climate futures.

This climate-informed robustness index provides a concise summary of a desirable performance outcome[27] that may sometimes be in tension with overall economic returns or other metrics. To the extent that reducing downside risk is a valued outcome (and one often achieved through more costly climate-robustness interventions), the climate-informed robustness index is a simple way to make this attribute of the project visible, and allows the team to make an informed choice about whether to select a project design with a lower likelihood of unacceptable returns (see also discussion around Figure 9 in Step 6).

Given that there will rarely be full confidence in the specification of the climate probability distribution, the greatest value of robustness metrics is often as a relative measure for comparing alternatives against the same set of uncertain climate conditions – that is, they do not indicate a formal probability associated with conditions of acceptable performance, but constitute likelihoods that can be used to make fair

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[26] This is also equivalent to calculating the robustness of the project as the fraction of the probability density function of the performance metric that is above the acceptability threshold, which may be a more practical method when using evaluating robustness to uncertainty among many variables, including non-climate variables.

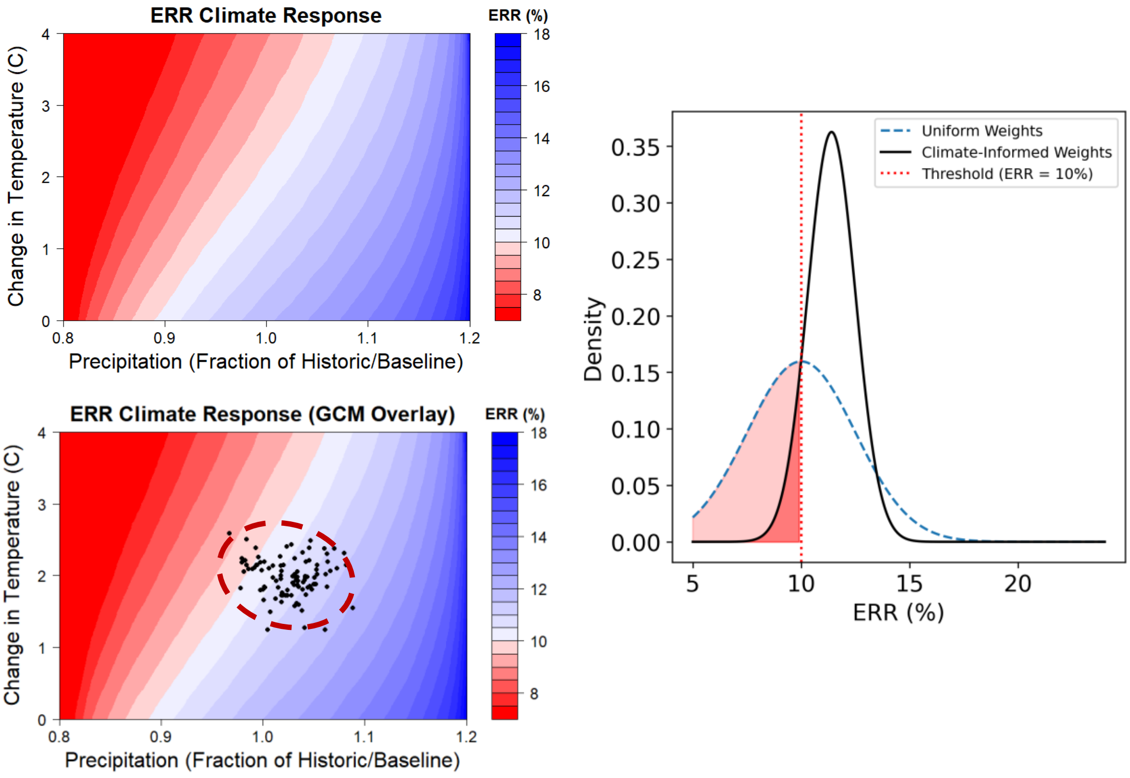
[27] Robustness is only one measure of performance under uncertainty. Other possible performance measures including **reliability**, **resilience**, **worst-case vulnerability**, and **sustainability.** Hashimoto *et al.* (1982) present a discussion of techniques for the quantification of reliability, resilience and vulnerability. The mathematical definitions for these measures presented by Hashimoto *et al.* have come to be referred to as the "engineering" versions of these metrics. Other mathematical conceptions of these metrics, such as those commonly used in public health and ecology, are possible. Loucks (1997) put forth a mathematical definition of sustainability, which is a direct combination of reliability, resilience and vulnerability. Again, other mathematical representations of sustainability are available.

This guidance note emphasizes robustness over these other possible measures for two primary reasons:

- It is the simplest extension of the expected-value ERR across an uncertain future climate space.
- It is typically representative of long-term averages (unlike, for example, resilience and vulnerability which are better descriptors of the system response to extreme events). Robustness aligns well with the CBA's interest in overall long-term performance. (While technically, robustness can incorporate summary metrics of dynamic performance on finer timescales if the model fidelity allows it, unlike resilience, it is not *fundamentally* associated with time dynamics).

comparisons *holding assumptions constant*. This use is described more in Step 6. As noted in 5.1, the analysis within this step can be repeated for different assumptions about the future climate distribution to further inform the overall robustness assessment.

FIGURE 6. DEMONSTRATING THE IMPORTANCE OF GCM-INFORMED PROBABILITIES FOR CLIMATE FUTURES



Outcome: The analyst can use the results of Step 5.2 to evaluate and describe the robustness of the project. Given this understanding, the project team will next decide if adaptation is necessary and if so, use insights from all the preceding steps to develop strategies to help safeguard project performance in the face of uncertainty.

2.5.3 STEP 5.3 [OPTIONAL]: CONDUCT REFINED SENSITIVITY ANALYSIS TO FURTHER CHARACTERIZE VULNERABILITY CONDITIONS

Objective: The objective of this step is to deepen understanding of vulnerabilities to further inform the level of concern and provide additional guidance on potential adaptation options, if necessary.

Approach: The results of Step 4 typically characterize vulnerabilities in terms of what this guidance refers to as “climate futures” – high-level descriptions of changes in long-term averages. In evaluating the level of concern around vulnerabilities, as well as conditions of robustness, it may sometimes be helpful to examine sensitivities of project outcomes at the level of the *climate-related model inputs* – i.e., the product of Step 3.2. This step can also usefully inform the generation of adaptation options. Note that this recommendation is a specific element of more general sensitivity analysis of the modeling workflow, which should be conducted regardless.

For example, Step 4 might show a design is vulnerable to a reduction in long-term average precipitation. However, there may be some ambiguity about whether that low performance is stemming from cases where the *intra-annual variability stays the same and precipitation decreases relatively evenly* across years, or if the vulnerabilities are due to an *increased prevalence of multi-year droughts* (even though wet years stay as wet as they have historically). This extra information can be combined with context-specific insights to point the way towards adaptation options: in this example, greater water storage (in reservoirs or groundwater) could be helpful in the case of more frequent droughts, but not very valuable in the case of a decreasing mean.

Conducting this analysis would likely involve developing additional summary statistics of the inputs to the climate-responsive model and using graphical and numerical factor mapping and sensitivity analysis approaches (discussed in Step 4.2) on those statistics. For model inputs that are daily or monthly time series, default statistics could include metrics of intra- and inter-annual variability (such as the autocorrelation of annual total precipitation series, or Markov Chain transition probabilities between years grouped according to their relative ‘wetness’). More generally, various moments (variance, skewness) and cumulative extreme values may be considered depending on the context (e.g., extreme degree days).

Outcome: The outcome of this step is a more detailed description of climate vulnerabilities in terms of specific climate impacts, rather than in terms of descriptors of long-term climate futures.

2.5.4 STEP 5.4: ASSESS LEVEL OF CONCERN REGARDING PERFORMANCE AND VULNERABILITIES, AND DETERMINE WHETHER TO ACCEPT DESIGN OR SEARCH FOR ADAPTATIONS

Objective: The objective of this step is to assess the level of concern that results from the identified vulnerabilities based on how likely the problematic climate conditions are to occur.

Approach: The assessment of the level of concern is a subjective process based on the judgment of the team in terms of what the best available scientific information implies for the likelihood of the problematic climate scenarios actually occurring. In short, if more climate information indicates that problematic conditions will occur, the higher the level of concern. There are three considerations that contribute to this assessment: 1) theory, 2) historical trends, and 3) climate projections. Most likely the modeling outputs will be most straightforwardly interpreted with historical trends (which inform natural variability) and GCM outputs for context, but these should always be assessed in the context of theoretical relationships that may not be captured at the relevant scales.

Outcome: This step results in a scientifically informed assessment of the concern associated with the identified climate vulnerabilities, and conversely, a summary indicator of the overall robustness of the project. The project team can use the results of this step to decide if the project is sufficiently robust or if further exploration of adaptations to climate uncertainty is merited. If the climate vulnerability conditions represent a large portion of possible climate futures and the climate information indicates that the problematic conditions are likely, then it will be important to consider modifications to the project design that will improve performance under those problematic conditions (see Step 6).

2.6 STEP 6: DEVELOP AND TEST ADAPTATION STRATEGIES, IF NECESSARY

This step is reached when the best available candidate project designs are still considered unacceptably vulnerable to climate hazards. This step describes multiple processes for generating potential ideas for ways to reduce vulnerability, which could involve relatively small adjustments to existing project elements (e.g., increasing road culvert size or changing construction material), or could involve more significant design changes, such as inclusion of a nature-based solution (planting upstream or coastal vegetation to reduce flood risk). Having identified different possible design adaptations, the evaluation process described in Steps 2-5 is repeated to enable a comparison of risk/return profiles to identify a suitable design change.

In terms of the level of effort and required expertise, this step primarily requires sectoral knowledge. Knowledge of climate change adaptation is beneficial, which could be drawn from a mix of international consultant expertise and local stakeholder context expertise. The overall level of =effort for a consultant with pre-existing familiarity with the sector would be one person-month for Step 6.1 and two to three person weeks for Step 6.2. Depending on the adaptation interventions chosen, it is possible that the model chain established in Step 2 of this framework will need to be revisited at this stage (if these models do not incorporate those design parameters that project teams have now identified as wanting to adjust), which can add additional time.

2.6.1 STEP 6.1: IDENTIFY POSSIBLE ADAPTATION STRATEGIES THAT INCREASE THE ROBUSTNESS OF THE PROJECT

Objective: The objective of this step is to identify a set of strategies that can lead to a more robust project design if Step 5 indicates unacceptable performance by the current design.

Approach: Steps 3 and 4 of this framework identified those uncertain variable combinations that are problematic for the project achieving acceptable outcomes. These insights (as well as those coming from optional Step 5.3) serve as the basis for identifying potential solutions that can improve the robustness of the project. When it comes to developing a list of potential adaptation strategies, it is recommended to cast a broad net with an open mind, withholding judgment on the different proposed strategies until after the evaluation outlined in Step 6.2 below (though some prescreening for cost and feasibility is helpful since assessment of options does take some time and effort). In addition, because they are relatively low cost, flexible, sustainable and adaptive, and can be instituted at a scale manageable by local communities, particular attention should be paid to the potential for nature-based solutions to enhance the climate robustness of the project (see Textbox 6 below).

When developing a list of possible strategies to enhance the robustness of a project to climate impacts, **stakeholder engagement is paramount**. Stakeholders, project beneficiaries, and local infrastructure owners/operators can identify strategies that have been attempted historically, as well as what is tractable for the future, given local resources and limitations. In addition to the options proposed by these groups, expert analysts and consultant project planners may propose a set of options that have been applied to similar problems elsewhere in the world and may be appropriate for the local system, assuming regional contextualization is carried out. Regional contextualization means among other elements, using building materials, organizational structures, and financial mechanisms appropriate to the local context. For example, a levee built using steel and concrete, financed and owned by the private sector, and managed by a corporation may be an instructive example of flood management from the United States, but for a rural location in low income countries on other continents, it may be more appropriate to design it using local stone (not steel), financed and owned by the government or local community (not the private sector), and managed communally by local residents (not a corporation).

Textbox 6: Nature-based solutions as a way to enhance the climate robustness of a project

There is a range of options available to project developers to address common climate impacts including the changing predictability, quantity, and intensity of rainfall, and more frequent severe and longer-lasting heat waves. Recently, nature-based solutions and more specifically, a subset of measures known as ecosystem-based adaptation, have been gaining prominence given mounting evidence of their critical contribution towards both climate change adaptation and mitigation while also supporting biodiversity conservation, health outcomes, poverty alleviation, food and water security and other societal objectives. For example, the creation or restoration of wetlands in the upper portions of a catchment can slow rainfall runoff thus reducing flood risk; store water and increase groundwater infiltration for use during dry periods; capture carbon, and enhance biodiversity for recreation and cultural benefits. These multi-functional measures are attractive to project developers and have the potential to generate additional economic value that can be included in a project CBA.

Examples of other ecosystem-based adaptation measures that could generate useful ecosystem services for MCC projects include revegetation of slopes; planting buffer strips along riverbanks; maintaining of forested hilltops for humidity and water infiltration; introduction of agroforestry and agro-silvopastural practices and the reintroduction of species such as beavers to help restore degraded ecosystems. When used in combination, these measures can be effective at helping reduce runoff; limiting soil loss and siltation in rivers and dams; enhancing groundwater infiltration; reducing flood risk; storing water; enhancing biodiversity; storing and sequestering carbon; as well as improving the aesthetics of an area. In short, they help address identified climate vulnerabilities and often generate other valuable co-benefits too.

The partnership developing this guidance document is also developing practical materials to identify and value ecosystem-based adaptation measures. In the meantime, helpful references include:

- The Ecosystem-based Adaptation Tools Navigator - a searchable database of over 200 tools and methods relevant to ecosystem-based adaptation
- The United Nations Environment Programme Ecosystem-based adaptation website which includes a series of briefing notes and links to toolkits and other resources for planning, designing, financing, monitoring and evaluating ecosystem-based adaptation measures
- The Ecosystem-based adaptation page on adaptationcommunity.net, a portal developed and maintained by GIZ to provide information on approaches, methods and tools that facilitate the planning and implementation of adaptation action, including links to recent publications, training courses and good practice examples.

There are a number of well-established processes for effective stakeholder involvement in the process of enumerating options for enhancement of the robustness of a planned project to climate change. The United Nations Development Programme and the United Nations Department of Economic and Social Affairs (2020) summarize their findings on the quality of stakeholder engagement in international development in three key principles: inclusion, participation, and accountability. As one structured approach, **Shared Vision Planning** (see for example Palmer *et al*. (2013) and Loucks, Kindler, and Fedra (1985)) is "a collaborative approach to formulating water management solutions that combines three disparate practices: 1) traditional water resources planning, 2) structured public participation and 3) collaborative computer modeling." Shared Vision Planning aims to avoid the (common) condition in which the infrastructure investment does not achieve acceptable outcomes because of inadequate communication between analysts and clients. St. George Freeman *et al*. (2020) similarly present a "**participatory human-hydrologic systems approach**" to the achievement of climate change resilience in a water system investment plan. St. George Freeman *et al.* frame the stakeholder elicitation process in terms of “resilience of what, to what, for whom, and what can be done.” The “of what” targets the selection of investment based on clearly-defined and well-articulated performance metrics; the “to what” unambiguously identifies the hazard of concern; and the “for whom” explicitly accounts for distributional and temporal (e.g., inter-generational) equity dynamics. The “what can be done” is the adaptation/investment options, which only become clear in the context of a shared understanding of the previous three questions.

In addition to considering different possible strategies to enhance project robustness, the project team should also consider **phased project investment as a possible adaptation strategy**, such that certain interventions are implemented now, and others later. The project planner might want to experiment with the initiation of project design changes (or system configurations) at different times and note the impact on discounted costs and benefits. The benefit of staged decision making (e.g., as demonstrated by Haasnoot *et al.* (2013) or Ray *et al.* (2012)), is the possibility to spend a relatively small amount to lower the cost of future investment should it be needed, and save currently available dollars for other, more urgent, investments. A classic example is the adoption of oversized foundations in the construction of a dam or levee so that the dam/levee can be raised as needed later in its design life.

In the MCC context, phased investments determined based on learning about *climate* impacts may not be feasible within the relatively short MCC compact implementation lifetimes, but other uncertainties do get resolved between the development of the investment memo and the years that pass until mid-compact implementation. Adaptation planning may still be utilized by the partner country governments after the compact end date as well. As one case illustrating both these concepts, the Energy Storage Project within MCC’s Kosovo Compact, is likely to establish a supporting footprint and infrastructure for Battery Energy Storage Systems larger than the MCC investment, which will allow Kosovo to expand to meet future needs at lower cost and with less delays related to works and permitting.

Additionally, to the extent that adjustments of the design parameters (including timing of phased implementation) are easy to automate and model runtime is relatively low, stakeholder input can be augmented by computer-assisted searches to help find the most robust design options, with stakeholders helping identify key design parameters to adjust, and the computer doing the work of searching for the values (Bartholomew and Kwakkel, 2020).

The literature on climate adaptation is vast, and not all is relevant to project adaptations at the stage being considered, however, the IPCC’s Principles for Effective Adaptation provide a concise overview of issues that should be borne in mind during this process.[28]

Outcome: At the end of this step, the project team will have identified a list of promising interventions that could enhance the robustness of the project. These may be variations in existing design parameters (e.g., changing the height of a dam, changing the size of road or bridge parameters), or more significant changes such as adding a new design element (e.g., adding an upstream catchment management component to an irrigation project, or mangrove restoration to a coastal tourism project.)

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[28] https://www.ipcc.ch/site/assets/uploads/2018/03/ar5_wgII_spm_en-1.pdf

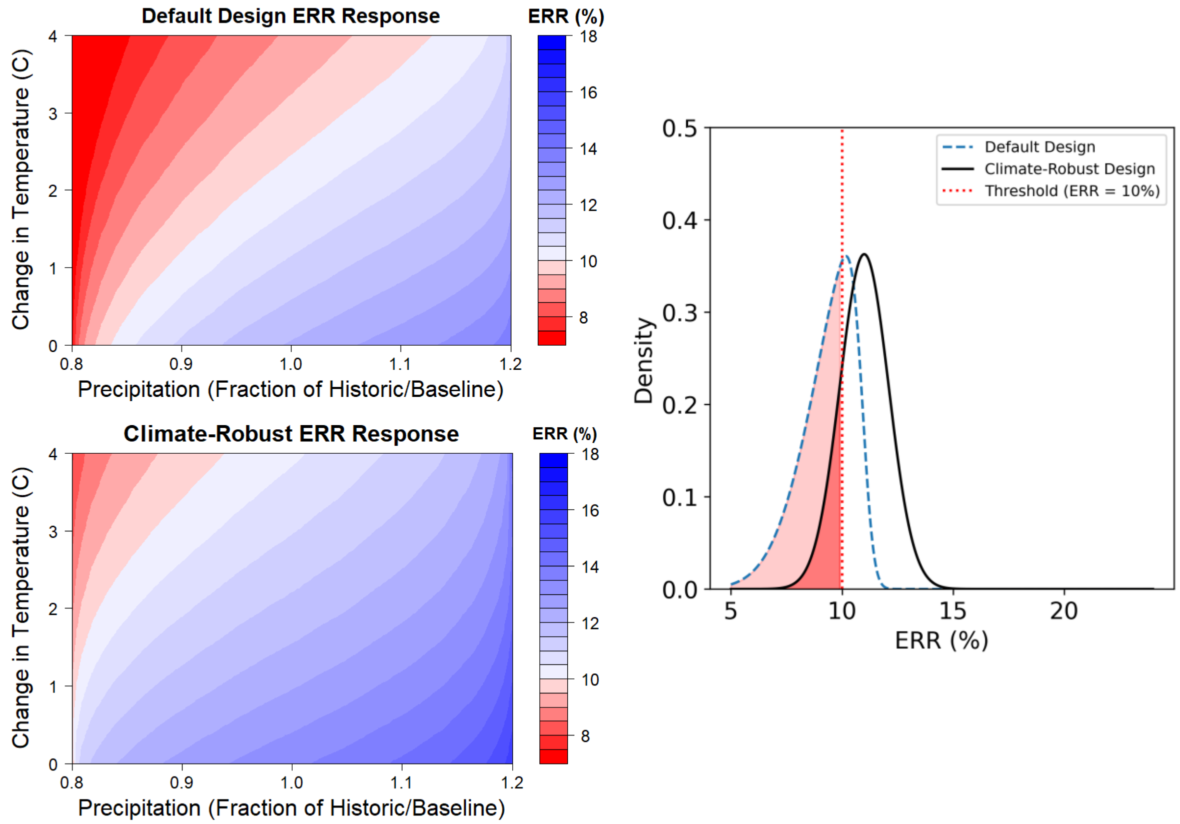
2.6.2 STEP 6.2: EVALUATE THE IMPACT OF STRATEGIES THAT INCREASE THE ROBUSTNESS OF A PROJECT (REPEAT STEPS 2-5 ON ADAPTATION STRATEGIES AS NECESSARY)

Objective: The objective of this step is to assess whether the strategies identified in Step 6.1 increase the robustness of the project following the same approach from Steps 2 through 5, and then select and communicate of the rationale for a final project strategy.

Approach: Having identified both project vulnerabilities and a list of possible strategies to enhance project robustness, this next step evaluates the individual adaptation strategies to identify the most promising ones. The essential activity of this step is a repetition of the climate vulnerability assessment performed in Steps 3 through 5 for each design modification intended to enhance robustness. Also, it may be necessary to update the modeling framework (Step 2) to allow representation of candidate adaptation if they are not currently easy to represent in the model that was developed in Step 2.

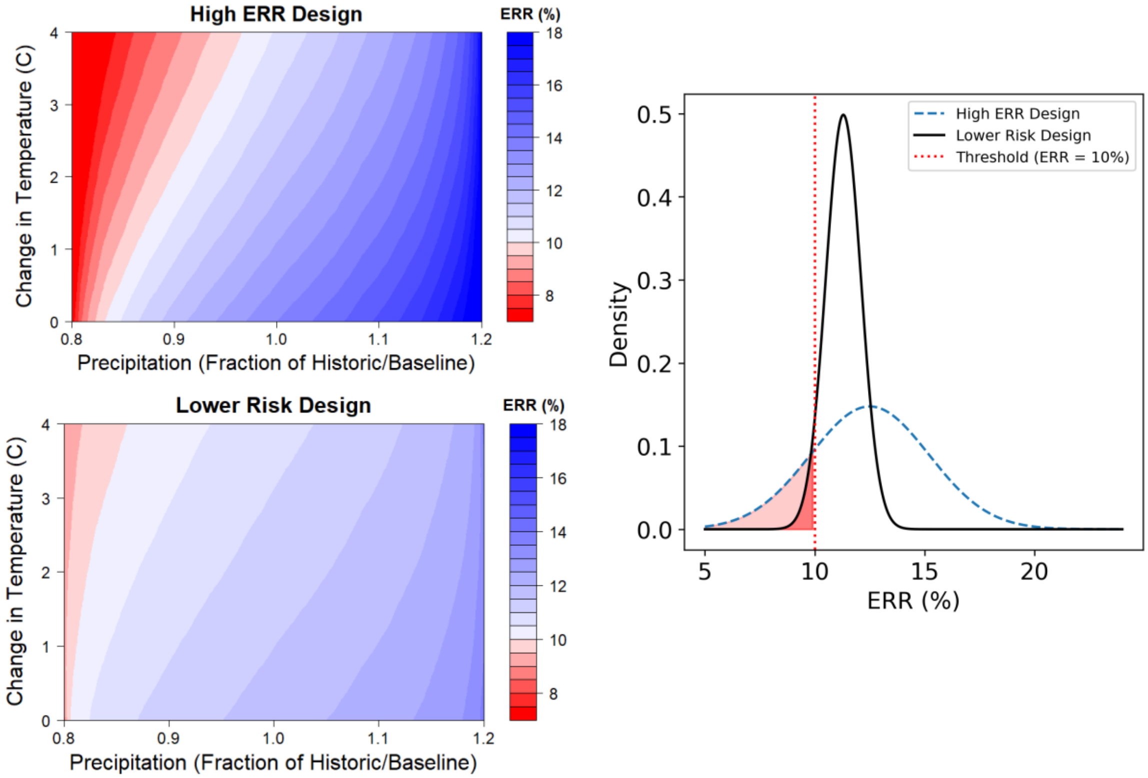
The designs from Step 6.1 will achieve different performance levels (potentially on multiple metrics) when run through Steps 3 through 5. With just two candidate designs and one key performance metric, one can directly compare both the project response surface plots (as introduced in Figure 5 and Figure 6 above) and the distributions of outcomes. An example of the graphical mapping between the vulnerability conditions associated with each design and their corresponding area under the histogram is shown in Figure 7.

FIGURE 7. DEMONSTRATING A DESIGN ENHANCEMENT THAT REDUCES BOTH VULNERABILITY AND IMPROVES THE ECONOMIC RATE OF RETURN



In the idealized case shown in Figure 7, the climate-robust design not only results in fewer cases where the ERR falls below the threshold, but also is projected to return a higher average ERR than the default design. It is of course also possible that the choice between a climate-robust and default design requires a tradeoff between vulnerability and ERR (i.e., the default design may be expected to return a higher ERR than the climate-robust design, but experience more cases where the ERR falls below the 10% threshold). This outcome is shown in Figure 8 below.

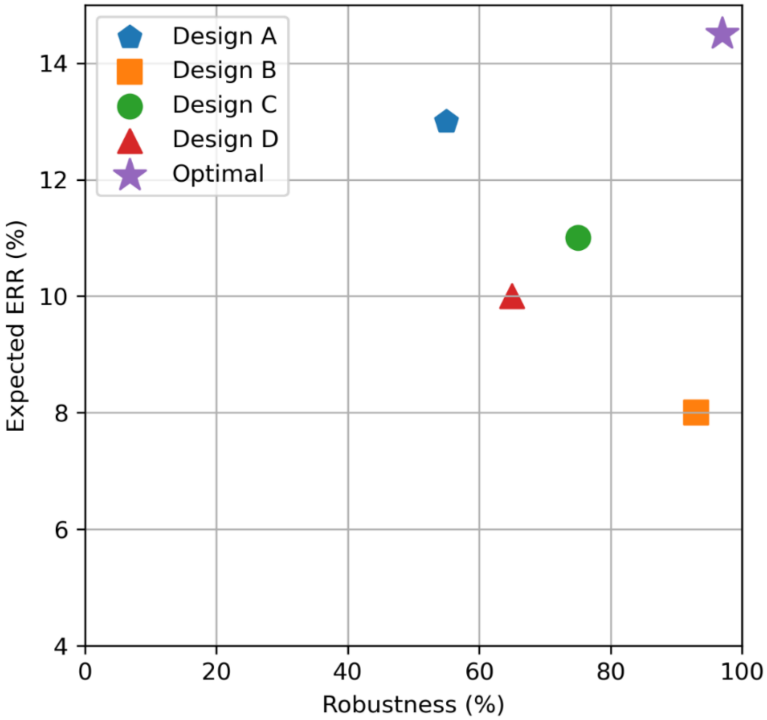
FIGURE 8. DEMONSTRATING A DESIGN ENHANCEMENT THAT REQUIRES A TRADEOFF BETWEEN VULNERABILITY AND THE ECONOMIC RATE OF RETURN



With multiple designs under consideration, plotting the expected value ERR and the climate-informed robustness index (explained in Step 5) can help clarify the key designs meriting attention, and the trade-offs involved (as well as which designs may be dominated – i.e., a less favorable choice across the entire uncertainty space).

Figure 9 shows an example of a trade-off analysis between the mean ERR and the climate-informed robustness index. In this example, Design A has the highest mean returns, but also is the least robust option. In contrast, Design B has the highest robustness, but the lowest estimated mean ERR. Design C is in between, but is better on both metrics than Design D, which can be ignored as it is dominated by Design C.

FIGURE 9. MEAN ESTIMATE OF THE ECONOMIC RATE OF RETURN (Y-AXIS) AND CLIMATE-INFORMED ROBUSTNESS INDEX (X-AXIS) FOR 4 DIFFERENT PROJECT DESIGNS



While the above approaches helpfully bring quantitative structure to the evaluation of different project designs, project teams will of course need to consider additional factors in selecting an adaptation option (or deciding not to implement such options). Carefully scrutinizing the combination of assumptions, restrictions, political challenges, and design parameters inherent in each strategy will be important to contextualize the quantitative results. Depending upon the magnitude of local political, financial, cultural, or institutional challenges, additional parameters to estimate costs and benefits may be required, and the collection of additional data may be necessary. If none of the strategies produces satisfactory results in terms of both improved robustness and good feasibility, it may be necessary to return to Step 6.1 and brainstorm additional adaptation strategies, possibly also informed by more in-depth analysis of the different modes by which a project can have unacceptable outcomes (Step 5.3). If the team is confident that feasible adaptation strategies have been reasonably exhausted, more effort may need to be spent on assessing trade-offs between options and likelihood of particular vulnerabilities. There are a range of existing methods designed to leverage computational capability to generate and explore project alternatives – a brief overview of these is presented in Appendix A.

Outcome: The outcome of this step is in the form of visual and quantitative products that show potential trade-offs between expected performance and robustness of alternative project designs. These can include comparisons of distributions of outcomes, or summary metrics comparing mean performance versus the climate-informed robustness index. The ultimate outcome of Step 6.2 is the selection of a design configuration for the project that has balanced stakeholder interest in reward and risk trade-offs.

3. CONCLUSION AND NEXT STEPS

This is the first version of this general guidance on achieving robust project design through climate-informed analysis that is being shared within the MCC community. It has been informed by engagement with country teams during the process of development, but has **yet to be fully tested through application by a team unaffiliated with the partnership who developed the guidance. It is therefore conceived as a living document, intended to be updated to reflect challenges and enhancements that may be experienced by country teams and consultants attempting to apply the guidance.** (See also Section 1.4 on already-planned updates.) The process laid out within this document requires time and contracted expertise, but given the costs of MCC projects and magnitude of benefit streams, the identification and even partial mitigation of vulnerabilities has the potential to bring significant value in terms of cost-effectiveness to MCC's stakeholders, and benefits to MCC partner country citizens.

This guidance is recognized to be a particular instance of procedures and philosophy that are often grouped under the banner of "Decision Making Under Deep Uncertainty" including methods such as Robust Decision Making, Decision Scaling (and related Decision Tree Framework at the World Bank), Adaptation Pathways, and Climate Risk-Informed Decision Analysis (often associated with the UNESCO). To the extent that country team members have familiarity or preference for the particular framings associated with these other approaches, the authors of this document would generally consider it a success for any such approach to be adopted as part of an MCC compact development. The guidance provided here intends to fill gaps in specificity as it is tailored to MCC's applied, time-constrained, and consultant-dependent project development process. The authors look forward to receiving feedback so that it can better serve this role.

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APPENDIX A: METHODS TO GENERATE AND EVALUATE PROJECT ALTERNATIVES

The World Bank's Decision Tree Framework (Ray and Brown, 2015) organizes options for evaluation of the relative performance of adaptation strategies and design alternatives according to analytical approach. Conventional decision analysis, based on principles from the field of operations research (Hillier and Lieberman, 2021), aims for an optimum system configuration, typically by minimizing expected cost or maximizing expected benefits. However, traditional expected value decision making, even in combination with tools for adding robustness, has significant drawbacks when the sensitivities of the system are substantial (Loucks, Stedinger, and Haith, 1981).

Some tools for traditional decision analysis are built on **search (optimization) algorithms** (Kasprzyk *et al*., 2013; Loucks, 1970; Ray, Kirshen, and Watkins, 2012; Steinschneider and Brown, 2012). Others **run simulations of the system repeatedly** (a so-called Monte Carlo experiment), systematically varying model parameters to identify preferred system configurations (Jeuland and Whittington, 2014; Lempert, *et al*., 2006; Lempert and Groves, 2010; Prudhomme *et al*., 2010). If a tool based on a search algorithm is used, emphasis should be placed on the generation of trade-off s between competing objectives (Kasprzyk *et al*., 2013; Ray *et al*., 2014). Robustness with respect to one objective (for example, maintenance of low flows for ecological well-being) will likely be won at the expense of some other objective (reservoir storage for water supply during drought, for instance). Other concepts to be emphasized in optimization objective functions are adaptability (real options analysis - Ranger *et al*., 2010) and diversification (redundancy and diffusion of risks - Brown and Carriquiry, 2007). A well-crafted optimization model for water systems planning and management will likely incorporate elements of all three objectives—adaptability, diversification, and robustness.

Decision scaling (Brown *et al*., 2012) has typically been employed to make iterative modifications to the design to trace out alternative performance and find robust designs. **Robust Decision Making** (Lempert *et al*., 2003) has typically taken a similar approach, if with a different approach to climate change uncertainties. **Stochastic optimization, multi- (or many-) objective robust optimization, and Real Options Analysis** use search algorithms to quickly home in on the most efficient design modifications to improve system robustness. Stochastic optimization has been integrated with Robust Decision Making (Kasprzyk *et al*., 2013) and decision scaling (St. George Freeman *et al*., 2022). For summaries of stochastic optimization techniques that make use of probabilistic uncertainty paradigms for water systems decision making, see Revelle, Whitlatch, and Wright (2004), Loucks, Stedinger, and Haith (1981), Loucks and van Beek (2005), and Sen and Higle (1999). Multi-objective robust optimization (Kasprzyk *et al*., 2013; Ray, Kirshen, and Watkins, 2012) extends stochastic optimization to make it more explicitly robust to challenging scenarios.

Adaptation tipping points are a key concept of **Dynamic Adaptation Policy Pathways**. In this approach, a rich set of potential current and future adaptation actions are used as the basic building blocks for the assembly of adaptation pathways. The performance of each of the actions is assessed in light of the defined objectives to determine the adaptation tipping point of the action. Once a set of actions seems adequate, potential pathways (that is, a sequence of actions) may be constructed, and one or more preferred pathways can subsequently be selected as input to a dynamic, robust plan. The aim of this plan is to stay on the preferred pathway as long as possible. Contingency actions for staying on the pathway are defined, and a trigger for each contingency action is specified and subsequently monitored (Kwakkel, Walker, and Marchau, 2010). The United Nations Educational, Scientific and Cultural Organization's Climate Risk-based Decision Analysis framework (Mendoza *et al.*, 2018) presents a unified approach to climate change risk management that couples decision scaling's approach to risk assessment with Dynamic Adaptation Policy Pathway's approach to adaptation. Robust optimization has also been integrated with Dynamic Adaptation Policy Pathways (Kwakkel *et al*., 2014).

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