Integrating Climate Change and Natural Disasters in the Economic Analysis of Projects

» A disaster and climate risk stress test methodology

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Contents

Acknowledgments

This guidance note on a methodology for integrating climate change and natural disasters in the economic analysis of projects was produced by Stephane Hallegatte, Rubaina Anjum, Paolo Avner, Ammara Shariq, Michelle Winglee, and Camilla Knudsen. Examples of the methodology applied to projects in four different sectors were prepared by Ammara Shariq (energy and transport), Rubaina Anjum (water), and Michelle Winglee (agriculture).

This guidance note is based on the work of a working group on the Resilience Rating System, which is led by Stephane Hallegatte, Veronique Morin, and Vladimir Stenek. Substantive inputs were received from: Suzana Abbott, Caspar Ammann, Margaret Arnold, Fatima Arroyo, Simone Balog-Way, Fatima Barry, Garo Batmanian, Anush Bezhanyan, Christian Borja-Vega, Greg Browder, Ana Bucher, Jack Campbell, Karan Capoor, Debabrata Chattopadhyay, Narae Choi, Viviane Clement, Fiona Collin, Mark Deinert, Caroline Devadason, Stephen Dorey, Coleen Dove, Xavier Espinet, Gregory Felter, Erick Fernandes, Francisna Fernando, Marc Forni, Ugo Gentilini, Christine Heumesser, Oscar Ishizawa, Anders Jensen, Pravin Karki, Oceane Keou, Nalin Kishor, Fabian Koehrer, Patricia Kristjanson, Ashok Kumar, Lisa Lau, Jia Li, Friederike Mikulcak, Ayah Mahgoub, Erkin Mamadaliev, Shomik Mehndiratta, Aurelio Menendez, Veronique Morin, Robert Mutyaba, Sean Nelson, Philippe Neves, Claire Nicolas, Samuel Oguah, Ninan Oommen, Angelica Parada, Karen Peffley, Leela Raina, Patrick Ray, Jun Rentschler, Kanta Rigaud, Julie Rozenberg, Nian Sadiq, Ommid Saberi, Amy Schweikert, Elham Shabahat, Sachin Shahria, Manu Sharma, Sundus Siddiqi, Natalya Stankevich, Ioannis Vasileiou, Yi Xu, Daniela Zingler, and Nkulumo Zinyengere.

Previous iterations of the methodology have benefited from comments from Timothy Brown, Barbara Buchner, June Choi, Joyce Coffee, Sarah Coll-Black, Fiona Collin, Mark Deinert, Willem Janssen, Ashok Kumar, Anne Kuriakose, Robert Lempert, Angelica Parada, Ujala Qadir, Kanta Rigaud, Jennifer Solotaroff, Asmita Tiwari, and the members of the Adaptation and Resilience Expert Group convened by the Climate Bonds Initiative.

As peer reviewers, Eric Dickson, Nathan Engle, Kulwinder Rao, and Iain Shuker provided invaluable suggestions and comments.

Lucy Southwood was the production editor. Brad Amburn designed the report.

The report and underlying work benefited from the guidance of John Roome and Bernice Van Bronkhorst, directors of the World Bank Climate Change Group.

Table of Acronyms

ANOVA	analysis of variance
ATAAS	Agricultural Technology and Agribusiness Advisory Services
BCR	benefit-cost ratio
CAPEX	capital expenditure
Cat 4–5	Category 4–5 cyclone
CBA	cost-benefit analysis
CCKP	Climate Change Knowledge Portal
CMIP	Coupled Model Intercomparison Project
EFA	economic financial analysis
GFDRR	Global Facility for Disaster Reduction and Recovery
IPCC	Intercontinental Panel on Climate Change
NPV	net present value
OPEX	operating expenditure
PAD	project appraisal document
PRIM	patient rule induction method
RCP	representative concentration pathway
RDM	robust decision making
RiST	Risk Stress Test
RRS	Resilience Rating System
SAIS	Sistemas Integrados de Agua Segura
SPEI	Standardized Precipitation Index
TC	tropical cyclone
TFP	total factor productivity

All dollar amounts are US dollars unless otherwise indicated.

1. Introduction

To maximize development gains, World Bank projects must consider climate change and disaster risks in their design and appraisal. Buildings could be exposed to heat waves, roads might be vulnerable to floods, and agricultural practices may be subject to drought and pests. Although projects can be simultaneously vulnerable to several such risks, in most cases, it is possible to design and implement projects that are resilient to future climate change and natural risks. Doing so, however, requires these risks to be considered at each step of the project cycle.

With growing attention to and awareness of climate change, an increasing share of project documents provide information on the exposure of the projects (and the assets they build or rely on) to risks, including through screening exercises. For example, all World Bank projects undergo a "disaster and climate risk screening" to identify possible threats at the early stages of project design. However, even when projects identify risks, the economic analysis provided to support a project's economic viability and desirability do not always consider the presence of natural risks. To select the best projects and ensure they deliver as expected, it is important to ensure that all project appraisal and assessment processes—including economic analyses—properly consider all risks.

This guidance note proposes a simple methodology for doing this by adding a stress test for climate change and natural disasters to the economic analysis of a project. Given the uncertainty on future climate change and its impacts, the lack of data (especially in low-income or fragile environments), and the complexity of the many interacting channels through which risk can affect a project, the methodology proposed here does not aim to predict or forecast the effect of climate change and natural disasters. If anything, doing so could create a false sense of certainty and overconfidence. Instead, it uses ranges for various impacts of climate change and disaster on a project's costs and benefits and identifies plausible risks for its viability and desirability. The goal is to help estimate the possibility and consequences of a project failing due to climate change or disaster to improve the quality of project design and provide important information to help decision makers assess project attractiveness and economic feasibility.

This stress testing methodology has been designed to highlight risks to project outcomes over long time horizons, accounting for risks along three dimensions:

1. Changes in average climate conditions
2. Impacts from natural disasters, with current frequency and intensity
3. Changes in the frequency of disasters due to changes in average climate conditions.[1]

The stress testing methodology described in this note is linked to the World Bank's Resilience Rating System (RRS) methodology and provides a tool (see RiST tool tip 1) and approach to obtain an A rating for **resilience *of* a project**, the first of two dimensions covered by the RRS (see World Bank Group 2021).

The results of this analysis should be considered a stress test of project robustness to ensure that future climate and natural disaster impacts do not make projects economically unviable. The purpose of the analysis is to assesses whether, under climate and natural disaster stressors, a project's net present value (NPV) or other indicators—such as benefit-cost ratio (BCR) or poverty or health-related monetary or nonmonetary metrics—remain above an acceptable threshold. The stress testing methodology presented in this guidance note helps task teams identify possible risks to the project, incorporate risk mitigation measures where necessary, provide a template for reporting on residual risk, and inform decision makers on project robustness.

RiST **TOOL TIP 1**

What is the risk stress test (RiST) tool?
The RiST tool is an Excel-based tool developed to help conduct the stress testing analysis described in this note. The tool provides a useful template and support for assessing risks from climate change and natural disasters, but the stress testing methodology can also be applied without use of the RiST tool. For a step-by-step breakdown of how to apply the RiST tool for incorporating climate and disaster risks in a project's economic analysis, please see the tutorial videos that accompany this note.

Caveats

This methodology can be applied to any project that has an economic analysis, but with some important caveats. First, it has been developed primarily to estimate the risks that climate change and disasters create for a project; for projects with risk reduction as their primarily objective, other tools and methodologies may better capture the benefits and co-benefits of risk reduction (Tanner et al. 2018).

The stress testing methodology explained in this note is meant to provide a simplified quantitative analysis to complement a project's existing economic analysis and highlight important considerations for improved resilience. It cannot, however, replace detailed engineering analysis when catastrophic failure is possible. In particular, projects whose failure could lead to catastrophic losses—for example, a large hydropower dam—should conduct a more sophisticated analysis than the one proposed here. Finally, the tool is designed for projects that do not already incorporate climate and disaster impacts in their economic analysis. If a project already accounts for some impacts, the tool can be used to enhance consideration of climate change and disasters, as long as impacts are not double counted.

1.1 • Document structure

This guidance note begins with a general overview of the stress testing methodology and is followed by an in-depth description of each step:

Overview

» **Section 2** provides an overview of the steps of the methodology and guidance for incorporating a project's main vulnerabilities in decision making. It also provides a template for reporting results.

Stress testing: Accounting for climate change and natural disasters in project costs and benefits

» **Section 3** describes the starting point—that is, an existing cost-benefit analysis that has not considered disaster and climate risks—and provides guidance on the necessary inputs for this assessment.

» **Section 4** discusses how to incorporate the impacts from changes in average climate conditions, such as a change in mean temperature or increased water scarcity.

» **Section 5** explains how to introduce impacts from disaster risks based on historical occurrence.

» **Section 6** discusses how to account for the impact of climate change on future extreme events and disaster occurrence.

Interpreting results and managing uncertainty

» **Section 7** focuses on managing uncertainty of climate change and disaster risks by analyzing multiple scenarios and identifying a switching scenario in which the project NPV or BCR may fall below an acceptable threshold.

» **Section 8** discusses how to incorporate uncertainty of project outcomes from other factors, such as socioeconomic trends or implementation risks, using optimistic and pessimistic baselines for a project's cost and benefit flows.

» **Section 9** explains how to use sensitivity analysis and RiST tool outputs to identify the main vulnerabilities and uncertainties that can affect the project.

» **Section 10** discusses key principles for selecting climate scenarios to account for uncertainty.

The note concludes with a list of useful resources in Appendix B, and four examples of applying the stress testing methodology and RiST tool to energy, transport, agriculture, and water sector projects in Appendices C–F. The RiST tool Excel files for each case study are published with this note.

2. In a nutshell: analysis, decision making, and reporting

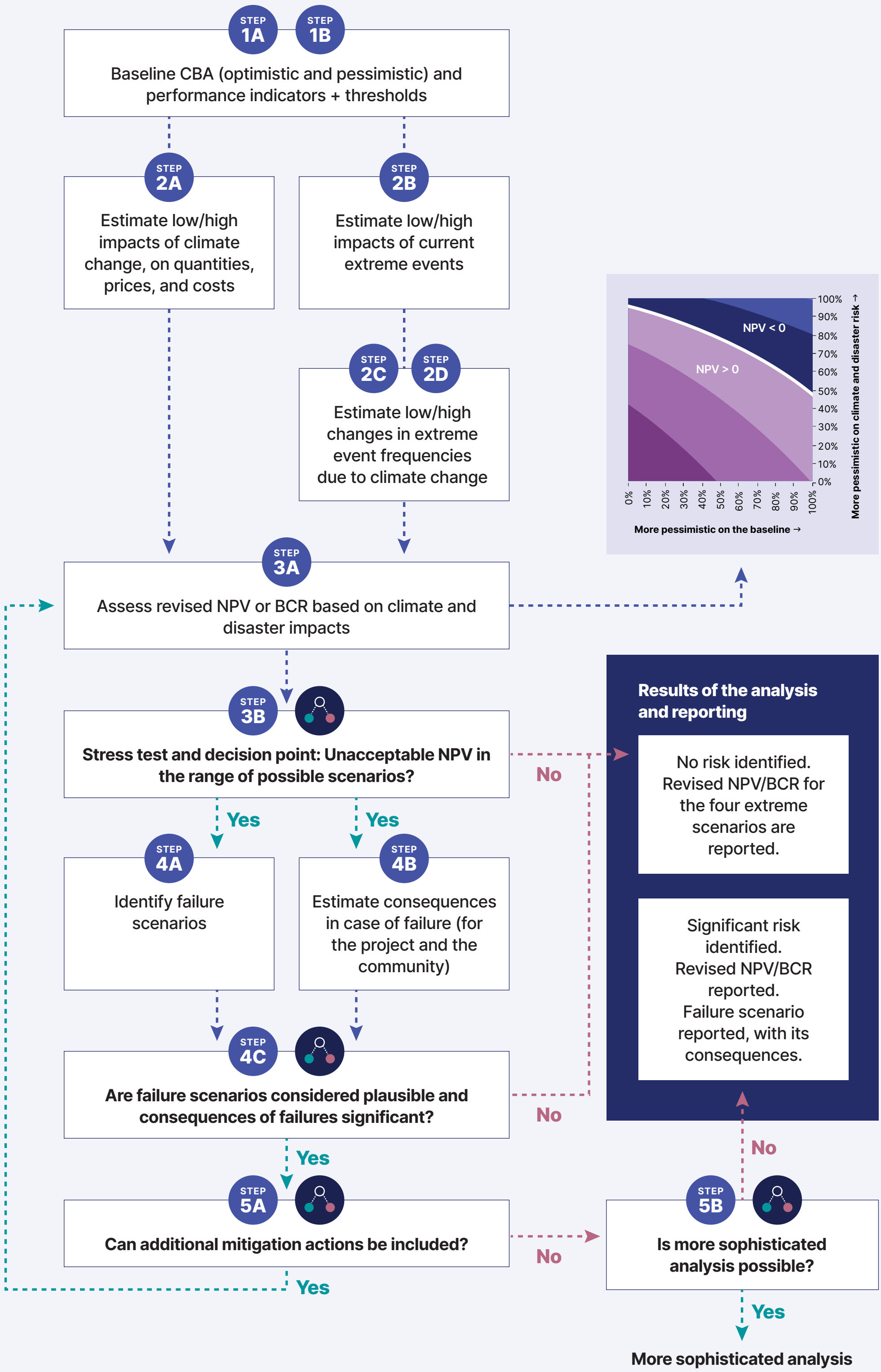
This section provides an overview of the stress testing methodology (figure 2.1), with detailed guidance on incorporating climate and disaster risks in decision making, and proposes a reporting template for project documents. Further details on implementing the steps can be found in sections 3 to 10. To properly disclose the results of a stress test (and achieve an RRS A rating for resilience of the project), project documents are expected to include all the information in the reporting template in Appendix A.

Step 1: The starting point: a "no climate risk" baseline analysis

STEP 1A **The analysis builds on a standard assessment of a project's cost and benefit flows—or a cost-benefit analysis (CBA)—that does not include impacts of natural disasters and climate change.** A CBA can have a single baseline, but it is preferable to consider (at least) two baseline scenarios, covering both optimistic and pessimistic scenarios of project implementation and outcomes. An optimistic scenario is generally used in a project's CBA while a pessimistic scenario—often included in a project's economic and financial analysis—accounts for implementation or socioeconomic risks, possibly leading to lower benefits and/or higher costs. For example, this could be a decline in expected benefits due to people adopting agricultural technology at a slower rate than expected or unexpected increases in project investment costs. The pessimistic scenario can be based on the sensitivity analysis in the existing CBA, or on a more sophisticated scenarios analysis.[2] See section 3 for more details on the baseline analysis and section 8 on the selection of optimistic and pessimistic baselines.

STEP 1B **To evaluate project performance, both in the baseline and climate change scenarios, the task team should identify one or more relevant performance indicators and thresholds for each indicator, indicating the minimum level of acceptable performance.** Typical performance indicators include NPV or BCR, but the task team may also decide to use nonmonetary performance indicators, such as water yield of a reservoir, gigawatts of energy produced in a hydropower facility, or an intervention's poverty implications. The threshold levels should be context- and project-specific, depending on country, region, sector, source of financing, and so on. In contexts with many development project opportunities where it is reasonable to ask for high returns, the task team may want to raise the bar and require, for example, that BCR > 1.2.

FIGURE 2.1 • Step-by-step overview of the stress testing methodology



Step 2: Assessing risks from climate change and natural disasters

STEP 2A **Sectoral guidance notes are used to estimate how future changes in average climate conditions may affect the outputs and costs of a project under otherwise normal conditions—that is, without considering extreme situations and events.** For each category of output that the project is expected to deliver, climate change can affect three primary dimensions: quantities produced, unit value of production, and unit production costs. For example, climate change may cause a decline in crop yields, a change in crop market prices, an increase in capital or operating expenditure (CAPEX or OPEX), or it may impact health or environmental externalities, by increasing soil erosion, improving breeding grounds for pests, or in some other way. The task team is expected to estimate a range of economic values for these impacts and consider, as a minimum, a low-impact and a high-impact scenario.[3] Best practice for a stress test is to incorporate the widest possible range of climate impacts, including very pessimistic estimates for large impacts, considering a project robust if it can succeed under such circumstances. For example, using at least five climate models and two representative concentration pathways (RCPs).[4] See section 4 for detailed information on estimating impacts from changes under average climate conditions and section 10 for guidance on selecting climate scenarios.

STEP 2B **The task team uses a climate hazard database, climate risk country profiles, and/or other location or sector-specific literature to identify the natural hazards that are relevant for the project.** For each of the identified hazards, low and high impacts on project costs and benefits are estimated based on disaster events with varying severity, using past events or modeling techniques. The task team should consider at least the 10- and 100-year return periods—that is, the impact of disasters that have a 10 or 1 percent chance of occurring or being exceeded each year. For projects with possible catastrophic outcomes, the task team should consider larger return periods, or smaller probability events. See section 5 for further details on estimating impacts from natural disasters based on historic occurrence.

STEP 2C **The task team estimates how climate change may affect the likelihood of hazards occurring.** They can estimate the change in frequency through modeling or expert opinion. The latter is often a good first step. Considering the large uncertainty of future extreme events, we advise using a wide range of possible values based on expert opinions in the analysis. See section 6 for further guidance on estimating changes in hazard return periods and section 10 for guidance on managing uncertainty. As in Steps 2a and 2b, the task team should consider, as a minimum, a low-impact and a high-impact scenario.

STEP 2D **If climate change is expected to significantly affect the costs (and not only the frequency) of extreme events, or if new types of extreme events are anticipated, then an additional step may be required.** This step would adjust the costs estimates from Step 2c, which describes a simplified approach where estimates of increased hazard frequency also serve as proxy for impacts from increases in the severity of an event. See section 6.2 for details.

Step 3: Revised performance estimates, stress test, and risks of failure

STEP 3A **The task team can assess the revised NPV and other performance indicators for a range of scenarios by varying the pessimism of the project baseline scenario (Step 1) and incorporating low versus high impacts of climate change and natural disasters (Step 2).** Standard outputs of the RiST tool include a sensitivity analysis that can highlight the types of climate risk that a project may be most vulnerable to, and a simple assessment of how the discount rate affects a project's NPV.[5]

STEP 3B **First decision point: If the NPV or another performance indicator value remains above the threshold level of acceptable performance (Step 1b) both in the pessimistic baseline and the high-impact climate scenarios, then the project is likely to be viable despite disaster and climate risks, especially if the team has considered very high-impact scenarios.**[6] We recommend that the task team includes the analysis results in the relevant project documents, thus giving decision makers both the initial and the revised estimates of the NPV for all scenarios and as a minimum for the four extreme scenarios (low/high climate impact and optimistic/pessimistic project baselines). Table 2.1 provides an example of a results matrix that includes NPV and BCR as performance indicators.

If the NPV or BCR "fails" or is below the acceptable level in some scenarios, then the analysis should continue to Step 4. For more detailed analysis of the different types of climate impact (including different types of hazard) and their impact on overall project performance, the task team can decide to continue to Step 4 even if the revised NPVs/BCRs are positive.

TABLE 2.1 • Sample results matrix

Adjusted NPVs and BCRs		Level of climate impact (Step 2)			
		Low		High	
		NPV ($, 1,000s)	BCR	NPV ($, 1,000s)	BCR
Baseline scenario (Step 1)	Optimistic	295	1.6	-32	0.95
	Pessimistic	99	1.2	-208	0.71

Note: The numbers in green indicate that, under a low climate impact scenario, the NPV and BCR remain above an acceptable threshold (NPV > 0 and BCR > 1). The numbers in red indicate that, under a high climate impact scenario, the project falls below acceptable thresholds (NPV < 0 and BCR < 1).

Step 4: Failure scenarios

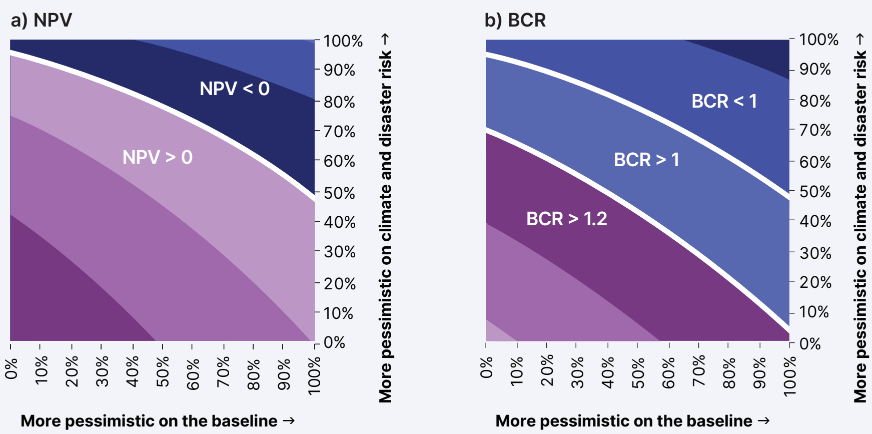
STEP 4A **Identifying the types of hazard or cost and benefit categories that can make a project "fail" can help task teams understand how to make their project more robust.** "Failure" here refers to a situation in which the project as a whole is not economically viable, where NPV < 0 or NPV and/or other performance metrics are below the threshold set in Step 1b. Box 2.1 has sample NPV and BCR maps that depict the range of possible outcomes for the switching scenario, above which the project risk is tolerable and below which the project "fails." The goal is to identify one or several climate change scenarios that lead to failure for different project baselines and determine (based on modeling or expert opinion) whether such a scenario is plausible or manageable. A qualitative estimate of likelihood and consequences can also be provided (see section 7.2).

BOX 2.1

Switching scenarios

This example shows how to present results as switching scenarios. The white line in figure B2.1.1 delineates the switching scenario between tolerable risk and "failure", denoted here as an NPV < 0 or BCR < 1). The horizontal axis depicts pessimism due to non-climate-related challenges that may affect the project—such as delays, government switchover, or procurement issues—while the vertical axis depicts pessimism due to climate and disaster risk. The graphs, which are a standard output of the RiST tool, show how different scenarios can be combined with different levels of climate change impact to result in failure. For example, panel (a) suggests that the project is vulnerable where non-climate factors are at 30 percent (with 0 percent representing the best-case scenario and 100 percent the worst-case scenario) and if climate impacts are high, at around 90 percent (with 100 percent representing the highest projected impacts). If the lines slant diagonally, it means that both baseline performance (non-climate factors) and climate impacts matter. If the lines are vertical, only non-climate factors are affecting the project. If they are horizontal, only climate and disaster risks are affecting the project.

FIGURE B2.1.1 • Sample NPV and BCR maps of the switching scenario



STEP 4B **The task team assesses the outcome in case of failure scenario, based on project performance—for example, in terms of NPV—and through a qualitative estimate of the broader effects on the community.** This could include implications for employment if the project is aborted or for public finance if infrastructure maintenance costs unexpectedly increase due to climate change. The objective is to make a difference between a marginal project that can fail without systemic effects, and projects that are "too big to fail" and require high resilience standards.

STEP 4C **Second decision point: If the switching scenarios appear excessively improbable—that is, the project might only fail in an extreme case of high climate impacts and pessimistic project outcomes—or if the consequences of failure appear manageable, then the project can remain acceptable, and the analysis can stop.** In this case, task teams must report the analysis results in the project documents to give decision makers:

» An NPV or BCR for the extreme scenarios (low/high-impact climate impact; optimistic/pessimistic baseline)

» A description of one or several switching scenarios, the consequences of "failure", and a narrative explaining why such scenarios are implausible (enough) or why consequences of failure are manageable.

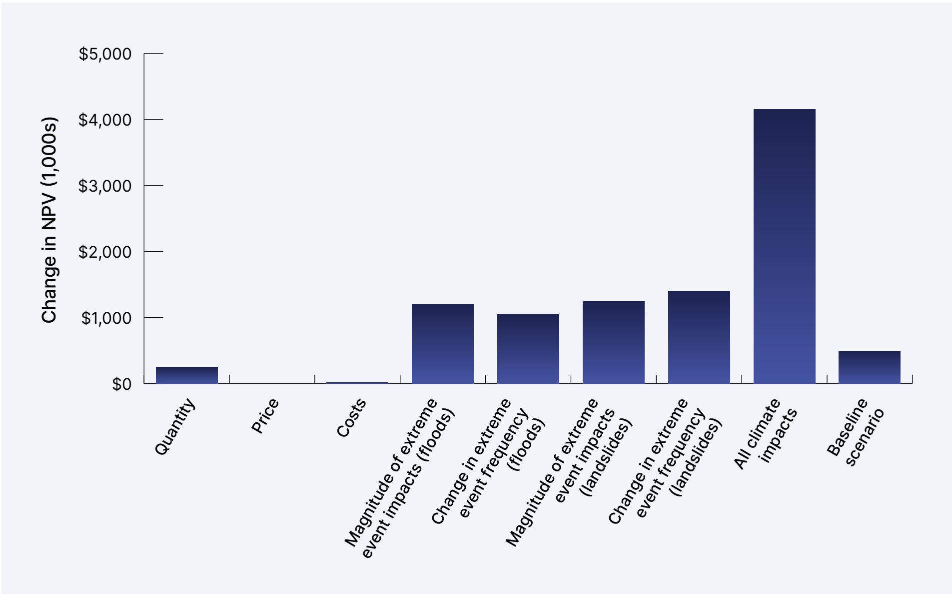
If the switching scenario appears plausible and consequences are serious, then the analysis should continue to Step 5.

Step 5: Redesign, further analysis, or reporting

STEP 5A **If the switching scenarios appear plausible and their consequences inacceptable or unmanageable, the task team should revisit the project design to investigate whether they can introduce additional risk reduction measures.** The task team can be guided by the results of the sensitivity analysis, since it identifies the factors that are most likely to lead to a reduction in NPV or BCR (figure 2.2). After reevaluating the design, the analysis can restart from Step 1.

Presenting results through a sensitivity analysis. A sensitivity analysis can help developers understand the impacts of each parameter, where the greatest vulnerabilities may be, and the role of the discount rate. Figure 2.2 illustrates an output of the RiST tool where the sensitivity analysis shows that the impacts and frequency of extreme events are the most important factors, suggesting that this is where opportunities lie for making the project more robust.[7] Depending on whether the project incorporates risk management measures and the cost of climate impact, the NPV under each disaster scenario may rise or fall, reflecting the disaster a project may be most vulnerable to and the benefits of risk management measures.

FIGURE 2.2 • Sensitivity analysis and the importance of various drivers



STEP 5B

If no additional risk reduction measure or design adjustment is possible or realistic, then the task team can decide to:

» Run more sophisticated analyses (which may lead to more optimistic results and rule out some of the identified threats to the project viability), or

» Conclude the analysis and ensure that project documents report on the significant residual disaster and climate risk to the project, leaving it to decision makers to decide whether it is acceptable, considering the context and their tolerance to risk. In this case, the project documents must report:

- The NPV or BCR for extreme scenarios (low/high climate impact; optimistic/pessimistic project baseline)
- A description of one or several switching scenarios and their possible consequences.

3. The starting point: a standard cost-benefit analysis

This section outlines how information from a standard CBA provides the baseline scenario to account for climate and disaster risks. For the purposes of this guidance note, we assume that the task team has produced a standard assessment of the annual flow of costs and benefits *with* the project, compared to a scenario *without* the project.[8]

The assumption is that the initial economic assessment makes no consideration of natural hazards or climate change. If the project design includes some adaptation activities, such as introducing drought-resistant seeds, the stress testing methodology presented here can still be applied. If, however, future climate or hazard impacts, such as decreased crop yield resulting from changes in precipitation, are already included in the project's economic analysis, those impacts should not be incorporated in the analysis proposed here to avoid double-counting.

A standard CBA estimates the discounted sums of costs and benefits over the lifetime of the project and calculates either the NPV (as the benefits minus the costs) or the BCR (as the benefits divided by the costs).[9] If NPV > 0, then the project delivers net benefits and is economically viable. More information on the choice of the discount rate "ρ" is available in the *Discount Rate Technical Note*.[10]

$$NPV = \sum_{\text{starting date, } y=0}^{\text{asset lifetime}} \frac{1}{(1+\rho)^y} [\text{Benefit}(y) - \text{Cost}(y)]$$

3.1 • The baseline flows of costs and benefits

The inputs for this analysis should be a timeseries of the costs and benefits, from the beginning of project implementation to the end of project outcomes over the project's lifetime. This could be, for example, the lifetime of the assets that are built, or the lifetime of the impacts expected from a new institution or social protection program. The analysis time horizon must be consistent with the impact of the project, even if those impacts exceed the lifetime of the project or assets. For example, it is well documented that the impact of a new transport infrastructure on land use and urbanization can extend beyond the lifetime of the infrastructure itself.

RiST **TOOL TIP 2**

Enter the baseline scenarios in the green-highlighted "Baseline scenario" tab. If adding more rows to the tables, make sure to make corresponding changes in other tabs.

The analysis should consider two baselines: an optimistic scenario in which the benefit and cost flows reflect the planned implementation and outcomes of the project, and a pessimistic baseline that accounts for non-climate-related uncertainty. This might include an increase in the price of goods to be procured, a change in labor costs, a delay in implementation, and other development challenges that may interact or be compounded by risks from climate change. The costs and benefits for the pessimistic project scenarios can be provided in a project's economic analysis if the sensitivity analysis appropriately accounts for a combination of possible negative impacts on cost and benefit flows.

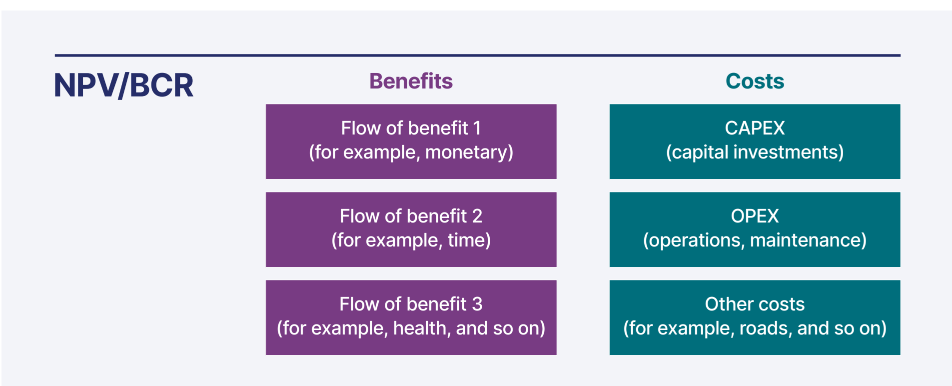
Ideally, the different cost and benefit categories are represented in gross rather than net form and are clearly itemized to reflect different benefit categories—monetary, health, and so on. Itemized cost and benefit flows enable the analysis to better assess the impacts of climate change, since the impacts may affect the various components of the cost and benefit flows differently.

For built infrastructure, for example, it often makes sense to separate costs into three categories (figure 3.1):

- **Cost-CAPEX (year):** series of capital investments
- **Cost-OPEX (year):** series of operation and maintenance costs
- **Cost-Other (year):** series of other costs or externalities—for example, for a road, the social cost due to traffic accident and air pollution.

Similarly, benefits can be broken down into components that correspond to different categories, such as financial and economic benefit, health benefits, and lives saved (figure 3.1), or different products—for example, when an agriculture project plans to produce both corn and pecan. An irrigation and water supply project, for example, could have two categories of benefit: (1) from yield increases (economic) and (2) from improved potable water availability (health).

FIGURE 3.1 • Illustration of the costs and benefits leading to a NPV or a BCR



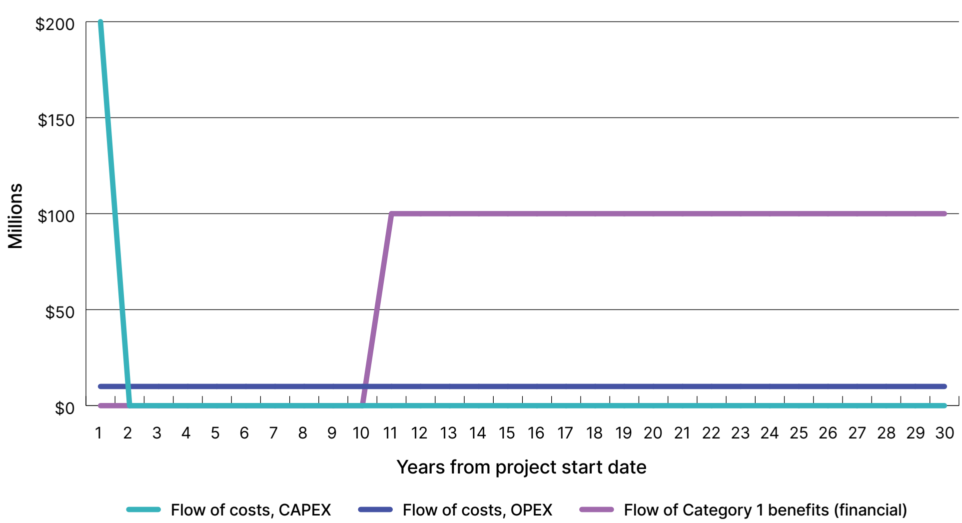
The analysis should consider "with project" and "without project" scenarios: In some cases, such as greenfield (new infrastructure) projects, the "without project" scenario is simple, as it corresponds to a zero-cost, zero-benefit scenario, and the analysis can be done on the "with project" scenario only. In other cases, such as brownfield projects that build on existing infrastructure, the "without project" scenario is more complicated. For example, when a project retrofits and enhances a road, the "without project" scenario may include existing costs and benefits for the existing infrastructure, while the "with project" scenario accounts for a different flow of costs and benefits. In these cases, the analysis needs to be done twice—with and without the project. When costs and benefits in each scenario have been aggregated already and only the net costs and benefits from the project are available, introducing climate and disaster risks can be challenging or even impossible. In this case, it is necessary to get back to the original data from the economic analysis.

3.2 • Illustration: forestry project example

Throughout this guidance note, we use a hypothetical forestry project to illustrate the stress testing methodology, and to exemplify the use of the RiST tool. For simplicity of exposition, we consider here a single baseline and will reintroduce the second baseline in section 8. In this case, the "without project" scenario is simple, as it corresponds to a zero-cost, zero-benefit scenario.

This hypothetical project aims to plant one species of tree, with an initial CAPEX cost of $200,000, a maintenance/OPEX cost of $10,000, an annual flow of benefit of $100,000 after 10 years, and a time horizon until 2050 (figure 3.2). In the economic analysis, the discounted costs (with a 6 percent discount rate) are $346,000 and the discounted benefits are $678,000. The NPV is $333,000, and the BCR is almost 2.

FIGURE 3.2 • Baseline flow of project costs and benefits (undiscounted)



This section has detailed the aspects of a standard CBA that are needed to inform this analysis. The following chapters detail a simple methodology to introducing climate change and natural disasters into those series of costs and benefits, and a framework to identify the necessary data and modeling results. It does so by separating the changes in average conditions from the occurrence of extreme events (with return periods ranging from 2 to 1,000 years).

For simplicity and clarity of exposition, sections 4 to 7 will consider the addition of climate and disaster risks into a single baseline. In section 8, we reintroduce the second baseline for a better consideration of all uncertainties.

4. Introducing changes in average conditions

Changes in average conditions can play a key role, especially in sectors that are highly sensitive to environmental conditions like agriculture, forestry, water management and hydropower, thermal power generation (with its cooling needs), energy demand, or tourism. Climate change will affect the flows of costs and benefits in different ways, which are specific to each type of project.

TOOL TIP 3

Enter the impact of change in average climate conditions in table 2a of the green-highlighted "Climate impacts" tab.

4.1 • Impact on the costs and benefits of the project

Climate change may affect the flow of CAPEX during the project's lifetime in several ways—for example, if additional reinvestment or retrofit is required, if an agricultural project that is viable now requires additional irrigation and supplementary CAPEX investment in the future due to reduced rainfall, or if a road project requires resurfacing with different materials in 20 years. It could also affect:

- **The flow of OPEX**—for example, more rainfall can increase the cost of road maintenance, lower rainfall can increase energy costs linked to water pumping for irrigation, and higher wildfire risks require better forest maintenance around transmission lines or higher recurrent cost for a commercial forest

- **Other components of costs, in ways that will be specific to the type of cost**—for example, higher temperatures tend to increase local air pollution, which may increase costs associated with the pollution created by an energy or transport infrastructure

- **The value of the benefit by affecting how much benefit the project produces**—for example, reduced rainfall and higher temperature can decrease future agricultural yields, or increased temperature can force the reduction of train speed

- **The unit price of the project output**—for example, most global agricultural models project an increase in global food prices due to climate change, making any agricultural production more valuable.

4.2 • Estimating impacts

Considering the large uncertainty in future climate scenarios and their impacts, using a range of possible values instead of a best guess is crucial. A best guess may hide a large vulnerability in the project if climate change differs from the most likely scenario, and climate models contain a large degree of uncertainty. Here, we label the two extreme scenarios of the range as low and high impact. However, in cases where climate change leads to benefits, the largest benefits are better included in the low-impact scenario, keeping the high-impact scenario for the most pessimistic case. See section 10 for more information on handling uncertainty and selecting climate change scenarios.

Estimates for the physical impacts of climate change—for example, the impact of higher temperature on tree growth—are project and sector-specific and cannot be derived from a generic multisector tool. Instead, they require sectoral knowledge and/or sector-specific tools and models. Appendix B provides a list of generic resources on disaster risk and climate change, and a list of sector-specific resources to inform physical impact assessments.

RiST **TOOL TIP 4**

The quality of inputs to the analysis will determine the quality of results, so it is important to document the type of information that estimates are based on. Below is a suggested color guide for all tool inputs.

COLOR	DESCRIPTION
GREEN	Estimate is supported by data sources/studies that are relevant to the project location and timeframe.
YELLOW	Estimate is supported by data sources/studies that have been conducted for a similar location/region.
ORANGE	Estimate is supported by data sources/studies and trend extrapolation.
BLACK	Estimate is based on inputs from a technical/regional expert.
RED	Estimate is based on tool user knowledge.

Where to find the data

climateknowledgeportal.worldbank.org

Estimates of future changes in average weather conditions are available in the Climate Change Knowledge Portal (CCKP). To access information on projected changes in temperature and precipitation, click **Download Data** and select **Projections**. Here, the user can select the emissions scenario—for example, RCP 6.0 for a medium-high emissions scenario and RCP 2.6 for a low emissions scenario—the relevant time period, and the country of interest or, for location–specific data, enter the coordinates (latitude and longitude) of the relevant location. For visual representations of this data, navigate to the country of interest and click on **Climate Data > Projections** in the navigation bar. To access specific indicators on temperature and precipitation—for example, monthly temperature or days with more than 20mm rainfall—go to the **Variable** drop-down menu.

Available variables also include sector-specific indicators for agriculture, water (drought), energy, and health. The user can further select the climate model. The default climate model is a multi-model ensemble of Coupled Model Intercomparison Project, Phase 5 (CMIP5) global climate models (see box 10.1). Figure 4.1 shows the projected change in monthly temperature for South Africa with the 10–90 percentile range. To access national-level projections or location-specific data, click on the visual heat mapping tool in CCKP (figure 4.2).

FIGURE 4.1 • Projected change in monthly temperature for South Africa (2040–2059)

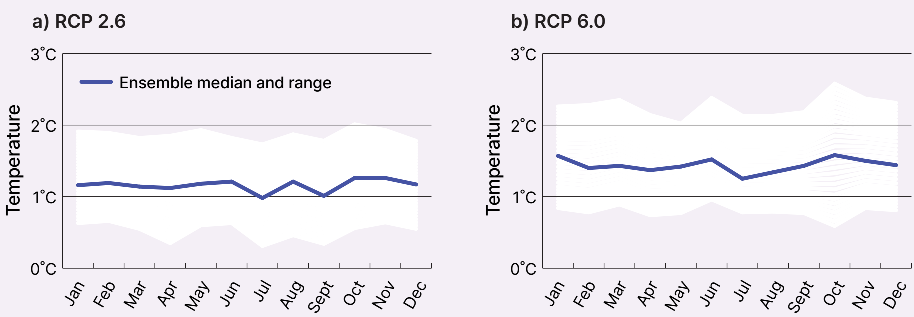


FIGURE 4.2 • Projected change in monthly temperature for South Africa (2040–2059, compared to 1986–2005)

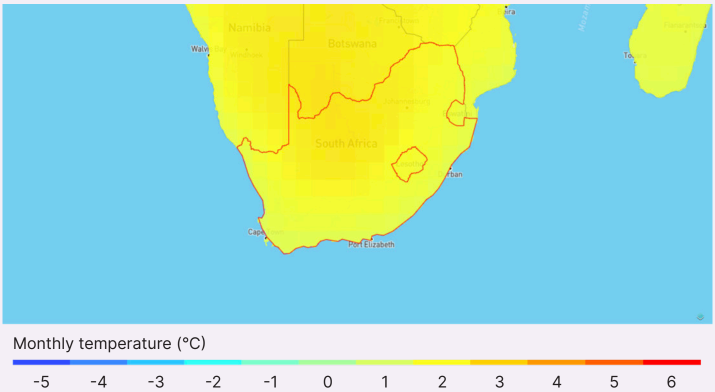


Table 4.1 and box 4.1 provide a simple approach to introducing the range of possible impacts of changing average climate conditions into a project CBA. The RiST tool uses the information in table 4.1 to interpolate the expected changes for every year between a project's start and completion dates and to calculate revised NPV or BCR values (using the equations in box 4.1). Informing table 4.1 is context-specific and should therefore take place at sector level. From table 4.1 and using the equations from box 4.1, it is possible to estimate the effect on the flows of costs and benefits to estimate a revised NPV or BCR of the project in low- and high-impact scenarios (see section 4.3 for a hypothetical forestry example).

TABLE 4.1 • Expected change (percentage or absolute) in average climate conditions under different climate scenarios

Project parameters	Benefits and costs categories	2030		2050		2100	
		Low-impact scenario	High-impact scenario	Low-impact scenario	High-impact scenario	Low-impact scenario	High-impact scenario
Expected change in quantity produced (e.g., corn yield)	Category 1 benefits (e.g., financial)						
	Category 2 benefits (e.g., saved time)						
	Category 3 benefits (e.g., health)						
Expected change in supply price/ value (e.g., unit corn price)	Category 1 benefits (e.g., financial)						
	Category 2 benefits (e.g., saved time)						
	Category 3 benefits (e.g., health)						
Expected change in operational or production costs	CAPEX						
	OPEX						
	Other (e.g., health)						

RiST

TOOL TIP 5

Inputting the table 4.1 values in the RiST tool will directly obtain the change in the flows of costs and benefits, and the revised values of the NPV and BCR. Make sure that the cost and benefit rows correspond directly to the cost and benefit rows entered in the "Baseline scenario" tab.

BOX 4.1

Calculations for introducing average climate changes into the CBA

This box summarizes how to introduce the impacts from table 4.1 into the CBA calculation:

- ΔQ (category, year, low or high impact): change in quantity produced (%)
- ΔP (category, year, low or high impact): change in price of production (%)
- ΔCAPEX (year, low or high impact): change in CAPEX (%)
- ΔOPEX year, low or high impact): change in OPEX (%)
- ΔOtherCost (year, low or high impact): change in other (out-of-project) costs (%)

Note: These changes are expressed in percentage change of the no-climate-change baseline, but it may be preferable to do it in absolute terms—for example, if CAPEX in 2030 goes from zero to a non-zero value.

The flow of costs and benefits can then be adjusted:

- RevisedBenefit (category, year, low or high impact) = Benefit (category, year) *(1 - ΔQ (category, year, low or high impact))*(1 + ΔP(category , year, low or high impact))
- RevisedCostCAPEX (year, low or high impact) = CostCAPEX(year) * (1 + ΔCAPEX (year, low or high impact))
- RevisedCostOPEX (year, low or high impact) = CostOPEX(year) * (1 + ΔOPEX (year, low or high impact))
- RevisedCostOther (year, low or high impact) = Cost-Other(year) * (1 + ΔOtherCost (year, low or high impact))

4.3 • Illustration: forestry project example

How to include changes in average climate conditions: In this section, all numbers are illustrative but for a real project we can use a range of climate models to estimate the possible impacts of climate change on quantity produced and thus the flow of benefits (table 4.2, row 1). These estimates use expected tree growth in different climates, based on a forestry model.[11] Based on global models, one can also estimate the impact of climate change on the future price of timber. For example, timber prices may grow 2–4 percent by 2030 and 4–6 percent by 2050 because of climate change and the impact on global forest productivity (table 4.2, row 2). The change in climate could also make it necessary to increase maintenance costs to prevent fires and due to an increased pest prevalence (see table 4.2, row 3 for estimated projections).

TABLE 4.2 • Expected change in yield, price, and OPEX for a hypothetical forestry project

Project parameters	2030		2050	
	Low-impact scenario	High-impact scenario	Low-impact scenario	High-impact scenario
1. Expected change in yield	-5%	-10%	-10%	-20%
2. Expected change in price	2%	4%	4%	6%
3. Expected change in OPEX	2%	10%	50%	100%

Note: The color coding reflects the data source for estimates. Green means that the estimate is supported by data sources/studies that are relevant to the project location and timeframe; orange that the estimate is supported by data sources/studies and trend extrapolation; and black that the estimate is based on inputs from a technical/regional expert (see also RiST tool tip 4).

Results: Based on these inputs, we would expect the discounted costs to increase from $346,000 to $362,000–382,000; the discounted benefits to decrease from $678,000 to $648,000–601,000; the NPV to be between $227k and $286k, and the BCR between 1.6 and 1.8. At this stage of the analysis, considering only the expected impacts of the change in average climate, the project remains viable.

5. Introducing natural hazards and disasters

> **TOOL TIP 6**
>
> Enter the impacts of up to three natural hazards in tables 2bi, 2bii, and 2biii in the green-highlighted "Climate impacts" tab.

As well as changes in average climate conditions, projects are vulnerable to extreme events, and project CBAs and assessments of climate change impacts need to take them into account. Many models focus on changes in average conditions, which makes it easier to treat extreme events separately. However, it is important to ensure there is no double counting. To do this, we must first include natural hazards based on current conditions. This section outlines the steps the task team should go through to measure the impact of natural disasters on the economics of a project.

5.1 • Identifying relevant hazards for a project or activity

Different projects will be exposed to different types of risk, based on their sector and localization. Identifying the hazards that a project may be exposed to is an important first step towards incorporating impacts from disaster risks in the economic analysis.

5.1.1 • Selecting return periods

Next, the task team will need to select a set of return periods for all relevant hazards. These range from very frequent hazards with a 2-year return period or 50 percent annual probability of occurrence to extremely rare hazards with a 1,000-year return period or 0.1 percent annual probability of occurrence. Of course, the return period selected can depend on the project type. A small project with limited risks, for example, does not need to consider a 1,000-year event, but it would be crucial for a large-scale hydropower dam or urban coastal protections to do so. The selection can be based on expert opinion or guided by table 5.1, which provides the likelihood of a 20- or 50-year asset being affected by 10-, 100-, and 1,000-year events.[12] It shows that even an extremely rare event like a 1,000-year flood has a 5 percent chance of affecting a 50-year asset over its lifetime.

TABLE 5.1 • Return periods of natural hazards and their likelihoods of affecting an asset

Return period of event	Likelihood of affecting the asset (%)	
	Asset with a 20-year lifetime	Asset with a 50-year lifetime
10-year	88%	99.5%
100-year	18%	40%
1,000-year	2%	5%

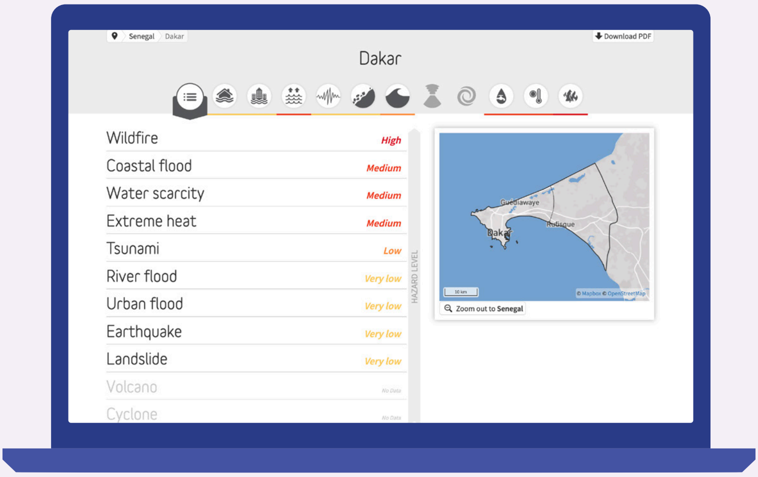
Where to find the data

thinkhazard.org

The ThinkHazard! database (https://thinkhazard.org/), developed by the World Bank Global Facility for Disaster Reduction and Recovery (GFDRR), provides historic national and subnational-level hazard ratings. These are rated as *high*, *medium*, *low*, or *very low*, based on the likelihood of the hazard exceeding predefined thresholds. The ThinkHazard! database can, therefore, help task teams identify key risks that a project may be exposed to, such as extreme heat, water scarcity, flooding, earthquakes, landslides, tsunamis, cyclones, and wildfires. Figure 5.1 provides an example of the natural hazards identified for Dakar, Senegal.

We recommend including all hazards ranked *high* in the economic analysis. If possible, all *high* or *medium* risks should be included, when relevant for the project. Note that the identification of climate-related risks and key hazards should be done with knowledge of the project and sector—for example, wildfire, listed as a high risk in figure 5.1, would not be relevant for a water project in Dakar. Sector-specific resources (Appendix B) and a literature review can be used to identify which hazards are relevant as a function of the project type.

FIGURE 5.1 • Snapshot of natural hazards for Dakar, Senegal from the ThinkHazard! database



5.1.2 • Assessing the expected scale and intensity of an event

Depending on data and model availability, the probability, scale, and intensity of an event at a given return period can be assessed using historical data. A simple approach might identify the largest flood in the last 100 years as an indication of the scale of a 100-year flood. A more complicated approach could use models or methodologies such as calibrating a generalized extreme value distribution based on 100 years of data. Task teams must be aware that historical data (or models calibrated on historical data) are an imperfect measure of current hazard level because hazards are changing fast in response to climate change and other environmental changes such as urbanization, deforestation, and infrastructure development. The ThinkHazard! database provides access to hazard maps from global models for many hazard types, while the CCKP provides scenario information for various extreme event indicators, such as intense rainfall or extreme temperature.

5.2 • Assessing the consequences of an extreme event

There are three main categories for assessing expected impacts for selected hazards and return periods:

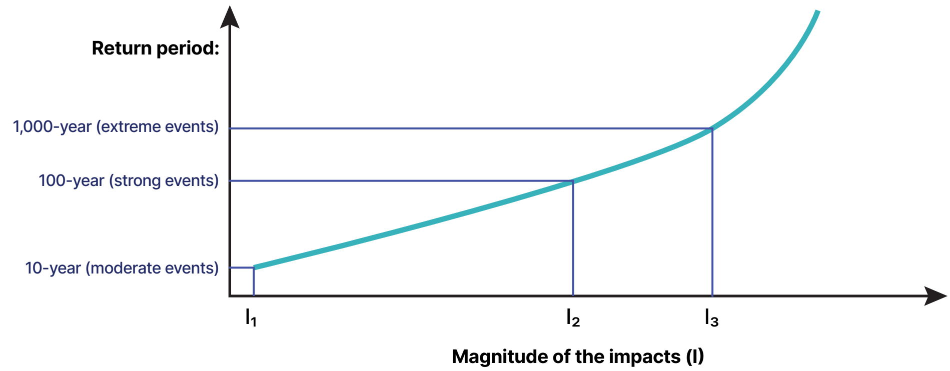
» **Repair and reconstruction costs:** These can be expressed in an absolute amount or as a percentage of full reconstruction value. Vulnerability curves link an event's physical characteristics and repair costs for many sectors, including buildings, roads, transmission and distribution infrastructure, agriculture, and forestry. For instance, if a road is flooded by more than 1 meter of water, the repair cost is around 15 percent of the initial construction cost. In table 5.2, this parameter is called *ShockRepair* and expressed as a monetary unit.

» **Loss of production:** Repair and reconstruction can take weeks, months, or even years, so it is important to consider loss of production during this time. It can be expressed as a fraction of annual production, or in duration of the full interruption of production. For example, if a road takes six months to be repaired after being destroyed by a flood, then 50 percent of its annual "service" will be lost, on top of repair costs. In table 5.2, this parameter is called *ShockServiceLoss* and expressed as percentage of annual production.

» **Out-of-system impact:** It is also important to account for the costs of natural disaster impacts when they affect more than the project outputs themselves. For example, an outage in a power generation unit generates lost revenues due to reduced electricity sales, but does not cover the full cost of a power outage. The real social cost, taking into account effects on firms and households, is at least twice as large (Hallegatte et al. 2019). In table 5.2, this parameter is called *ShockOutofSystemLoss* and expressed as a monetary unit.

The task team should describe each hazard by a curve that represents the relationship between the magnitude of the impacts to the probability of occurrence (figure 5.2). The higher the magnitude, the lower the probability of occurrence, and the higher the return period. In most cases, it is possible to represent the full curve with two to four events. Figure 5.2 has three, corresponding to moderate (10-year), strong (100-year), and extreme (1,000-year) storms.

FIGURE 5.2 • The relationship between the magnitude of the impacts and the probability of occurrence (or return period)



Note: Impacts can be measured in both monetary and nonmonetary units—for example, losses in $ or fraction of fallen trees.

For each of the hazards identified, the task team should complete table 5.2, using at least two return periods, and then use these values, with the equations in box 5.1, to calculate a revised NPV and BCR.

If there are multiple threats—for example, if a forestry project is vulnerable to hurricanes, droughts, and pests—then the process should be repeated for each threat. It is possible to summarize all threats into one table, but combining different hazards with different return periods into a single period is not straightforward and depends on spatial and temporal correlation across events, so we recommend keeping different hazards separated.

TABLE 5.2 • Inputs needed to introduce natural hazard costs into a CBA

Frequency of event	Low-impact scenario	High-impact scenario
Recurrent (1-in-2 year)		
Repair/reconstruction cost (ShockRepair, $)		
Impact on quantity produced (ShockServiceLoss, % of yearly output)		
Additional out-of-system impacts (ShockOutofSystemLoss, $)		
Moderate (1-in-10 year)		
Repair/reconstruction cost (ShockRepair, $)		
Impact on quantity produced (ShockServiceLoss, % of yearly output)		
Additional out-of-system impacts (ShockOutofSystemLoss, $)		

Strong (1-in-100 year)		
Repair/reconstruction cost (ShockRepair, $)		
Impact on quantity produced (ShockServiceLoss, % of yearly output)		
Additional out-of-system impacts (ShockOutofSystemLoss, $)		
Extreme (1-in-1,000 year)		
Repair/reconstruction cost (ShockRepair, $)		
Impact on quantity produced (ShockServiceLoss, % of yearly output)		
Additional out-of-system impacts (ShockOutofSystemLoss, $)		

BOX 5.1

Equations to introduce natural hazard costs into a CBA

Calculating the expected annual cost for repairs and reconstruction can be based on the values for the four return periods (2 to 1,000 years):

ExpectedShockRepair=

$$\frac{1}{1{,}000}\ \text{ShockRepair}\ (1{,}000) + \sum \left(\frac{1}{RP_{i+1}} - \frac{1}{RP_i} \right) \text{ShockRepair}\ (RP_i)$$

And similarly, for the two other dimensions of the cost of natural disasters:

ExpectedShockServiceLoss=

$$\frac{1}{1{,}000}\ \text{ShockServiceLoss}\ (1{,}000) + \sum \left(\frac{1}{RP_{i+1}} - \frac{1}{RP_i} \right) \text{ShockServiceLoss}\ (RP_i)$$

ExpectedShockOutofSystemLoss=

$$\frac{1}{1{,}000}\ \text{ShockOutofSystemLoss}\ (1{,}000) + \sum \left(\frac{1}{RP_{i+1}} - \frac{1}{RP_i} \right) \text{ShockOutofSystemLoss}\ (RP_i)$$

Based on the results from table 5.2, the expected benefits and costs can then be adjusted with the following rules:

- **WithTodaysHazardBenefit(year, low- or high-impact) =**
  RevisedBenefit(category, year) *(1 – ExpectedShockServiceLoss) (year, low- or high-impact)
- **WithTodaysHazardCostCAPEX (year, low- or high-impact) =**
  RevisedCostCAPEX(year) + ExpectedShockRepair (year, low- or high-impact)
- **WithTodaysHazardCostOther(year, low- or high-impact) =**
  RevisedCostOther(year) + Expected ShockOutofSystemLoss (year, low- or high-impact)

An alternative approach is to start from the impacts and estimate the probability of occurrence, rather than start from a few return periods and estimating the impacts. In this approach, the task team could estimate the impacts and probabilities of occurrence of earthquakes of different magnitude or a flood that can overtop coastal defense. In most cases, civil engineers would estimate the impacts while geoscience experts would estimate the probabilities of occurrence. Using this approach, the task team would need to complete table 5.2 and adjust the probability of occurrence or return period.

5.3 • Illustration: forestry project example

We assume that the forest project is vulnerable to high wind and that this is the only hazard the project is exposed to. High wind can damage the trees, thereby leading to production losses. The numbers in table 5.3 indicate the impact of repair and construction costs, loss of production, and out-of-system impacts for four different return periods and low- and high-impact climate scenarios.

How to include impacts from natural disasters: For the 2-year return period, the quantities lost are around 1–2 percent, and the costs of responding to the event are limited—for example, removing a few trees that fall on roads, with a total cost of $1,000–2,000 in operational costs and $5,000–10,000 for the consequences of road closures. At the other extreme, a 1,000-year wind event would damage multiple trees, equivalent to 50–100 percent of annual production. If 5 percent of trees are harvested each year, 2.5–5 percent of all trees would be down after the storm. There would then be $100,000 costs to remove the dead trees, and the impact of road closures and power lines being struck by falling trees on the economy would reach $100,000–200,000 (table 5.3).

TABLE 5.3 • Inputs needed to introduce natural hazard costs into a CBA

Frequency of event	Low-impact scenario	High-impact scenario
Recurrent (1-in-2 year)		
Repair/reconstruction cost (ShockRepair, $)	$1,000	$2,000
Impact on quantity produced (ShockServiceLoss, % of yearly output)	-1%	-2%
Additional out-of-system impacts (ShockOutofSystemLoss, $)	$5,000	$10,000
Moderate (1-in-10 year)		
Repair/reconstruction cost (ShockRepair, $)	$5,000	$10,000
Impact on quantity produced (ShockServiceLoss, % of yearly output)	-2%	-5%
Additional out-of-system impacts (ShockOutofSystemLoss, $)	$20,000	$40,000
Strong (1-in-100 year)		
Repair/reconstruction cost (ShockRepair, $)	$1,000	$20,000
Impact on quantity produced (ShockServiceLoss, % of yearly output)	-20%	-40%
Additional out-of-system impacts (ShockOutofSystemLoss, $)	$50,000	$100,000

Extreme (1-in-1,000 year)		
Repair/reconstruction cost (ShockRepair, $)	$100,000	$200,000
Impact on quantity produced (ShockServiceLoss, % of yearly output)	-50%	-100%
Additional out-of-system impacts (ShockOutofSystemLoss, $)	$100,000	$200,000

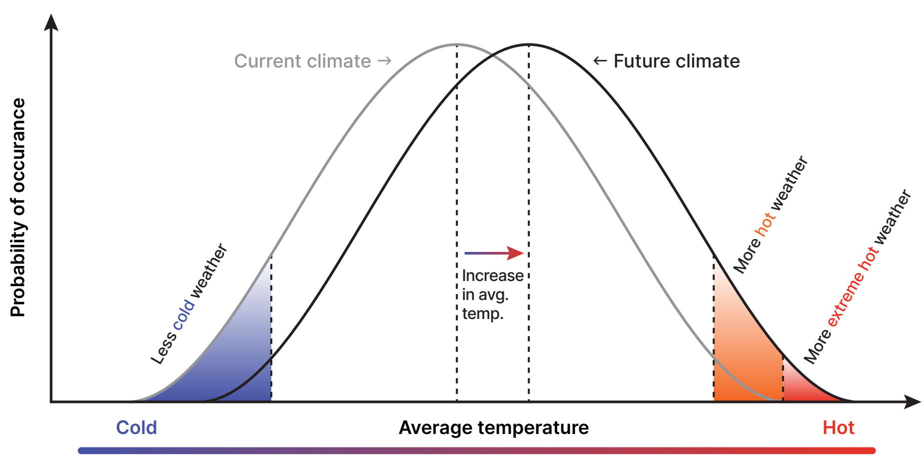
Results: With these assumptions, we find that the discounted costs increase from $362,000 to $456,000 in the low-impact scenario and from $382,000 to $571,000 in the high-impact scenario. With discounted benefits dropping respectively from $648,000 to $643,000 and from $610,000 to $600,000, the NPV drops to either $187,000 or $28,000, with BCR between 1.4 and 1.1. At this stage of the analysis, the project remains viable, even in the high-impact scenario. However, its NPV in the high-impact scenario is close to zero (and the BCR is close to one), highlighting a vulnerability of the project. Since there are probably other relevant hazards—say, drought or pests that are sensitive to climate and environmental conditions—the task team will need to revise the costs and benefits of all the relevant hazards.

6. Introducing the effect of climate change on natural hazards and disasters

Since the frequency, intensity, duration, and spatial extent of natural hazards are expected to vary quickly, it is crucial to take those changes into account (figure 6.1 and box 6.1). However, this is also challenging, because the severity of a natural event cannot be measured by a single number—for example, loss through drought depends on its intensity (that is, how much rainfall has dropped below normal values), its duration and its spatial extent. Climate change can make some of the determinants of severity change in different directions, making it difficult to represent the effect on extreme events through a single number.

> **RiST TOOL TIP 7**
>
> Enter the impacts of climate change on natural hazards in tables 2ci, 2cii, and 2ciii in the green-highlighted "Climate impacts" tab.

FIGURE 6.1 • Illustration of the impact on extreme events of a change in average value



BOX 6.1

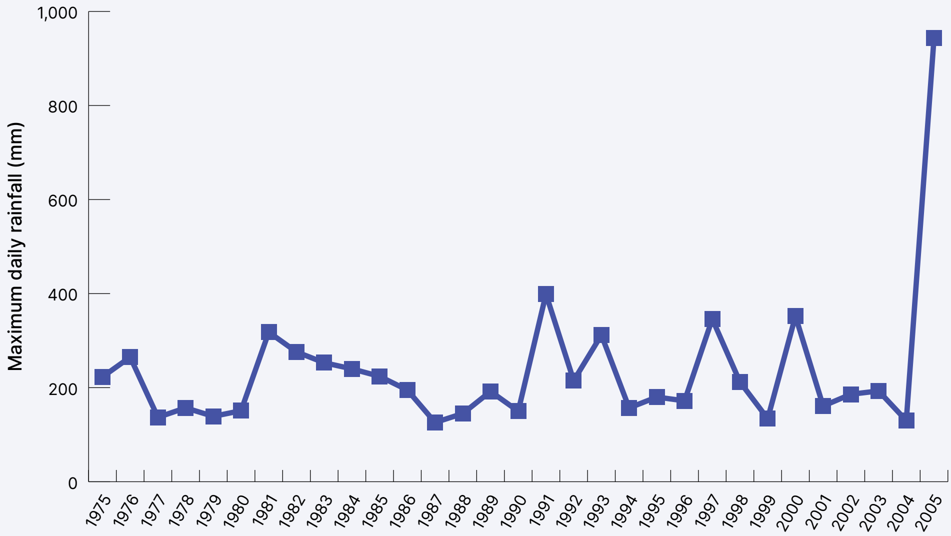
Taking care when using historical data

Based on data from 1975 to 2004 (figure B6.1.1), an easy conclusion would be that designing infrastructure in Mumbai to cope with a 600 millimeters maximum possible daily rainfall should be sufficient. A sophistical analysis using the 1975–2004 series finds that the return period of a daily rainfall of 600 millimeters is higher than 1,000 years, which means that the annual probability of occurrence is below 0.1 percent. Such a low probability appears as an acceptable residual risk for many investments.

However, adding one more year changes the picture dramatically. On July 26, 2005, more than 900 millimeters of rain fell over Mumbai, leading to large-scale flooding and more than 800 deaths. The same analysis including 2005 concludes that a 600-millimeter rainfall event has a return period of about 30 years in the city, and so is clearly an insufficient safety standard for many infrastructure assets.

The fact that a single year of data—in fact, a single *day* of data—could shift the assessment of the return period from more than 1,000 years to 30 years is a reminder of the care we must take when using historical data to assess risks. **Assessing the vulnerability of any critical asset to events that are unprecedented but not physically impossible is an important step in designing resilient societies.**

FIGURE B6.1.1 • Maximum daily rainfall in Santa Cruz, Mumbai, India (1975–2005)



Source: Ranger et al. 2011

Where to find the data

://climateknowledgeportal.worldbank.org

To help estimate the impacts of climate change on natural disasters and to better understand *potential* for change in the intensity, frequency, and duration of intense rainfall and extreme heat conditions, enhanced data on extreme events will be made available and integrated within the CCKP (climateknowledgeportal.worldbank.org).[a] Similar data for hurricane and high wind risks are also being produced and will be available soon. Task teams can use these data on weather extremes alongside expert opinion to inform planning and support rapid stress testing.

Task teams will be able to download projections of the different return periods (and the associated confidence intervals) of events for select time periods between 1 and 1,000 years. They will be able to access projections for extreme (hot or cold) temperatures and extreme precipitation (as proxies for floods and droughts) and at defined subnational aggregation scales.

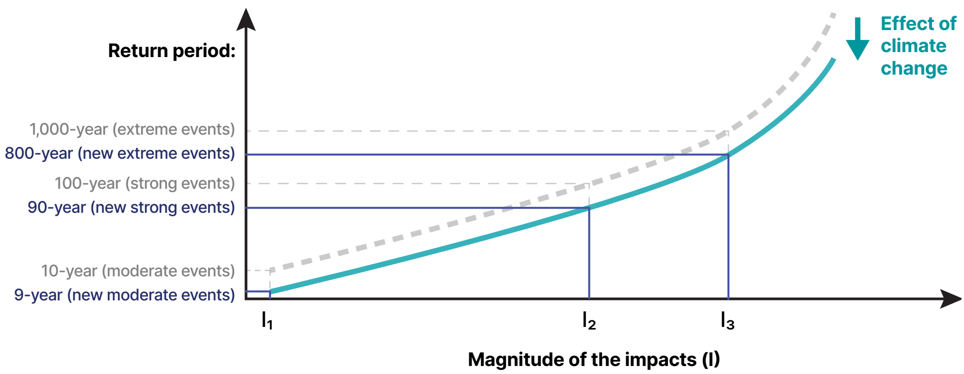
Data on weather extremes are derived from daily output data from approximately 30 CMIP5-generation global climate and Earth system models. Predictions under RCP 4.5 and RCP 8.5 are based on a 30-year projection period (2010–2039, 2020–2049, 2036–2065, or 2071–2100) compared to a historical reference period (1986–2015). It is important to note that large variability is present when considering individual grid points, especially when assessing small islands, coasts and mountainous areas, since the data is derived from coarse (1º×1º or 100km x 100km) resolution global models and limited to 30-year intervals.

a) World Bank teams can contact the CCKP Help Desk (climateportal@worldbank.org) with project-specific data requests.

6.1 • A simple assessment: assuming climate change only affects likelihoods (or return periods)

As a first approximation to stress test a project's vulnerability, it is possible to represent the change in extreme event characteristics as a change in frequency of possible events (figure 6.2). Indeed, climate change rarely leads to new events: over the next decades in particular, its main impact will be changing the frequency of extreme events, making some events that used to be exceptional more frequent. For example, sea level rise means that the water level that used to be reached once a century will be reached once a decade—that is, a 100-year event becomes a 10-year event. With this simplification, the task team can use table 6.1 to summarize change in extreme events for all threats.

FIGURE 6.2 • Illustration of a climate change-related shift of the extreme event curve



Note: Impacts can be measured in both monetary and nonmonetary units—for example, losses in $ or fraction of fallen trees.

TABLE 6.1 • Inputs needed to include the effect of climate change on natural hazard costs (simplified approach)

Frequency of event (2020)	2030		2050		2100	
	Low-impact scenario	High-impact scenario	Low-impact scenario	High-impact scenario	Low-impact scenario	High-impact scenario
Recurrent (1-in-2 year)						
New return period						
Moderate (1-in-10 year)						
New return period						
Strong (1-in-100 year)						
New return period						
Extreme (1-in-1,000 year)						
New return period						

6.2 • A more comprehensive (and complicated) assessment: considering changes in likelihoods and consequences together

Using table 6.1 is equivalent to defining extreme events by the losses they produce. For example, if the 100-year hurricane causes $1 million in losses in 2020, then we can estimate the frequency of the $1-million hurricane in 2050 and change the frequency accordingly in the table. An alternative is to define extreme events by their physical characteristics. For example, if hurricane strength is measured by maximum wind speed, then the 100-year hurricane can be a Category 4 hurricane (with wind speed higher than 209 kilometers per hour) in 2020. In that case, climate change may affect the frequency and return period (for example, by reducing the return period of a hurricane with 209 kilometers per hour wind speed to 50 years), but also increase the losses (for example, due to sea level rise). To accommodate an increase in losses, the table needs to include, for each initial return period and time horizon, the estimates of the losses. This is shown in table 6.2 (going to 2050 and with only 2- and 10-year return period events, for readability reasons).

TABLE 6.2 • Inputs needed to include the effect of climate change on natural hazard costs (simplified approach)

	2020		2030		2050	
Frequency of event (2020)	Low-impact scenario	High-impact scenario	Low-impact scenario	High-impact scenario	Low-impact scenario	High-impact scenario
Recurrent (1-in-2 year)						
New return period						
Impact on quantity produced (% of yearly output)						
Repair or reconstruction cost (CAPEX)						
Additional out-of-system impacts						
Moderate (1-in-10 year)						
New return period						
Impact on quantity produced (% of yearly output)						
Repair or reconstruction cost (CAPEX)						
Additional out-of-system impacts						

RiST **TOOL TIP 8**

The RiST tool extrapolates changes linearly, providing a year-by-year projection, with the three categories of expected impacts—ExpectedShockRepair, ExpectedShockServiceLoss, and ExpectedShockOutofSystemLoss—adjusted for each year. It then uses the same equations as before to calculate a revised NPV and BCR.

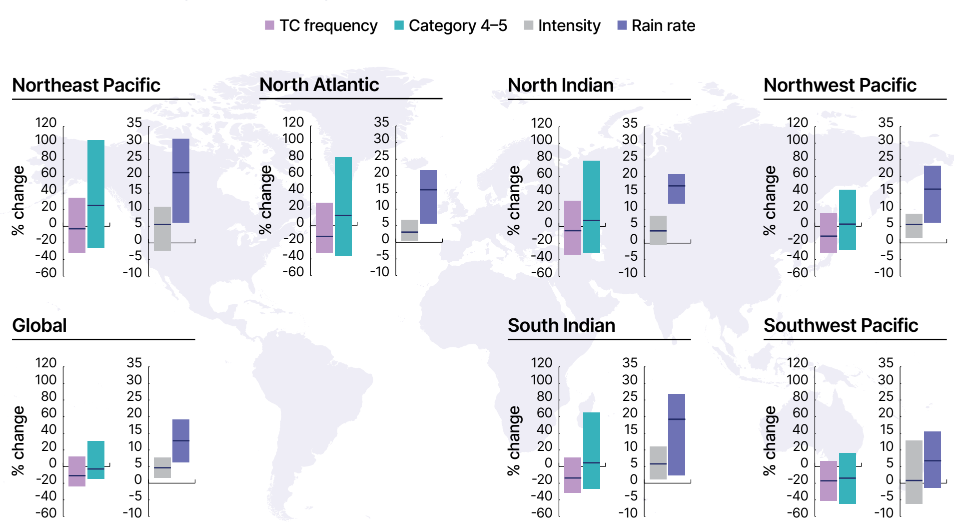
6.3 • Illustration: forestry project example

We continue to assume that the forestry project is still only exposed to high wind, due to tropical cyclones or localized storms (with high-frequency events most likely caused by localized storms and high-intensity events by tropical cyclones). To estimate how changes in cyclone intensity and frequency would affect the project, the task team needs to assess low- and high-impact scenarios to the change in the return period of what are today 2-, 10-, 100-, and 1,000-year storms.

How to integrate climate change impacts on natural disasters: The future of tropical cyclones is highly uncertain (figure 6.3) and heterogenous. Different storm basins are likely to respond differently. If our forestry project is in the North Atlantic, for example, the model projection for the change in Category 4–5 tropical cyclone frequency ranges from -30 to +80 percent. Models consistently expect an increase in maximum intensity and precipitation from these storms. In the South Indian basin—for example, in Mozambique—models tend to project a decrease in number of storms, no change in frequency of the strongest tropical cyclones, and an increase in precipitation. Of course, the frequency of landfall in one location will depend on its localization in each of the basins: higher latitudes may, for example, be hit more often, because higher sea temperatures allow storms to travel farther away from the tropics with high wind speed.

Figure 6.3 shows a summary of tropical cyclone projections for a 2°C global anthropogenic warming. It shows median and percentile ranges for projected percentage changes in the frequency of tropical cyclones (TC frequency) and Category 4–5 cyclones specifically (Cat4–5), as well as their intensity, and near-storm rain rate (rain rate) for each basin and the globe.

FIGURE 6.3 • Summary of climate model projections related to tropical cyclones in the major world basins (2°C global warming)



Source: Knutson et al. 2020.
Notes: For TC frequency, the figure shows the 5th–95th-percentile range across published estimates; for Cat 4–5, intensity, and rain rates, it shows the 10th–90th-percentile range. Note the different vertical axis scales for the combined TC frequency and Cat 4–5 frequency plot vs the combined intensity and rain rate plot.

Looking at figure 6.3, it seems reasonable and prudent to assume that, if the project is in the northwest Pacific (for example, in Fiji), tropical storms can become either more or less frequent. The frequency of intense storms (Cat 4 or 5) may decline by 20 percent or increase by 50 percent. There is much more confidence that intensity and rainfall will both increase, by up to 10 and 25 percent, respectively.

For including the effect of climate change on natural hazard costs, using the simple approach described in section 6.1, table 6.3 identifies new return periods in 2030 and 2050, respectively.

TABLE 6.3 • Inputs needed to include the effect of climate change on natural hazard costs (simplified approach)

	2030		2050	
Frequency of event (2020)	Low-impact scenario	High-impact scenario	Low-impact scenario	High-impact scenario
Recurrent (1-in-2 year)				
New return period	2	2	2	1
Moderate (1-in-10 year)				
New return period	10	5	10	3
Strong (1-in-100 year)				
New return period	150	50	200	30
Extreme (1-in-1,000 year)				
New return period	1500	500	2000	200

Results: The project's NPV would range between a $186,000 gain in the low-impact case (BCR = 1.4) and a $130,000 loss (BCR = 0.8). These results suggest that the project is potentially vulnerable to climate change, since the most pessimistic assumptions take the NPV in negative value territory. However, it does not mean that the project will fail, since it keeps a positive NPV in the low-impact scenario.

7. Managing uncertainty in future climate change impacts

If an analysis concludes that a project is viable even in the high-impact scenario, it is a robust project. However, this does not mean that there are no better ways to achieve the same goal, since the analysis is a stress test. If the analysis suggests that the project is vulnerable, even in low-impact scenarios, then the project is probably not viable. On the other hand, if a project is viable in the low-impact scenario and not in the high-impact scenario, it is more difficult to decide on its desirability. This section discusses this case.

One traditional approach to managing uncertainty in CBA is to create multiple scenarios and allocate probabilities to each of them.[13] We do not recommend this approach, as it would require the task team to identify all possible scenarios—which would require a much more in-depth analysis of all climate scenarios than is often possible—and allocating a probability of occurrence to each of them is broadly considered impossible based on current knowledge.[14]

Instead, managing climate change risks is better approached as a decision making under deep uncertainty problem. This means that various experts and stakeholders do not know or cannot agree on (1) models that relate key forces that shape the future, (2) probability distributions of key variables and parameters in these models, and/or (3) the value of alternative outcomes (Lempert et al. 2003). In such a context, we recommend starting by identifying the vulnerabilities of the project or strategy—that is, the scenarios or situation in which it fails—and then considering solutions to reduce these vulnerabilities and whether the residual vulnerabilities are acceptable, in the context of the project. This section follows this approach. It does not attempt to calculate an expected or most likely impact, but rather to disclose the project's vulnerabilities to decision makers so that they can make informed decisions.

7.1 • Identifying the switching scenario and assessing its implications and likelihood

We recommend task teams identify switching scenarios—that is, the most optimistic scenarios that make the project fail—and then discuss their likelihood and consequences. It is best to use ranges for each disaster or climate change impact, and to interpret the resulting range in performance, such as the range in NPV or BCR.

TOOL TIP 9

The RiST tool uses a "pessimism" parameter to navigate this range. If the parameter is at zero, it selects the low climate impact scenario; at 100 percent, it selects the high climate impact scenario. The higher the percentage, the more "pessimistic" the climate change and associated impacts would be. In between, the RiST tool does a linear interpolation between the low- and high-impact values in each of the categories.

Using the Excel Solver Add-in, the tool also allows for a "switching pessimism" calculation—that is, the level of pessimism, represented as a percentage, that makes a project fail. This could be, for example, NPV = 0 or another redetermined criterion from the task team. In this case, the RiST tool provides a climate and disaster scenario—in terms of change in quantity produced, prices, extreme event frequencies, and so on—that makes the project fail, allowing the task team to analyze this scenario.

This process can be broken down to three steps:

1. **Defining an acceptable threshold for the NPV or BCR.** For example, the task team can use BCR = 1 as the threshold. In the presence of many competing needs, however, they may feel that such a BCR is too low and pick a higher minimum acceptable BCR, such as 1.2.

2. **Identifying options available to stakeholders and beneficiaries if and when climate change starts to threaten a project's viability:** For example, if an asset's lifetime extends to 2045 but starts to underperform in 2030 due to climate change impacts, can it be retrofitted to compensate for these impacts? What are the options when it becomes evident that it is underperforming?[15]

3. **Estimating the likelihood of the "failing" scenario, based on existing models and expert opinions:** The task team can then use these estimates to describe the consequences and options available to stakeholders in case of failure, and disclose this information for the decision maker(s) to make their own decision.

7.2 • Illustration: forestry project example

In our forestry example, the project's NPV would range between a $186,000 gain in the low-impact case (BCR = 1.4) and a $130,000 loss (BCR = 0.8). Assuming that we are aiming at a (minimum) BCR of 1.2, what impact of climate change would be needed to make the project fail? Using the RiST tool, we find a "pessimism" parameter of 40 percent. Tables 7.1 and 7.2 illustrate the changes in average climate conditions and frequency of natural hazard events that would make our forestry example fail.

TABLE 7.1 • Failing scenarios based on changes in average climate conditions

Project parameters		2030	2050
Expected change in quantity produced	Yield	-7.0%	-13.9%
Expected change in price/value of supply	Price	2.8%	4.8%
Expected change in operational or production costs	OPEX	5.2%	69.7%

TABLE 7.2 • Failing scenarios based on changes in the frequency of natural hazard events

Frequency of event (2020)	2030	2050
Recurrent (1-in-2 year)		
New return period	2.0	1.6
Repair/reconstruction cost (ShockRepair, $)	1.4	
Impact on quantity produced (ShockServiceLoss, % of yearly output)	-1%	
Additional out-of-system impacts (ShockOutofSystemLoss, $)	7.0	
Moderate (1-in-10 year)		
New return period	8.0	7.2
Repair/reconstruction cost (ShockRepair, $)	7.0	
Impact on quantity produced (ShockServiceLoss, % of yearly output)	-3%	
Additional out-of-system impacts (ShockOutofSystemLoss, $)	27.9	
Strong (1-in-100 year)		
New return period	110	132
Repair/reconstruction cost (ShockRepair, $)	13.9	
Impact on quantity produced (ShockServiceLoss, % of yearly output)	-28%	
Additional out-of-system impacts (ShockOutofSystemLoss, $)	69.7	
Extreme (1-in-1,000 year)		
New return period	1105	1290
Repair/reconstruction cost (ShockRepair, $)	139.5	
Impact on quantity produced (ShockServiceLoss, % of yearly output)	-70%	
Additional out-of-system impacts (ShockOutofSystemLoss, $)	139.5	

Tables 7.1 and 7.2 show a scenario in which the project starts to fail, as:

- Project productivity drops by 7 percent in 2030 and 14 percent in 2050, due to higher temperature and lower precipitation in normal years.
- OPEX increases by 5 percent in 2030 and 70 percent in 2050, due to more costly action against forest fires, for example.
- Frequent natural shocks cause relatively small losses (-3 percent of annual production for the 10-year event) and increase moderately in frequency by 2030 (the 10-year return period decreases to 8 and 7 years, respectively, in 2030 and 2050).

- Rare and intense extreme events are more destructive (up to 70 percent of annual production for the 1,000-year event) but become less frequent over time in response to climate change.

- The value of the product increases due to global scarcity, by 3 percent in 2030 and 5 percent in 2050.

Next, the task team should consult experts or look at models and scenarios to estimate the likelihood of such a scenario. Since the scenario described here is clearly far from extreme, it suggests that the project has a significant vulnerability. If this scenario materializes, since the choice of tree species is not reversible, the implication would be a choice between a below-market return on the project or a new large investment to replant trees, with the same $200,000 CAPEX and 10-year delay before production can start. The community's ability to absorb this loss would depend on the context and other economic activities in the area.

8. Managing uncertainty on the “no climate risk” baseline

The baseline cost and benefit flows are also highly uncertain, due to possible implementation obstacles, such as delay or cost overrun, or unpredictable technological or socioeconomic changes, such as change in demand. To provide a fair assessment of the risk to the project, we recommend using an optimistic and a pessimistic baseline to better consider all uncertainties.

If we were to focus only on the expected NPV and climate shocks were uncorrelated with other uncertainties, we could first average the non-climate uncertainties and then explore the climate uncertainties. However, there are some non-climate-related situations that would affect the project’s baseline costs and benefits and its vulnerability to climate change—for example, while more rapid urbanization may increase the benefit of an urban infrastructure project, it could also increase the potential cost of urban floods. It is common for drivers, such as urbanization, to have some correlation with the project baseline costs and benefits and the impacts of climate change.

For these reasons, where possible, we recommend that all uncertainties are integrated in a single analysis. Usual methods include creating many scenarios by varying the values of all parameters in the analysis (the drivers of both baseline costs and benefits, and climate change impacts) and providing optimistic and pessimistic scenarios that cover all uncertainties. Ideally, such an approach can highlight the parameter values that make the project fail, combining climate and non-climate threats.

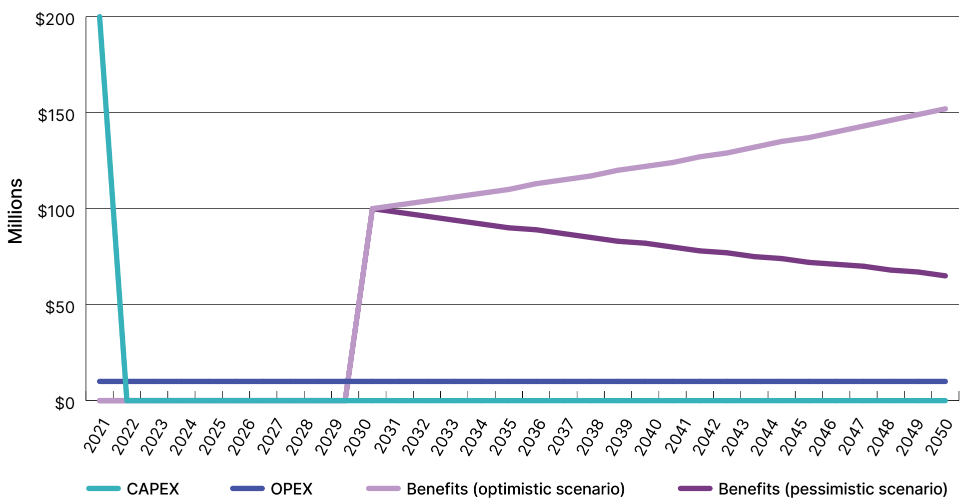
For example, robust decision making (RDM)[16] combines all uncertainties into a common framework developed specifically for decisions with long-term consequences and deep uncertainty. An RDM analysis begins with an existing or proposed project plan and exhaustively explores its vulnerabilities and sensitivities, through stakeholder involvement and analytical methods. It then uses this information to identify potential vulnerability-reducing modifications to the plan, which can be presented to decision makers, who evaluate their adoption. RDM is designed to support stakeholder dialogues that help define project objectives, including the range of uncertainties considered and the scenarios that best describe any vulnerabilities. As a “context-first” process that inverts the traditional ordering of an analytic decision-making process, RDM only considers probability distributions in the final steps of the analysis, thus facilitating both the use of imprecise or missing probabilistic information and engagement among stakeholders who may hold different expectations about the future. The approach is particularly appropriate when stakeholders disagree on the monetary value of a project’s costs and benefits—for example, the value to attribute to its health or biodiversity implications—since it does not require defining of a single metric to value the project, such as NPV.

If a full analysis is not possible, however, the task team could run the same analysis as in the previous sections, but instead of a single baseline, using multiple baselines that cover the range of possible "no climate change" costs and benefits. The limits will be the implicit assumption that climate and non-climate risks are uncorrelated, but it is an acceptable approximation if a more sophisticated analysis is impossible.

8.1 • Illustration: forestry project example

Here, we assume that the flow of baseline costs and benefits include one optimistic and one pessimistic value. The difference is that the baseline benefits are growing at 2 percent per year in the optimistic scenario and declining at 2 percent per year in the pessimistic scenario (figure 8.1).

FIGURE 8.1 • Baseline flow of costs and benefits for optimistic and pessimistic scenarios



The RiST tool calculates the NPV and BCR as functions of how pessimistic we are on climate change (as in section 7.2) and on the baseline (using the same linear interpolation between the two optimistic and pessimistic scenarios). It allows us to calculate the NPV and BCR in the four extreme scenarios (table 8.1).

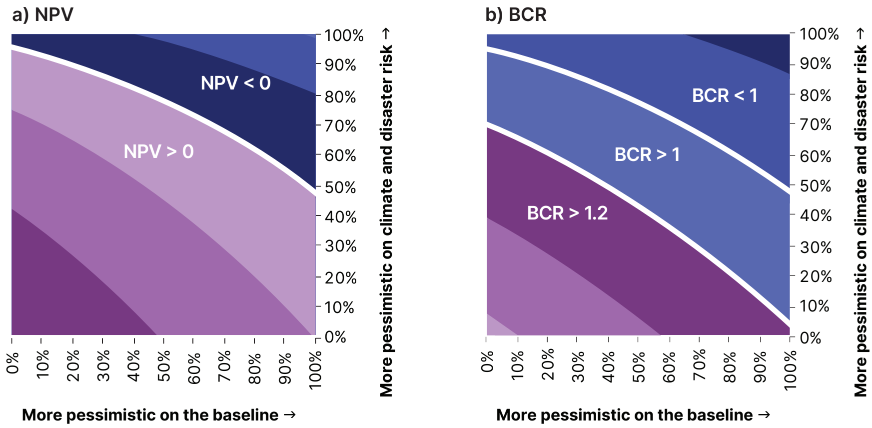
TABLE 8.1 • Results under four extreme climate scenarios

Adjusted NPVs and BCRs		Level of climate impact			
		Low		High	
		NPV ($, 1,000s)	BCR	NPV ($, 1,000s)	BCR
Baseline scenario	Optimistic	-32	0.95	295	1.6
	Pessimistic	-208	0.71	99	1.2

Note: The numbers in green indicate that, under a low climate impact scenario, the NPV and BCR remain above an acceptable threshold (NPV > 0 and BCR > 1). The numbers in red indicate that, under a high climate impact scenario, the project falls below acceptable thresholds (NPV < 0 and BCR < 1).

The RiST tool also helps tasks teams calculate the switching value of the pessimism parameters. Figure 8.2(a) shows the project pessimism in terms of the climate scenario (on the y-axis) that makes the project "fail" (where "failure" is defined as NPV = 0) as a function of the pessimism of the baseline (on the x-axis). Panel b shows the same scenario where "failure" is defined as BCR < 1.2. In this case, a large part of the uncertainty space corresponds to a failure scenario.

FIGURE 8.2 • NPV and BCR maps of the switching scenario



Overall, the results presented in panel b suggest a significant vulnerability and suggests that, with a definition of failure based on a BCR below 1.2, the project may fail in a pessimistic baseline, even if we are very optimistic on climate change. And with an optimistic baseline, the project remains vulnerable to high-impact climate scenario.

As in section 7, to determine whether this means the project requires an adjustment in design, the task team will have to explore the consequences of failure. If a failure of the project remains manageable for the community, then the decision makers may decide to go ahead despite a significant residual risk. But if a failure of the project could have catastrophic consequences for the community—for example, because it is their main source of income—then a redesign may be preferable. However, in all cases, the residual risk must be properly disclosed to decision makers, investors, and stakeholders.

9. Analyzing sensitivity and identifying the most vital threats to the project

9.1 • The importance of sensitivity analysis

If the vulnerability that has been identified is considered unacceptable because the consequences of failure are too large, then the task team should look in more detail at the scenarios that make the project fail and reinvestigate their likelihood.

A good first step is a simple sensitivity analysis to better understand what can make the project fail. In practice, it is possible to vary the following parameters independently:

- Pessimism related to the impacts on future quantity produced
- Pessimism related to future prices
- Pessimism related to CAPEX and OPEX costs
- Magnitude of impact of extreme events
- Future change in frequency of extreme events.

There is also uncertainty in relation to the baseline. The RiST tool enables task teams to conduct a simple uncertainty analysis by systematically varying each parameter and looking at the impact on the NPV.

The most important uncertainty is also the factor that is most capable of making the project fail. The following would therefore be useful:

- **More data and modeling** to give a better estimate of the likelihood (and plausibility) of failure scenarios

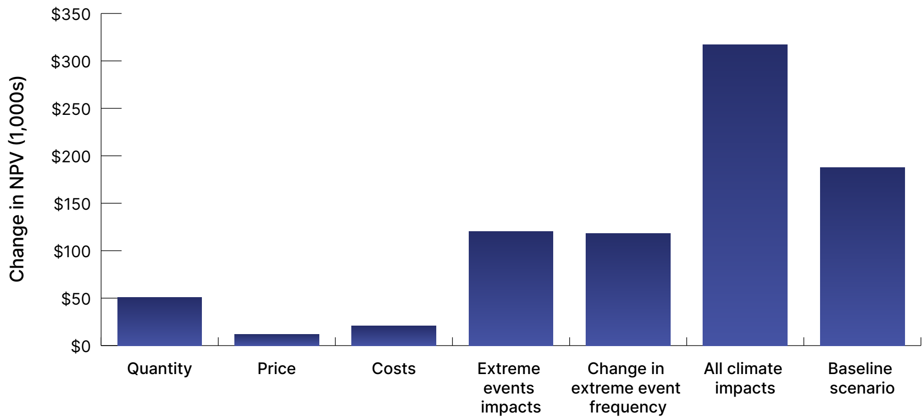
- **Further identification of mitigation opportunities**—for example, if the project is mostly vulnerable to flood risks, adding a flood management component to the project is the most promising option for reducing or removing identified vulnerabilities.

As additional information for task teams and decision makers, the RiST tool also provides an estimate of how different discount rates affect the project NPV in the median scenarios and how each disaster might affect a change in NPV.

9.2 • Illustration: forestry project example

A simple sensitivity analysis of our forestry example shows that both climate and baseline uncertainty matter (figure 9.1).

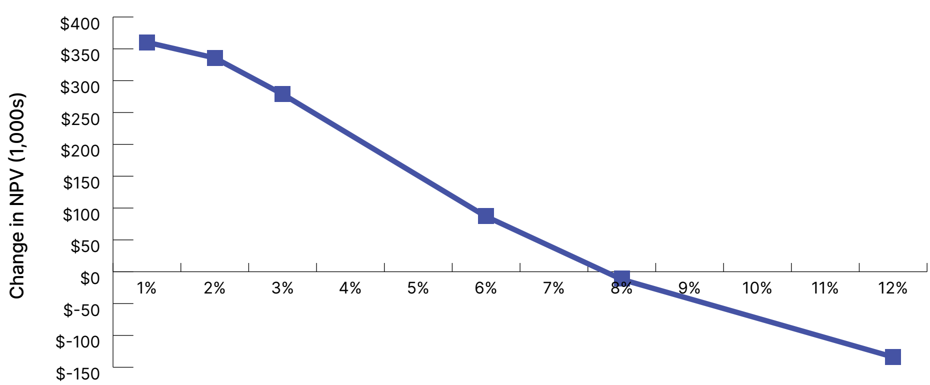
FIGURE 9.1 • Sensitivity analysis of a hypothetical forestry project



Among climate change vulnerabilities, figure 9.1 shows that the most important issues are the impact of extreme events and their expected change frequency due to climate change. We would therefore conclude that (1) more work could be done to better assess the impact of extreme events on the project, since it is so important for its success, and (2) options to make the project less vulnerable to extreme events are most likely to make the project less vulnerable and therefore more attractive.

The analysis of the sensitivity to the discount rate provides another piece of information on project robustness. Such an analysis takes the median baseline and median climate scenario and calculates how the NPV depends on the discount rate. Figure 9.2 shows that, due to the time profile of costs and benefits, our forestry project is highly sensitive to the choice of discount rate, and the significant benefit of $100,000 in the median scenario with a 6 percent discount rate (the value recommended for World Bank project when no country-specific discount rate is available) would disappear with an 8 percent discount rate.

FIGURE 9.2 • Role of the discount rate (on the median scenario)



9.3 • A more sophisticated assessment: identifying possible failure scenarios

There are many limits in this simple sensitivity analysis. First, the baseline is represented by a unique uncertainty, while it is the combination of many uncertainties. Some of these, such as change in demography or economic structure, are linked to underlying socioeconomic trends, while others, such as cost overrun, delay in implementation, are linked to project implementation. Second, the analysis is linear and may miss the result of nonlinear interactions across parameters—for example, uncertainty on climate does not matter, unless economic growth is low. And third, it disregards the fact that the different uncertainties are correlated, so that varying each parameter individually can hide vulnerabilities that arise from correlated vulnerabilities—for example, low economic growth affects both the baseline and the climate change vulnerability.

Another, more sophisticated, approach is to create hundreds of scenarios to cover the full space of uncertainty. Here, the challenge is to interpret the many scenarios that are created. The classical approach is to use an analysis of variance (ANOVA) model or a scenario elicitation methodology such as the Patient Rule Induction Method (PRIM) to identify the most important input parameters (very often, only a few parameters eventually matter), and the thresholds in these input parameters that make the project fails.

This more comprehensive approach—sometimes referred to as decision making under deep uncertainty—is required to achieve an A+ rating in the RRS "resilience *of* the project".[17] Its advantage is that it can clearly identify the main vulnerabilities of a project. For example, our forestry project may be vulnerable to climate change (as demonstrated earlier), but only for one specific reason, such as the impact of high winds with a return period beyond, for example, 20 years. This more precise identification of the vulnerabilities helps identify and design risk mitigation measures.

10. Selecting climate scenarios

One challenge in the approach is the choice of values for the low- and high-impact scenarios. For exceptional disasters and long-term climate change, the uncertainty is often very large, and it is difficult to determine what is impossible or implausible. However, the challenge of selecting an appropriate range of values for the economic analysis of a project is not only related to climate change. Similar issues exist for selecting other parameters, such as future economic growth, exchange rate, and interest rate, which are also highly uncertain.

10.1 • Principles

For socioeconomic trends, as for climate change scenarios, the choice of optimistic and pessimistic scenarios should follow a few important principles:

» **It is better to overestimate than underestimate the uncertainty.** The first objective is to identify vulnerabilities, which is better done by considering a wide range of possible scenarios. It is best to calculate the switching value and determine the switching scenario, for which the project NPV is null (unless using another definition of failure). The switching scenario will not be affected by the range of values selected for low- and high-impact scenarios, so we can safely select these as relatively extreme scenarios.

» **It is important to consider a wide range of possible futures when a project failure can have catastrophic impacts.** When a project can fail catastrophically, it is preferable to identify low-probability risks than to miss important vulnerabilities. Not implementing a project (or increasing its cost to reduce vulnerability) is unlikely to lead to catastrophic outcomes, while implementing a vulnerable project can be catastrophic. For small projects and when a failure is manageable with limited impacts, then it is more acceptable to fail, and we can select a narrower range of value.

» **The low- and high-impact scenarios should be plausible, but most people tend to be too conservative regarding what is possible in the future** (see, for example, Hoekstra 2018). It is well documented that most people underestimate the plausibility of massive structural changes and exploring low-probability scenarios is a good way of identifying a project's vulnerabilities.

» **Most importantly, a project that fails in the high-impact scenarios may still be a good project, provided it has a good return in more optimistic cases and that failure is not catastrophic.** By accepting that a project can fail in pessimistic cases, we make it easier to explore pessimistic scenarios and improve design and resilience.

10.2 • Climate scenarios

When choosing climate scenarios, project developers should consider which greenhouse gas emission scenarios and climate models to use (see box 10.1 for an explanation of climate scenarios and RCPs). A project's time horizon will also influence their choices. For example:

For projects ending before 2030, developers can consider current climate conditions and risks as constant and need not consider emission scenarios. When assessing current risk levels, however, it is important to consider that natural hazards are not stationary and have already been affected by climate change. In the absence of good climate (and hazard) observed data, we recommend using climate models.

For projects ending before 2040, the impact of greenhouse gas emissions is minimal, so it is possible to use just one emission scenario, such as RCP 4.5. Since emission scenarios also differ along other dimensions—such as non-CO_2 greenhouse gas or aerosol emissions—there may be special cases where it is useful to consider different emissions before 2040, but those will be exceptions. However, even for a project ending before 2040, there will be significant differences in risks across climate models, so we recommend using more than one climate model.

For projects continuing beyond 2040, it is important to consider different emission scenarios and climate models. We recommend using RCP 6.0 or RCP 8.5 as a pessimistic emissions scenario, and RCP 2.6 as an optimistic scenario in terms of emissions and human impact on the climate.

Note that, while RCP 8.5 has been used in most of the literature as the pessimistic scenario, existing climate policies and changes in the price of carbon-free technologies (particularly renewable energy) make this scenario unrealistically pessimistic today. However, considering other sources of uncertainty (and especially the response of the climate system), it is acceptable to use RCP 8.5 impact assessments in the context of a stress test, especially if other high-impact impact assessments are not available.

There are now many climate models, and their main results are regularly reviewed in academic journals and by the Intercontinental Panel on Climate Change (IPCC). Although these models are all based on similar knowledge of climate system mechanisms and similar approaches to modeling, they may still lead to different results. While all models agree on projecting an increase in global temperatures, they may disagree radically on local changes, especially in terms of changes in precipitation or extreme events. For this reason, it is essential to use more than one climate model when defining low- and high-impact scenarios. We therefore recommend exploring the outcome of at least five climate models from leading climate research centers before selecting scenarios.

BOX 10.1

What are climate scenarios and RCPs?

The term “scenarios” is used to refer to descriptions of possible futures, either qualitative or quantitative. Scenarios differ from forecasts or predictions, because they are based on a set of assumptions regarding external factors, such as policy choices or technological evolutions, and do not pretend to predict the future. For example, a scenario can describe the evolution of the world in the absence of climate policies, without being a forecast (since there are climate policies). Scenarios can be more or less likely but are only rarely associated to probability of occurrence. Worst-case scenarios are designed to be unlikely but must be possible and internally consistent.

Climate scenarios are simulations using global climate models that show the evolution of the main climate variables—temperature, precipitations, humidity, cloud cover, wind, and so on—over time, in response to an emission or atmospheric concentration scenario. When used with an emission scenario, global climate models include a (carbon cycle) module to translate emissions into concentrations of gases in the atmosphere.

RCPs are concentration scenarios developed as the input concentration assumptions for the CMIP, which coordinates the production of climate scenarios reviewed by the IPCC. They also include other factors that are external to climate models, such a land use and land cover. The initial RCPs describe four different 21st century pathways of greenhouse gas emissions and atmospheric concentrations, air pollutant emissions and land use. They represent different intensities in the additional radiative forcing (in watts per square meter) caused by human activities and can be linked to socioeconomic scenarios (shared socioeconomic pathways), which represent different possible evolution of the world in terms of demography, technology, economy, behaviors, and so on.

The RCPs include one stringent mitigation scenario (RCP 2.6, broadly consistent with a 2°C target), two intermediate scenarios (RCP 4.5 and RCP 6.0), and one scenario with very high greenhouse gas emissions (RCP 8.5). RCP 8.5 is today considered unrealistic in view of recent technological and policy evolutions. RCP 2.6 is representative of a scenario that aims to keep global warming less than 2°C above pre-industrial temperatures (IPCC 2014). A new RCP—1.9—has been recently added to represent a scenario consistent with the 1.5°C target.

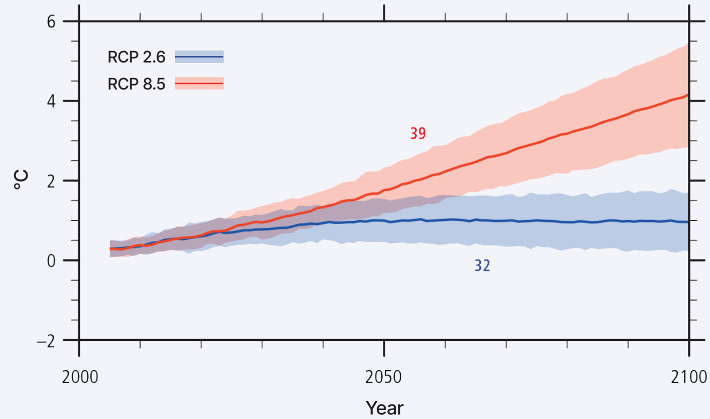
Using RCPs as input, climate models simulate future changes in the characteristics of Earth systems such as temperature, precipitation, and storms. Due to differences in climate sensitivity across models, each RCP leads to a range of increases in global mean temperatures (see figure B10.1.1). Other differences across models lead to further differences in terms of precipitation, storm tracks and intensity, and so on. It means that one RCP is consistent with many different climate scenarios, and therefore different impacts. Climate scenarios are generated by CMIP. Current available scenarios correspond to CMIP5, which generated scenarios for IPCC’s Fifth Assessment Report. A new generation, CMIP6, is currently being produced (with first results already available), in preparation of the IPCC’s Sixth Assessment Report.

BOX 10.1
continued

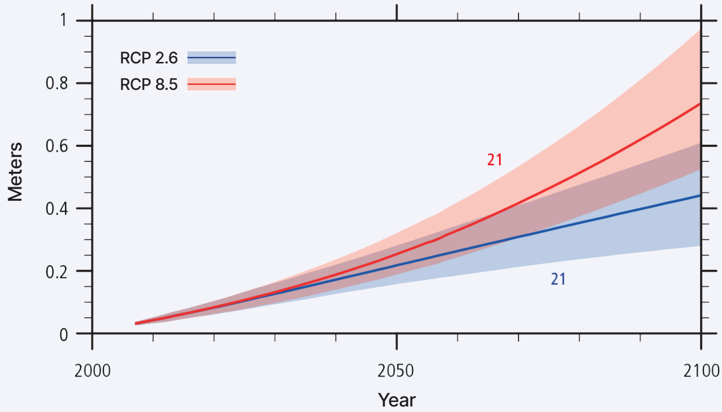
For a stress test, it is important to consider a range of possible climate scenarios, including various magnitudes of global warming (usually measured by change in average temperature, which can be done using climate scenarios with different forcing, such as RCP 2.6 and RCP 6.0 or 8.5). It is also important to consider a range of possible climate change patterns to capture the differences in local climate patterns, which can be done using multiple climate models. Note that even though RCP 8.5 is considered unrealistic in terms of carbon emissions, the scenario can still be used to generate a high climate change impact scenario for stress testing purposes.

FIGURE B10.1.1 • Projected change in temperature and sea level under RCP 8.5 and RCP 2.6 scenarios

a) Global average surface temperature change (relative to 1985–2005)



b) Global mean sea level rise (relative to 1985–2005)



Source: IPCC 2014

Appendix A: Reporting template

We recommend the economic analysis section of a project document includes a section on disaster and climate risks, which could be built around this template:

1. Provide the background of the analysis.

» Identify the key climate and disaster risks to the project and the selection of natural hazards included in the analysis.

» Establish the optimistic and pessimistic project scenarios used for the baseline without climate change impacts.

» Select the climate change scenarios, including choice of emission scenario or RCP, climate and impact models, and use of expert opinion.

» Select the metric, such as NPV, and threshold, such as NPV > 0, to determine the project's success or failure. Other relevant context or sector-specific metrics could include establishing a reservoir's threshold water yield, gigawatts of energy produced in a hydropower facility, or the poverty implications of an intervention.

2. Present results as NPV or BCR in extreme scenarios (other relevant metrics for project success or failure are also acceptable).

Provide the results for at least four extreme scenarios, based on maximum and low climate impact and on optimistic and pessimistic project scenarios. Table A.1 provides an example of results under different low/high and optimistic/pessimistic scenarios. The numbers in green indicate that, under a low climate impact scenario, the NPV and BCR remain above an acceptable threshold (NPV > 0 and BCR > 1). The numbers in red indicate that, under a high climate impact scenario, the project falls below acceptable thresholds (NPV > 0 and BCR > 1).

TABLE A.1 • Results under four extreme climate scenarios

Adjusted NPVs and BCRs		Level of climate impact			
		Low		High	
		NPV ($, 1,000s)	BCR	NPV ($, 1,000s)	BCR
Baseline scenario	Optimistic	295	1.6	-32	0.95
	Pessimistic	99	1.2	-208	0.71

Note: The numbers in green indicate that, under a low climate impact scenario, the NPV and BCR remain above an acceptable threshold (NPV > 0 and BCR > 1). The numbers in red indicate that, under a high climate impact scenario, the project falls below acceptable thresholds (NPV < 0 and BCR < 1).

3. If failure is possible, describe the identified switching scenarios.

» Provide NPV or BCR maps (figure A.1) showing the uncertainty space in which the project fails. If failure is determined through another metric—such as a low number of lives saved—then provide the uncertainty map for this metric. Also include a sensitivity analysis (figure A.2) highlighting the factors that have most influence on project success or failure, including sensitivity to key disasters if applicable. These should correspond to the project's main vulnerabilities and are therefore the best opportunities to make the project more robust.

» Describe the socioeconomic and climate context in one or more scenarios in which the project fails—for example, if NPV or BCR is equal to the limit set by the task team.

Depending on the results of the plausibility or consequence analysis, there are then three options:

If failure scenario(s) are considered implausible, report on why the identified switching scenarios appear implausible—for example, the project fails only with an extreme sea level rise scenario that exceeds most published estimates. Conclude with a "no identified vulnerability" estimate.

If failure scenario(s) are considered manageable, provide an explanation of the options available in case of failure to restore the project's economic viability or explain why the failure is not material for the beneficiaries, countries, or areas. Conclude with a "no identified vulnerability" estimate.

If failure scenario(s) are plausible, unmanageable, and threaten the economic viability of the project or make it unbeneficial, provide a qualitative (and quantitative if possible) estimate for the plausibility of the scenario and its consequences. Based on the sensitivity analysis figure, indicate the most likely origin of failure—for example, quantities produced in the average year v. increase in likelihood of extreme disaster. Conclude with a "significant vulnerability identified" estimate.

FIGURE A.1 • Sample NPV and BCR maps of switching scenarios

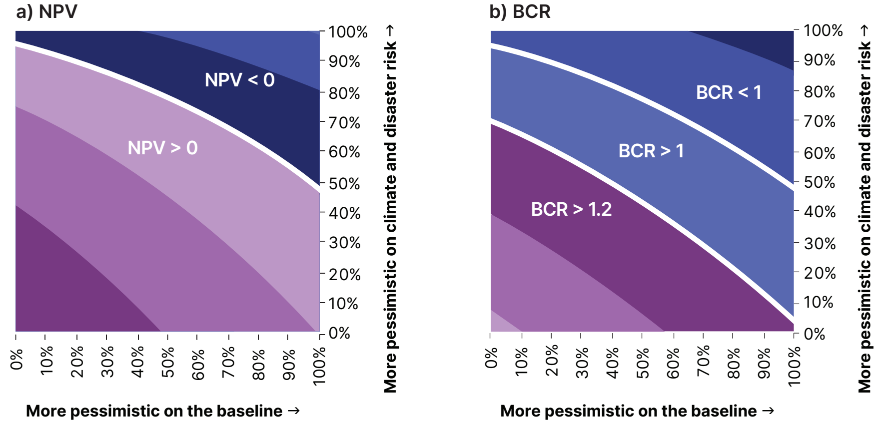
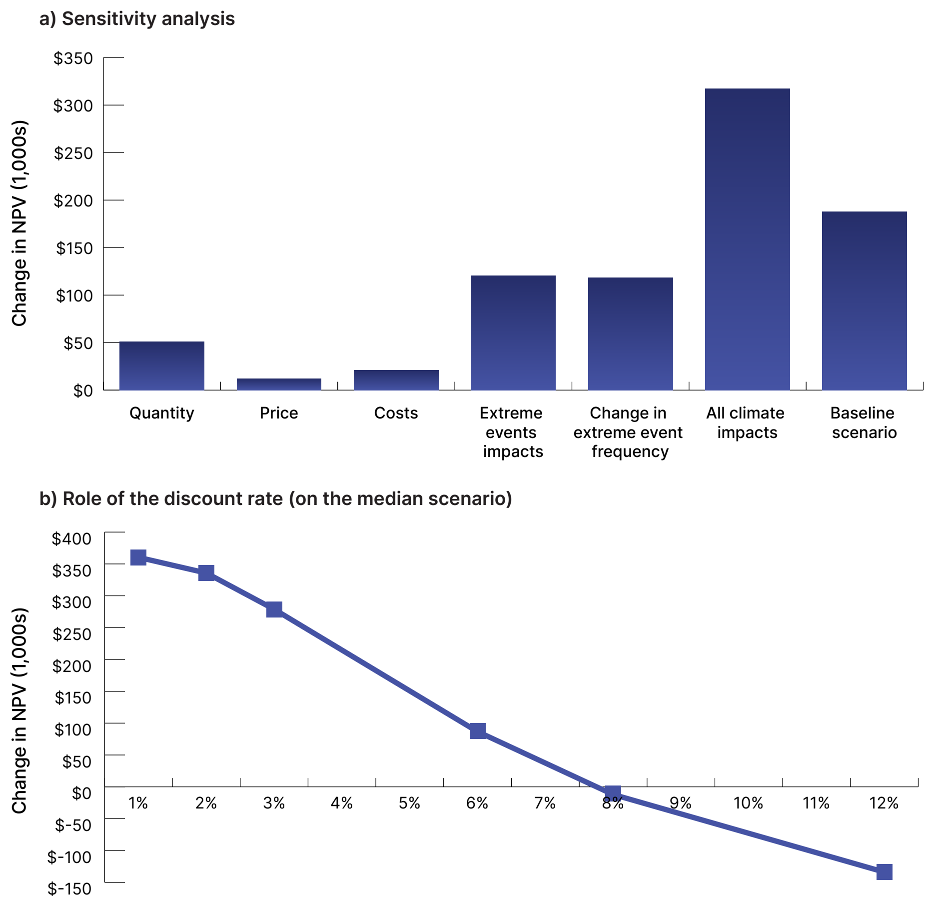


FIGURE A.2 • Sample sensitivity analysis



Appendix B: List of resources for climate information

B.1 • General climate and disaster information resources

Climate Change Knowledge Portal: The World Bank's 'one stop shop' for global data on historic and future climate trends, vulnerabilities, and sectoral impacts for all countries. Country profiles and subnational data also available. https://climateknowledgeportal.worldbank.org/; https://climateknowledgeportal.worldbank.org/country-profiles.

ThinkHazard!: Developed by the World Bank Global Facility for Disaster Reduction and Recovery (GFDRR), this platform provides hazard-level ratings for all countries and subnational units.[18] Rated hazards—including extreme heat, water scarcity, flooding, earthquakes, landslides, tsunamis, cyclones, and wildfires—can help identify a project location's baseline exposure to risks. https://thinkhazard.org/.

National meteorological agencies: Often provide more localized climate information. To access via the World Meteorological Organization's member resource page, search by country. https://public.wmo.int/en/about-us/members/national-services.

B.1.1 • Floods

Frequency of extreme precipitation increases extensively with event rareness under global warming (*Scientific Reports* 9, 16063. Myhre, G, Alterskjær, K, Stjern, C W, Hodnebrog, Ø, Marelle, L, Samset, B H, Sillmann, J, Schaller, N, Fischer, E, Schulz, M, and Stohl, A 2019): Using current data on damages and frequency of intense precipitation events, finds that the most intense precipitation events observed today are likely to almost double in occurrence for each degree of further global warming. https://doi.org/10.1038/s41598-019-52277-4.

FM Global Flood and Earthquake Risk Map: Highlights areas of high and moderate risk. https://www.fmglobal.com/research-and-resources/nathaz-toolkit/flood-map.

B.1.2 • Hurricanes

Global increase in major tropical cyclone exceedance probability over the past four decades (*Proceedings of the National Academy of Sciences of the United States of America*, 117 (22) 11975–11980. Kossin, J P, Knapp, K R, Olander, T L, Velden, C S 2020): Discusses the frequency of tropical cyclones in ocean basins based on a 39-year period from 1979–2017. Between the early and latter halves of the time period, the probability of major cyclones increased by about 8 percent per decade. https://www.pnas.org/content/117/22/11975.

"Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming." (*Tropical Bulletin of the American Meteorological Society*, 101(3), E303–E322. Knutson, T, Camargo, S J, Chan, J C, Emanuel, K, Ho, C H, Kossin, J, Mohapatra, M, Satoh, M, Sugi, M, Walsh, K, and Wu, L 2020): This paper reviews the modeling results on the change in intensity, frequency, and rainfall from tropical cyclones, globally. https://doi.org/10.1175/BAMS-D-18-0194.1.

B.1.3 • Earthquakes

OpenQuake Map Viewer (Global Earthquake Model): Depicts the geographic distribution of peak ground acceleration with a 10 percent probability of being exceeded in 50 years, computed for reference rock conditions (shear wave velocity, VS30, of 760–800 m/s). https://maps.openquake.org/map/global-seismic-hazard-map/#3/28.46/90.35.

B.2 • Sector-specific resources

B.2.1 • All infrastructure

Overview of Engineering Options for Increasing Infrastructure Resilience (Miyamoto International 2019. Washington, DC: World Bank): Provides a list of resilience options in infrastructure regularly implemented in leading countries. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/474111560527161937/final-report.

- ***Increasing Infrastructure Resilience: Technical Annex:*** Technical annex to Miyamoto (2019); provides further detail. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/620731560526509220/technical-annex.

Lifelines: The Resilient Infrastructure Opportunity (Hallegatte, S, Rentschler, J, and Rozenberg, J 2019. Washington DC: World Bank): Lays out a framework for understanding infrastructure resilience—the ability of infrastructure systems to function and meet users' needs during and after a natural shock—and makes an economic case for building more resilient infrastructure. Concludes by identifying five obstacles to resilient infrastructure and offering concrete recommendations and specific actions to improve the quality and resilience of these essential services. http://hdl.handle.net/10986/31805.

B.2.2 • Agriculture

Online Guide to Climate-Smart Agriculture: Comprehensive guide on climate-smart agriculture (CSA) basics, planning, financing, investing, including a resources library and case studies developed by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) for the World Bank in collaboration with a range of other partners and institutions. https://csa.guide/.

- **CSA country profiles:** Overview of the agricultural challenges in countries around the world, and how CSA can help them adapt to and mitigate climate change. Developed by the International Center for Tropical Agriculture (CIAT) and CCAFS, in partnership with the World Bank, Costa Rica's Centro Agronómico Tropical de Investigación y Enseñanza, and USAID's Bureau for Food Security. https://p4s.ccafs.cgiar.org/tools/csa-country-profiles-and-climate-risk-profiles.

» **Climate Smart Agriculture Investment Plans (CSIAPs): Bringing CSA to Life.** Developed by the World Bank in cooperation with a wide range of partners—including the Adaptation for African Agriculture Initiative, the CIAT and the International Institute for Applied Systems Analysis—built off the CSA profiles. Identify concrete actions governments can take to boost CSA, through investment opportunities and policy design and implementation. Countries can also use the CSAIPs to inform their nationally determined contribution updates and national agriculture investment plans. https://www.worldbank.org/en/topic/agriculture/publication/climate-smart-agriculture-investment-plans-bringing-climate-smart-agriculture-to-life.

Ag Observatory: Aims to support the World Bank and partners to access and deploy high resolution and near real-time geospatial agrometeorological data for productive and resilient food systems and landscapes. https://worldbankgroup.sharepoint.com/sites/Agriculture/Pages/SitePages/Ag-Observatory-Providing-Agricultural-Intelligence-for-the-World-Bank-and-Partners-03252020-115126.aspx?tab=sitepages&page=managecontentadmin (World Bank Group internal link).

Future of Food: Shaping a Climate-Smart Global Food System (World Bank 2015): Guidance on improving the productivity and resilience of the current food system, and ways to make agriculture part of the solution to climate change. http://hdl.handle.net/10986/22927.

Guidelines for Climate Proofing Investment in Agriculture, Rural Development, and Food Security (Asian Development Bank 2012): A step-by-step methodological approach to help task teams assess and incorporate climate change adaptation measures into investment projects. https://www.adb.org/sites/default/files/institutional-document/33720/files/guidelines-climate-proofing-investment.pdf.

Shock Waves: Managing the Impacts of Climate Change on Poverty (Hallegatte, S Bangalore, M, Bonzanigo, L, Fay, M, Kane, T, Narloch, U, Rozenberg, J, Treguer, D, and Vogt-Schilb, A 2016): An analysis of hundreds of baseline scenarios for future economic development in the absence of climate change in 92 countries shows that the drivers of poverty eradication differ across countries. Results from the agriculture sector analyses include climate impacts on agriculture yields and prices. https://openknowledge.worldbank.org/handle/10986/22787.

The Impacts of Climate Change on Poverty in 2030 and the Potential from Rapid, Inclusive, and Climate-informed Development (Rozenberg, J and Hallegatte, S 2015): This background paper to Shock Waves assesses the impacts of climate change on poverty. https://openknowledge.worldbank.org/handle/10986/23447.

B.2.3 • Energy

The Good Practice Note for Energy Sector Adaptation (World Bank 2020): Helps World Bank project developers incorporate climate adaptation and resilience into power sector projects for client countries. https://worldbankgroup.sharepoint.com/sites/energy/Documents/Energy%20Resilience%20Good%20Practice%20Note/Energy%20Resilience%20Good%20Practice%20Note_Feb2020.pdf (World Bank internal link).

Stronger Power: Improving Power Sector Resilience to Natural Disasters (Nicolas, C, Rentschler, J, Potter van Loon, A, Oguah, S, Schweikert, S, Deinert, M, Koks, E, Arderne, C, Cubas, D, Li, J and Ichikawa, E 2019). Investigates the vulnerability of the power system to natural hazards and climate change and provides recommendations to increase its resilience. http://hdl.handle.net/10986/31910.

Hydropower Sector Climate Resilience Guide (International Hydropower Association 2019): A methodology for identifying, assessing, and managing climate risks to enhance the resilience of hydropower projects. https://www.hydropower.org/publications/hydropower-sector-climate-resilience-guide.

Enhancing Power Sector Resilience: Emerging Practices to Manage Weather and Geological Risks (World Bank Group 2016): Provides a list of concrete adaptation measures for the energy sector. http://hdl.handle.net/10986/26382.

Guidelines for Climate Proofing Investment in the Energy Sector (Asian Development Bank 2013): A step-by-step method for assessing climate risk and incorporating adaptation measures into energy projects. https://www.adb.org/documents/guidelines-climate-proofing-investment-energy-sector.

Hands-On Energy Adaptation Toolkit (HEAT) (World Bank Energy Sector Management Assistance Program 2010): A stakeholder-based, semiquantitative, risk assessment tool for project developers who want to undergo more in-depth risk assessments. Prioritizes risks to a country's energy sector and identify adaptation options. https://esmap.org/node/312.

B.2.4 • Forestry

Forest Adaptation Resources: climate change tools and approaches for land managers, 2nd edition (US Department of Agriculture 2016): Provides a collection of resources designed to help forest managers incorporate climate change considerations into management and devise adaptation tactics. https://www.nrs.fs.fed.us/pubs/52760.

Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment (National Wildlife Federation 2011): A guide for natural resource managers for assessing key components of vulnerability, focusing on species, habitats, or ecosystems. https://www.nwf.org/Educational-Resources/Reports/2011/01-19-2011-Scanning-the-Conservation-Horizon.

B.2.5 • Health

Climate and health vulnerability assessments (World Bank. Health, Nutrition and Population Global Practice): Provided by the Health-Climate and Environment Program (H-CEP) to help countries understand their climate-related exposures and provide recommendations to strengthen the capacity of their health systems to adapt to climate change. Energy efficiency audits are also available through H-CEP. Reductions in energy use present recipient countries with important financial as well as emissions related savings.

https://worldbankgroup.sharepoint.com/sites/Health/CCH/Pages/Climate-and-Health-Knowledge-10092019-131758.aspx (World Bank Group internal link).

Building Resilience Against Climate Effects (BRACE) Framework (Centers for Disease Control and Prevention): Allows health officials to develop strategies and programs to help communities prepare for the health effects of climate change. Part of this effort involves incorporating complex atmospheric data and both short and long-range climate projections into public health planning and response activities. https://toolkit.climate.gov/tool/building-resilience-against-climate-effects-brace-framework.

- **Guide for assessing health vulnerability to climate change for health departments**. Part of the BRACE Framework. https://toolkit.climate.gov/tool/assessing-health-vulnerability-climate-change-guide-health-departments.

Methodological Guidance: Climate Change and Health Diagnostic. A Country-Based Approach for Assessing Risks and Investing in Climate-Smart Health Systems (World Bank Group 2018): Provides steps to identify events and conditions where climate stresses and shocks undermine the effectiveness of health systems (at local or national scales), increasing morbidity and mortality. Uses these insights to prioritize interventions toward establishing climate-smart health systems that both increase resilience and reduce climate forcing emissions. http://documents1.worldbank.org/curated/en/552631515568426482/pdf/122328-WP-PUBLIC-WorldBankClimateChangeandHealthDiagnosticMethodologyJan.pdf.

Climate and Health Intervention Assessment Evidence on Public Health Interventions to Prevent the Negative Health Effects of Climate Change (Centers for Disease Control and Prevention (CDC) and the Building Resilience Against Climate Effects (BRACE) Midwest/Southeast Collaborative 2017): Outlines the findings of the BRACE Midwest/Southeast Collaborative on the evidence of effectiveness of various interventions for reducing the negative health impacts of climate change. https://www.cdc.gov/climateandhealth/docs/ClimateAndHealthInterventionAssessment_508.pdf.

Tracking Progress on Health and Climate Change (Lancet Countdown 2019): Tracks the relationship between health and climate change across five key domains and 41 indicators. https://www.lancetcountdown.org/.

Geographic Hotspots for World Bank Action on Climate Change and Health (World Bank Group 2017): A guide to countries that would most benefit from immediate efforts to ensure that health considerations are at the forefront of climate change adaptation responses and mitigation measures. Draws on vulnerability indices related to health outcomes, data outlining the disease burden linked to pollution, and proxies that measure country health systems' performance or readiness to cope with increased burden of disease. http://documents1.worldbank.org/curated/en/209401495434344235/pdf/113571-Working-Paper-PUBLIC-Final-WBG-Climate-and-Health-Hotspots.pdf.

Climate-Smart Healthcare: Low Carbon and Resilience Strategies for the Health Sector (World Bank Group 2017): A menu of tools for building low-carbon healthcare and addressing climate-related health impacts. http://documents1.worldbank.org/curated/en/322251495434571418/pdf/113572-WP-PUBLIC-FINAL-WBG-Climate-smart-Healthcare-002.pdf.

Health and Climate Country Profiles (WHO and UNFCCC 2015): Developed in collaboration with national health services. Snapshots of the climate hazards and expected health impacts of climate change facing countries that highlight opportunities for health co-benefits from climate mitigation actions, track current policy responses and summarize key priorities for action. https://www.who.int/globalchange/resources/countries/en/.

Reducing Climate-Sensitive Disease Risks (World Bank 2014): Builds on scientific and operational knowledge of early action tools to help practitioners reduce the risks of key climate-sensitive infectious diseases by strengthening risk management systems for disease outbreaks. Includes an assessment of known interventions such as the establishment of surveillance systems, the development of region and nation-specific disease outlooks, the creation of climate-sensitive disease risk maps, and the construction and implementation of early warning advisory systems. http://hdl.handle.net/10986/18634.

B.2.6 • Telecommunications

No Broken Link: The Vulnerability of Telecommunication Infrastructure to Natural Hazards (Sandhu, H S, and Raja, S 2019): Discusses the impact of climate events on various types of digital infrastructure, highlighting key considerations for governments and digital infrastructure owners to make their infrastructure more resilient, while maintaining affordability of services. http://hdl.handle.net/10986/31912.

B.2.7 • Transport

From a Rocky Road to Smooth Sailing: Building Transport Resilience to Natural Disasters (Rozenberg, J, Espinet, X, Fox, C, Hallegatte, S, Koks, E, Rentschler, J, and Tariverdi, M 2019): Summarizes the main findings on the risks to transport networks and users from natural disasters and climate change, and the main recommendations for building more resilient transport networks. http://hdl.handle.net/10986/31913.

Highway Development and Management Model (HDM-4) Dissemination Tools (World Bank): Help predict road network performance as a function of climate, among other input factors. https://collaboration.worldbank.org/content/sites/collaboration-for-development/en/groups/world-bank-road-software-tools.html.

Vulnerability Assessment and Adaptation Framework (US Federal Highway Administration (FHWA) 2012, 2018): For use in analyzing the impacts of climate change and extreme weather on transport infrastructure, assessing adaptation options, and informing decision making. https://www.adaptationclearinghouse.org/resources/fhwa-vulnerability-assessment-and-adaptation-framework.html.

- ***Hydraulic Engineering Circular No. 25–Volume 2–Highways in the Coastal Environment: Assessing Extreme Events*** (FHWA 2014): Provides technical guidance on how to incorporate extreme events and climate change into coastal highway designs, with a focus on sea level rise, storm surge, and wave action. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/nhi14006/nhi14006.pdf.

- ***Hydraulic Engineering Circular No. 17–2nd Edition--Highways in the River Environment: Floodplains, Extreme Events, Risk, and Resilience*** (FHWA 2016): Provides technical methods for incorporating floodplain management, risk, extreme events, resilience, and adaptation for highways in the riverine environment. Draws on the best actionable engineering and scientific methods and data. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif16018.pdf.

Green Roads for Water: Road Infrastructure in Support of Water Management and Climate Resilience (World Bank Transport Sector Guideline 2019): Includes principles, techniques, and case studies on road-water harvesting and roads for watershed management. https://roadsforwater.org/guideline/roads-for-water-harvesting-in-semiarid-areas/.

Global Roadmap of Action Toward Sustainable Mobility (GRA) (Sustainable Mobility for all (SuM4All) 2019): Produced in cooperation with the World Bank Group and German Cooperation. A guide for decision makers on mobility that is efficient, accessible, safe, and green. https://www.sum4all.org/gra.

Country Mobility Diagnostic (SuM4All): Combines standardized performance assessments on mobility with policy solutions and investment plans to achieve sustainable mobility. https://www.sum4all.org/key-products/country-mobility-diagnostic-cmd.

Addressing Climate Change in Transport (Vol. 2): Pathway to Resilient Transport (World Bank Group 2019): Lays out a pathway to a low-carbon and climate-resilient transport sector in Vietnam and provides a methodological framework to analyze critical and vulnerable points of the transport network. http://hdl.handle.net/10986/32412.

Climate and Disaster Resilient Transport in Small Island Developing States (World Bank Group 2017): Provides a framework for integrating climate change and disaster risks considerations in transport asset management systems along the asset lifecycle. http://documents1.worldbank.org/curated/en/879491510323939763/pdf/120998-PUBLIC-11-15-2017-WB-RTSIDS-Report.pdf.

Enhancing the Climate Resilience of Africa's Infrastructure: the Roads and Bridges Sector (World Bank Group 2016): Develops a methodology to compare the cost of inaction against proactive adaptation measures in the transport sector, looking at three main dimensions: assessing the cost of road assets over their entire life cycle, considering a variety of climate change scenarios, and quantifying the broader impact of climate-related traffic disruptions. https://www.worldbank.org/en/topic/transport/publication/enhancing-the-climate-resilience-of-africas-infrastructure-the-roads-and-bridges-sector.

Incorporating Climate Change Adaptation in Infrastructure Planning and Design (USAID 2015): First in a series created to address how to incorporate climate change adaptation in planning and designing infrastructure projects. https://www.climatelinks.org/resources/incorporating-climate-change-adaptation-infrastructure-planning-and-design-overarching. Includes:

- **Additional guidance on roads.** https://www.climatelinks.org/resources/methodology-incorporating-climate-change-adaptation-infrastructure-planning-and-design-1.

Moving toward climate-resilient transport: The World Bank's Experience from Building Adaptation into Programs (Ebinger, J O and Vandycke, N L 2015): Takes stock of the World Bank's efforts and experience in building resilient transport systems. http://hdl.handle.net/10986/23685.

Climate Proofing ADB Investment in the Transport Sector: Initial Experience (ADB 2014): Presents transport case studies based on a selection of climate risk and vulnerability assessments conducted by ADB. Captures lessons learned and identifies opportunities to further mainstream climate risk management in transport sector investment projects. https://www.adb.org/sites/default/files/publication/152434/climate-proofing-adb-investment-transport.pdf.

Piloting the Use of Network Analysis and Decision-Making under Uncertainty in Transport Operations: Preparation and Appraisal of a Rural Roads Project in Mozambique under Changing Flood Risk and Other Deep Uncertainties. (Espinet, X, Rozenberg, J, Rao, K S, and Ogita, S 2018): This paper presents a methodology to identify key priority areas for transport investments. The methodology uses a geospatial data-driven approach and proposes an innovative economic analysis for project appraisal. The two main steps involve prioritizing road interventions based on a set of economic, social, and risk reduction criteria and assessing monetized and nonmonetized costs and benefits of road interventions under many scenarios covering the uncertainty on future risks and other factors. https://openknowledge.worldbank.org/handle/10986/29943.

B.2.8 • Water

Water Infrastructure Resilience: Examples of Dams, Wastewater Treatment Plants, and Water Supply and Sanitation Systems (Stip, C, Mao, Z, Bonzanigo, L, Browder, G, and Tracy, J 2019): Aims to inform water system managers on the importance of and measures to build the resilience of water service provision to natural hazards and climate risks while ensuring that water systems can safeguard service provision by reducing their exposure to the risks associated with natural hazards. http://hdl.handle.net/10986/31911.

Confronting Climate Change Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework (World Bank Group 2015): Outlines a pragmatic bottom-up process for assessing project risks that can support decision making and project planning under uncertainty, including climate risk management responses. http://hdl.handle.net/10986/22544.

Building the Resilience of WSS Utilities to Climate Change and Other Threats: A Road Map (World Bank Group 2018): Practical guidance for incorporating uncertainty into water supply and sanitation (WSS) utilities'—through design, planning, or operations—to help project developers design projects that consider current and expected climate change impacts and maximize their projects' adaptation and mitigation co-benefits. http://hdl.handle.net/10986/31090.

Resilient Water Infrastructure Design Brief (World Bank 2020): General guidance on resilient design principles of specific assets within a broader water utility system to allow project developers to verify that World Bank-financed infrastructure uses sound resilience design principles and contributes to the overall objective of utility resilience. Complements Building the Resilience of WSS Utilities to Climate Change and Other Threats: A Road Map (World Bank 2018). http://hdl.handle.net/10986/34448.

Guidelines for Climate Proofing Investment in the Water Sector: Water Supply and Sanitation (Asian Development Bank 2016): A step-by-step methodological approach to assist task teams in managing climate change risk in the context of water supply and sanitation investment projects. https://www.adb.org/documents/guidelines-climate-proofing-investment-water-sector.

Incorporating Climate Change Adaptation in Infrastructure Planning and Design (USAID 2015): This report presents an overview of potential impacts on typical infrastructure activities, adaptation responses, with guidance and checklists to follow for assessing infrastructure assets that are exposed to changing climatic conditions and selecting planning and management decisions. https://www.climatelinks.org/resources/incorporating-climate-change-adaptation-infrastructure-planning-and-design-overarching.

It also provides strategies for a climate altered future, including resilience for:

- **Sanitation:** https://www.climatelinks.org/resources/methodology-incorporating-climate-change-adaptation-infrastructure-planning-and-design-2.
- **Flood management:** https://www.climatelinks.org/resources/methodology-incorporating-climate-change-adaptation-infrastructure-planning-and-design-0.
- **Potable water:** https://www.climatelinks.org/resources/potable-water-incorporating-climate-change-adaptation-infrastructure-planning-and-design.

Appendix C: Zambia–Tanzania Interconnector Project

Country:	Zambia and Tanzania
Project name:	Zambia–Tanzania Interconnector Project
Project number:	P166099

Hypothetical reporting results of a climate and disaster risk stress test in project documents for a transmission and distribution project in Zambia

Overview

This case study is based on a series of projects that are being prepared to establish cross-border transmission capacity between the Southern African Power Pool and the Eastern Africa Power Pool to enable regional power trade. Project activities involve constructing transmission and distribution infrastructure between Zambia and Tanzania. As the Zambia portion of the series remains outstanding, the stress-testing analysis looks at the costs and benefits of a potential project scenario in Zambia, based on preliminary estimates from economic assessments. This potential project scenario includes financing the construction of transmission system infrastructure (including a 330 kV transmission line), and distribution network rehabilitation and expansion. We learned that in the project planning documents, the task team recognizes and accounts for the risks associated with Zambia's electricity sector relying on a single river basin, which results in a power sector that is vulnerable to seasonal and hydrological shocks.

Hypothetical excerpt from project appraisal document (PAD) economic analysis section

Decision point and switching scenario
After setting all climate parameters and baseline pessimism at 100 percent, we arrived at an NPV value of 78.5 and BCR of 1.06. This is above the NPV = 0 threshold we had decided on. Setting the baseline pessimism at 100 percent to identify the switching scenario, we learnt that climate impacts would have to be at 108 percent for the NPV to fall below the threshold.

After including climate and disaster risks into the project's preliminary economic analysis, the results show that the project is robust. Even if we take the most pessimistic baseline, and further assume that climate risks would have a high impact on the outcomes of the project, the NPV remains positive (table C.1). The project has considered the potential impacts of climate risks (such as fluctuating rainfall patterns and temperature increases) on its expected benefits by incorporating hardening measures—such as adding structural reinforcement to transmission and distribution lines—into the project design. This alone would provide a rating B for the resilience of the project. Figure C.1 shows that measures to address impacts from natural disasters would further strengthen the project.

Hypothetical excerpt from PAD annex

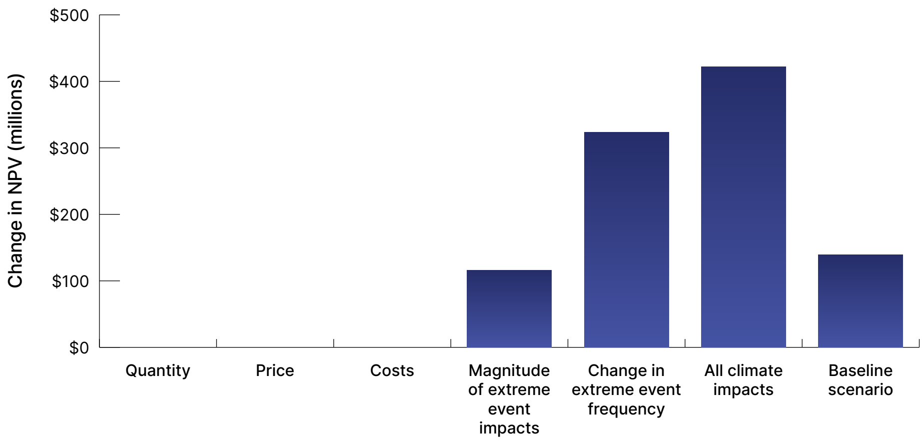
Methodology: To assess the impacts of climate change on the project outcomes, we used the

TABLE C.1 • Results under four extreme scenarios based (climate impact and baseline pessimism)

Adjusted NPVs and BCRs		Level of climate impact			
		Low		High	
		NPV ($, millions)	BCR	NPV ($, millions)	BCR
Baseline scenario	Optimistic	639.7	1.90	217.6	1.18
	Pessimistic	500.70	1.62	78.5	1.06

Note: The numbers in green indicate that, under both low and high climate impact scenarios and optimistic and pessimistic baseline scenarios, the NPV and BCR remain above an acceptable threshold (NPV > 0 and BCR > 1).

FIGURE C.1 • Sensitivity analysis



stress testing methodology outlined under Resilience Rating A. This involves two steps:

1. Selecting and reporting a baseline scenario that does not account for climate change.
We calculated the benefits as the difference in "with project" and "without project" system costs, with the former being two lines with a transfer capacity of up to 592 MW and the latter one line with a transfer capacity of up to 296 MW. The project also aims to finance 14,000 connections without which only 30 percent of planned connections in Northern and Muchinga Provinces will materialize.
The project expects to reduce duration of outages by 24 hours (one day) per year and help ZESCO, Zambia's state-owned power company, reach its target of a maximum of 36 hours of outages per year. The reported flow of costs is the project's CAPEX and OPEX. OPEX is assumed to be 2 percent of CAPEX per year.

2. Assessing the impact of climate change on the reported costs and benefits of the project.
We measured these by accounting for:

a. Projected changes in average conditions
b. Natural hazards most likely to impact the project location and assets
c. Projected changes in frequency and severity of the natural hazards

2a) Assessing the climate impacts from projected changes in average climate conditions: To assess the impact of changes in temperature and rainfall patterns on the outcomes of the project, we used the CCKP to assess the climate changes most likely to impact the performance of Zambia's power sector. Since the original project design and analysis already account for low hydrology, we mainly considered the impact of a rise in temperature on electricity transmitted.

To determine the extent to which changes in temperature would impact the expected benefits of the project, we referred to the *Good Practice Note for Energy Sector Adaptation* (see section B.2.3), which provides estimates of how temperature changes impact transmission line efficiency and substation capacity. We also assumed that the overall impact of temperature changes on the system are equal to impact on assets—that is, the power system behaves like the assets. Since the project design considers the impact of temperature increase on the infrastructure performance, the decrease in benefits is greater without the project than with it.

2b) Assessing climate impacts from natural hazards: After referring to ThinkHazard! and consulting the task team to select the hazards the project assets were most vulnerable to, we found that transmission and distribution infrastructure (poles and wires) is most vulnerable to damage from storms and wildfires, and substations are most vulnerable to floods.

To assess the impact of storms and wildfires, we created scenarios around the expected damages from weak, moderate, strong, and extreme events, and the percentage of CAPEX that would be spent to fix them, based on cost estimates for various components of transmission and distribution infrastructure from the task team. For weak storms, we assumed that no transmission infrastructure would be destroyed (as it is more resilient) but 5 percent of the distribution poles would be damaged, resulting in repair costs = 5 percent of the amount spent on poles. For stronger storms, we assumed that some percentage of transmission infrastructure, and a substantial percentage of distribution infrastructure would be damaged, and then calculated repair costs by adding the two together. For wildfires, which are reported to lead to higher damages than wind, we increased the percentage impacts on CAPEX.

2c) Climate impacts based on changes in frequency/severity of natural hazards:
Floods: According to ThinkHazard!, the hazard level may increase in the future as a result of climate change, while CCKP indicates that the region could experience increases in the intensity of extreme precipitation events. Based on this information, we doubled the probability of floods in the high-impact scenario and kept it unchanged in the low-impact scenario.

Wildfires: According to ThinkHazard!, climate change could lead to an increase in frequency of wildfires in this region, fueled by an increase in temperature and greater variance in rainfall. Areas that have already been impacted by wildfires are likely to experience longer fire seasons. Climate change could also lead to an increase in fire severity. Even areas that have previously not been impacted by wildfires could experience an increase in fire hazard. Based on this, we doubled the likelihood of wildfires in the high-impact scenario and kept it unchanged in the low-impact scenario.

Appendix D: Meghalaya Integrated Transport Project

Country:	India
Project name:	Meghalaya Integrated Transport Project
Project number:	P168097

Hypothetical reporting results of a climate and disaster risk stress test in project documents for a transport project in India

Overview

The project is based in Meghalaya, a small and hilly state in northeastern India. According to the PAD, the road density of Meghalaya (0.48 square kilometers) is below the country average (1.7 square kilometers) and there is no effective rail or air connectivity. The project aims to improve transport connectivity and efficiency and modernize transport sector management. The project development indicators include:

- Percentage of population served with improved transport connectivity
- Percentage of road network in good and fair conditions as a share of total classified roads
- Reduced average travel time/operating cost on project corridors
- Meghalaya Transport Board established and functional
- Road network under performance-based maintenance contracts.

Results of a hypothetical climate and disaster risk stress test on the PAD's economic analysis section

1. Summary of results

A stress test that accounted for climate risks (including changes in average conditions and disaster shocks) on the project's economic analysis showed that even when considering high climate impacts with a baseline pessimism of 100 percent, the project generates an NPV > 0, and a BCR > 1 (table D.1). We assessed the impacts of changes in average conditions based on their effects on the project's capital and operating costs and its ability to reduce vehicle operating costs and travel time costs. Based on information available on ThinkHazard!, the disaster shocks considered included flooding and landslides. Figure D.1 indicates the results of the sensitivity analysis when baseline pessimism and climate impacts are both set at 100 percent; it shows that at those levels of pessimism and climate impacts, change in the frequency of extreme events seems to drive the change in NPV.

2. Detailed description of the analysis

Hazard selection

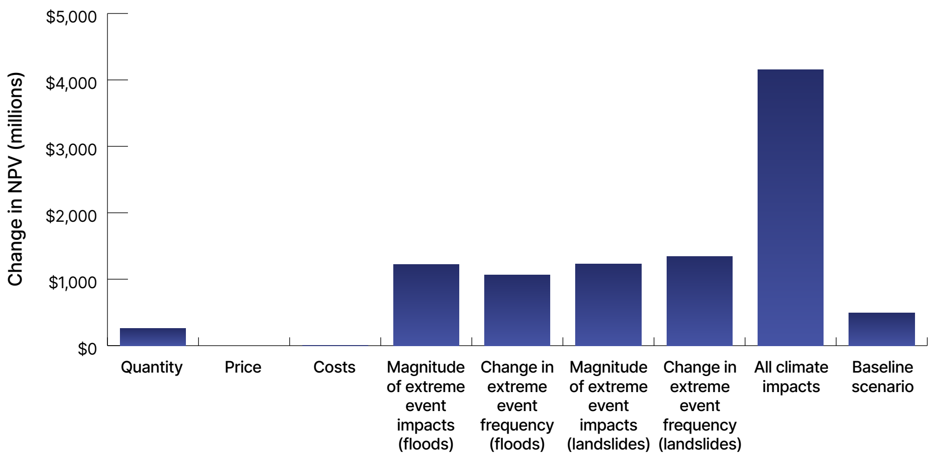
ThinkHazard! classifies flooding, landslides, and extreme heat as high risks to the area and its infrastructure. Considering that the project is not located in a temperature-based vulnerability hotspot, we only analyzed the impact of flooding and landslides on the project's expected costs and benefits.

TABLE D.1 • Results under four extreme scenarios

Adjusted NPVs and BCRs		Level of climate impact			
		Low		High	
		NPV ($, millions)	BCR	NPV ($, millions)	BCR
Baseline scenario	Optimistic	9,015.80	3.24	4,858.96	1.83
	Pessimistic	8,519.35	2.89	4,362.5	1.68

Note: The numbers in green indicate that, under both low and high climate impact scenarios and optimistic and pessimistic baseline scenarios, the NPV and BCR remain above an acceptable threshold (NPV > 0 and BCR > 1).

FIGURE D.1 • Sensitivity analysis



Analysis baseline: The baseline scenario analyzed the costs and benefits associated with the construction of a network of 10 roads across Meghalaya State between 2020 and 2044.

Costs included the CAPEX associated with the initial road construction and any long-term changes to the structure in the future. Benefits: We measured project benefits as a reduction in the following between "with project" and "without project" scenarios:

1. Motorized vehicle operating costs
2. Motorized vehicle travel time costs
3. Nonmotorized vehicle operating costs
4. Nonmotorized vehicle time costs
5. OPEX borne by government agencies

Incorporating impacts from change in average climate conditions

Meghalaya State experiences the highest rainfall in the country and is very vulnerable to extreme precipitation and flooding (Mishra, Kumar, and Garg 2017). Within the region, however, there is high spatial variability in the amount of rainfall and the extent of temperature change. Based on localized future projections of rainfall and temperature change, we identified some vulnerability hotspots.[19]

Change in precipitation: Rainfall is projected to increase by 3–7 percent in the near term, 3–6 percent in the medium term, and 5–13 percent in the long term (by 2100) under RCP 2.6, 4.5 and 6.0. Our project infrastructure touches some of the precipitation-based vulnerability hotspots identified.

Change in temperature: Temperatures are projected to increase by 2.2–3.5°C by 2100, but our project does not lie in the temperature-based vulnerability hotspots.

As Meghalaya is expected to experience an increase in rainfall, this is likely to increase operating expenditures on road maintenance, particularly in the high-impact scenarios. In this case, we did not have historical data on exact percentages, so we consulted transport experts to arrive at estimates.

To calculate the impact of an increase in precipitation, we treated frequent heavy precipitation events like "small floods"—that is, floods that impact the performance and accessibility of roads for up to 10 days but cause limited damage to the assets. We discuss the impact of larger floods—which occur less frequently but cause significant damage to the assets—in the natural hazards section below. We assumed that small floods lead to no increase in CAPEX and only lead to an increase in user costs when the roads are flooded (for example, due to vehicles having to make a longer journey or drive more slowly) and some increase in OPEX (for clearing roads and culverts, and more frequent maintenance). We used the following equation to calculate the increase in user costs:

Change in user costs =

$$(1-\alpha) * \text{user cost without avg. climate change} + \alpha * \text{ratio} * \text{user cost without avg. climate change}$$

where **α** is the fraction of time during the average year when the road is affected by frequent floods, and *ratio* is the factor by which vehicle speed is affected by frequent floods. We determined the estimates for **α** and the *ratio* through consultations with experts and discussions within the task team (table D.2).

Incorporating impacts from disasters

Based on information from ThinkHazard!, the project design, and experience from previous projects, the climate and disaster stress test considered flooding and landslides. Flooding events can lead to an increase in repair and reconstruction costs, loss of services provided by the roads (through traffic disruptions and road closures), and out-of-system impacts, such as business shutdowns, disruption of utility services, and so on. Since the project aims to build roads that are to a certain extent resilient to floods, we assumed that the assets would not be damaged by weak-intensity events, and the "without project" costs of floods would be higher than the "with project" costs. We used the following equation to calculate the impact of floods on user costs (table D.3):

TABLE D.2 • Estimates for α and ratio for different periods and impact scenarios

	With project (low-impact scenario)	With project (high-impact scenario)	Without project (low-impact scenario)	Without project (high-impact scenario)
α				
2030	0	0.01	0.01	0.02
2044	0.01	0.01	0.02	0.03
Ratio				
2030	0	0.2	0.2	0.25
2044	0.2	0.25	2	2.5

TABLE D.3 • Estimated impact of floods on user costs

Prob(a)	Loss of service with project (low-impact scenario)	Loss of service with project (high-impact scenario)	Loss of service without project (low-impact scenario)	Loss of service without project (high-impact scenario)
0.1	0.03	0.06	0.05	0.08
0.01	0.08	0.11	0.11	0.16
0.001	0.14	0.19	0.22	0.27

User cost with floods =

(1-Prob(α) ∗ *LossOfServices*) ∗ User cost without floods + Prob(α) ∗ *LossOfServices* ∗ Ratio ∗ User cost without floods

where *Prob(α)* refers to probability of flooding event and *LossofServices* refers to the proportion of days in a year when the roads are inaccessible due to large floods. Since we have already accounted for a change in user costs, we kept out-of-system costs as zero.

We determined the estimates of percentage increase in CAPEX through consultations with local transport experts and calculated the increase in CAPEX by multiplying the estimated percentage damage to roads to the total CAPEX incurred.

To analyze the impact of landslides on user costs and CAPEX, we replicated the methodology used for analyzing the impact of floods (table D.4).

Changes in frequency of disasters

Incorporating the impacts in change in frequency (and severity from disasters)

Floods: ThinkHazard! Indicates that the hazard level may increase in the future as a result of climate change. According to CCKP, there is considerable uncertainty around projections of local long-term future precipitation trends in India under all emission scenarios, but there is agreement that the intensity of extreme precipitation events in northern India will increase. Between 2020 and 2039, the number of very wet days is projected to increase by 21.79 percent in under RCP 8.5, which could increase flood risk. Based on this information, and in the spirit of a stress test, we doubled the probability of floods in the high-impact scenario and kept it unchanged in the low-impact scenario.

Landslides: According to ThinkHazard!, climate change could alter the slope and bedrock stability in the area due to changes in precipitation and/or temperature. But it is difficult to predict the location and timings of such events. We assumed that the probability of landslides would also double in the high-impact scenario, while remaining unchanged in the low-impact scenario.

TABLE D.4 • Estimated impact of landslides on user costs

Prob(a)	Loss of service with project (low-impact scenario)	Loss of service with project (high-impact scenario)	Loss of service without project (low-impact scenario)	Loss of service without project (high-impact scenario)
0.1	0.05	0.08	0.07	0.10
0.01	0.11	0.16	0.12	0.18
0.001	0.22	0.27	0.23	0.29

Appendix E: Agricultural Technology and Agribusiness Advisory Services Project

Country:	**Uganda**
Project name:	**Agricultural Technology and Agribusiness Advisory Services (ATAAS) Project**
Project number:	**P109224**

Hypothetical reporting results of a climate and disaster risk stress test in project documents for an agriculture project in Uganda

Overview

Building on previous World Bank engagement to increase the agricultural productivity and incomes of participating farmers, the project focused on strengthening agricultural research and extension systems for improved technologies and advisory services. However, changing rainfall patterns, drought, pest outbreaks, and flooding—challenges exacerbated by climate change—put the project development objectives of increasing crop yields and farmer incomes at risk. Meanwhile, the need to set up irrigation systems, increase input intensity, and rehabilitate storage facilities or washed-out roads also threatened to increase costs. When combined with other non-climate risks, such as implementation delays or government turnover, these challenges could have led to reduced benefits, increased costs, and significant project underperformance. But including activities to manage the agriculture sector's high sensitivity to climate change and disasters increased the project's resilience, potentially also increasing its net benefits under climate and disaster scenarios compared to a "without project" scenario. This sample write-up of the results from a hypothetical climate and disaster risk stress test are based on the project's economic analysis. Both the analysis and results are hypothetical. Estimates are based on the project's economic financial analysis (EFA), a literature review, climate data sources, and other approximations. Best practice entails engaging with the task team and on-the-ground expertise for more accurate estimates.

Results of a hypothetical climate and disaster risk stress test on the PAD's economic analysis section

1. Background of the analysis

Identifying key disasters: According to ThinkHazard!, there is a high risk of river flood, landslide, and wildfire, and a moderate risk of water scarcity and extreme heat.[20] Agriculture in Uganda is mainly based on rainfed and subsistence farming, making the sector particularly vulnerable to changes in rainfall patterns and drought (CIAT and BFS/USAID 2017). In 2020, Uganda was also one of the East African and South Asian countries hit by the worst locust infestation for decades (Muhumuza 2020). We therefore considered drought/change in rainfall patterns, pest outbreaks, and flooding as the three key disasters in this analysis.

Optimistic and pessimistic project scenarios: As a baseline for the analysis, we chose optimistic and pessimistic project scenarios based on the project's EFA. The optimistic scenario reflects the expected flow of costs and benefits under the project where costs are project investment costs and benefits were calculated as the net of "with project" and "without project" interventions over the EFA's 20-year timeframe. We assumed "with project" benefits as gains from:

- Increased yields from growth in total factor productivity (TFP)
- Increased yields from more intensive use of inputs
- Shifts in the enterprise mix to more profitable commodities, and
- Improved marketing, yielding higher farm-gate prices from stronger agribusiness and greater integration of smallholders in the value chain.[21]

Almost all ATAAS investment costs are off-farm costs, focused primarily on research and extension.[22] The pessimistic scenario reflects benefit and cost streams in which the project fails to induce TFP spillovers to farmers not receiving inputs (calculated as a scenario in the EFA).

Climate change scenarios: We based the climate change scenarios for this analysis on RCP 2.6 and RCP 8.5, representing a range of low- to high-impact scenarios. While RCP 8.5 is considered unrealistically high by some, we used the scenario to represent a high climate change impact scenario for stress testing purposes. We also used the CMIP5 models from the IPCC's Fifth Assessment Report for the analysis.

Incorporating impacts from change in average climate conditions: To evaluate the impacts of changing average climate conditions on crop yields, we used data for the sub-Saharan Africa region (Hallegatte et al. 2016) and Uganda (RegioCrop data platform).[23] Where RegioCrop country-specific crop data was available, we used those numbers and compared them with regional data from Hallegatte et al (2016). Where discrepancies existed, we included a wider range of possible impacts in the low and high climate impact estimates to reflect uncertainty.[24] We also assumed that impacts on crop prices would remain the same in the event of yield increases or decreases—for example, a drop in yields might not reflect a subsequent increase in prices due to trade, lag in price responsiveness to changes in supply, and lack of bargaining power of farmers to set prices.

Incorporating impacts from drought/change in rainfall patterns, pests, and flooding: We based our estimates of impacts on "without project" yields on a literature review of past extreme events in Uganda/East Africa (Mubiru et al. 2018; Leng and Hall 2019; FAO 1997; FAO and WFP 2008). As the project includes a focus on developing drought-resistant seeds, integrating pest management techniques, and sustainable land management practices, we assumed that the impact on "with project" yield would be lower than on "without project" yield. Almost all ATAAS investment costs are off-farm costs, related to research and extension, rather than infrastructure, which might be more directly impacted by disasters. We based the estimated out-of-system costs—such as setting up additional irrigation mechanisms, time for gathering water supplies, and cost of rebuilding damaged infrastructure due to floods—on farm labor and input costs provided in the project's EFA. For a non-hypothetical example, however, it is important to clearly define and discuss out-of-system costs should always be with technical experts who are familiar with the project. Other resources on cost estimations could include sector or country postdisaster needs assessments.[25]

Incorporating change in disaster frequency: We based the estimates of projected change in disaster frequency on a range of CMIP5 models from the CCKP and a literature review. Consultation with climate modeling experts, data from local weather stations, and technical experts who are familiar with recent trends could help to further inform the analysis.

- **Droughts:** We based the estimated changes in drought/rainfall pattern frequency on CCKP projections in annual severe drought likelihood for Uganda.[26] Although projections contain a high degree of uncertainty, trends show a slight increase in the projected range of change in annual severe drought likelihood, while the median or minimum projected change is negligible under both RCP 8.5 and RCP 2.6 scenarios. Increased average temperatures—especially during Uganda's dry season from June to August—may exacerbate drought and impact the length of the growing season.

- **Pests:** We based the estimated changes in the projected frequency of pest outbreaks on internal calculations and a literature review. East Africa's severe locust outbreak of 2019–2020 is similar to the one in 1956. Because two major outbreaks occurred in the last century, we estimate a 1-in-50 likelihood of such a pest outbreak each year, in current conditions. Other studies have shown that locust breeding may have been affected by the Indian Ocean Dipole, which has led to wetter conditions and improved locust breeding grounds (WMO 2020). Projections suggest that the situation that may have led to the latest pest outbreak could double in frequency in the future (Cai et al. 2018). For a strong intensity (1-in-50-year) event, the high estimate changes from a 50-year to a 30-year return period. We interpolated estimates for the change in frequency of less severe events from there.

- **Flooding:** We based the estimated changes in projected frequency of flooding events on CCKP data for Uganda. The future change in rainfall of very wet days—defined as the top 5 percent of precipitation events—reflects a range of outcomes and uncertainty. This analysis assumes a maximum increase in frequency of around 40 percent under a high-impact RCP 8.5 scenario in the 2030 timeframe, and at minimum, remaining relatively unchanged. RCP 2.6 projections reflect a similar range. The projected changes in very wet days by month show the greatest increases will overlap during Uganda's rainy seasons—April through May and August through October—which could further exacerbate flooding events (figure E.1).

Establishing a threshold: The metric for the stress test is the project's NPV. The level of acceptable performance under worst-case scenario shocks is an NPV > 0.

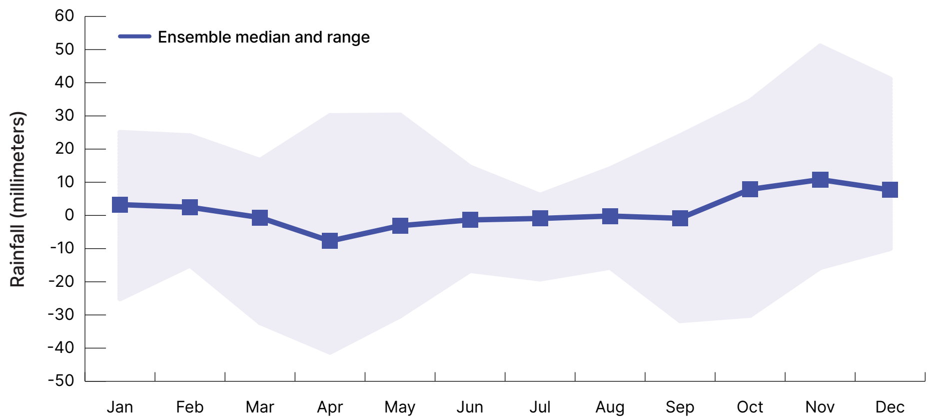
2. Results

Table E.1 provides the results of our analysis using the RiST tool, which stress-tests the impacts from changing average climate conditions, disasters, and changes in disaster frequency on the project's economic analysis. The results reflect scenarios based on climate impact (RCP 2.6–8.5) and non-climate-related project challenges (in the event of low TFP spillovers). The four scenarios reflect model parameters in the RiST tool—with the worst-case scenario reflecting high climate impacts combined with pessimistic project performance due to non-climate-related factors.

Failure scenarios

The likelihood of project failure or significant underperformance is unlikely. For the NPV to fall below zero, parameters for climate impacts would have to be above 557 percent (where 100 percent is considered the high/worst case scenario). Failure is also unlikely,

FIGURE E.1 • Projected change in monthly precipitation for Uganda under an RCP 8.5 scenario (2020–2039)



Source: CCKP

TABLE E.1 • Results under four extreme scenarios

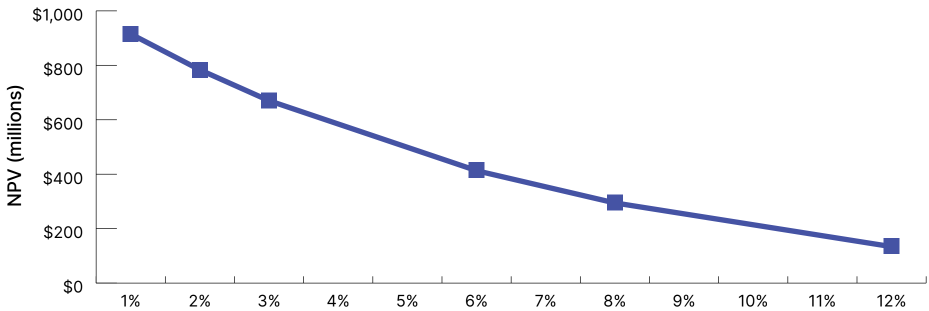
Adjusted NPVs and BCRs		Level of climate impact			
		Low		High	
		NPV ($, millions)	BCR	NPV ($, millions)	BCR
Baseline scenario	Optimistic	699.57	2.65	568.14	1.53
	Pessimistic	100.16	1.24	119.58	1.11

Note: The numbers in green indicate that, under both low and high climate impact scenarios and optimistic and pessimistic baseline scenarios, the NPV and BCR remain above an acceptable threshold (NPV > 0 and BCR > 1).

given that the NPV remains above zero despite a relatively high discount rate (12 percent compared to the typical 6 percent) in this analysis and very pessimistic cost assumptions for the identified disasters (figures E.2 and E.3). Risk reduction activities included under the project help increase the project's NPV in the event of climate disaster impacts. For example, the project includes a focus on developing drought-resistant seeds, so the impacts of drought or change in rainfall patterns are higher without the project than with it.[27] Similarly, the impact of pest outbreaks on crop yields is mitigated by the pest management techniques the project established for Fall Army Worm, and crop varieties that can better withstand Cassava Mosaic Disease, Brown Streak Disease, and Banana Wilt Disease.[28] Project interventions for sustainable land management practices also help to lessen the impacts of flooding while comparatively increasing project benefits.[29]

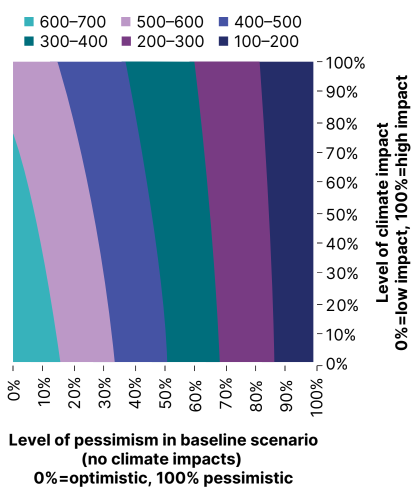
The horizontal axis in figure E.3 depicts pessimism due to non-climate-related challenges that may affect the project—such as low TFP spillovers—while the vertical axis depicts pessimism due to climate and disaster risk. The graph, which is a standard output of the RiST tool, shows how different scenarios can be combined with different levels of climate change

FIGURE E.2 • Impact of the discount rate on project NPV



impact. If the lines slant diagonally, it means that both project pessimism and climate impacts are affecting the project; if they are vertical, then only non-climate factors are affecting the project; if they are horizontal, then only the pessimism of climate and disaster risks are affecting the project. This NPV map suggests that project failure is unlikely even under a worst-case 100 percent climate impact and project pessimism scenario.

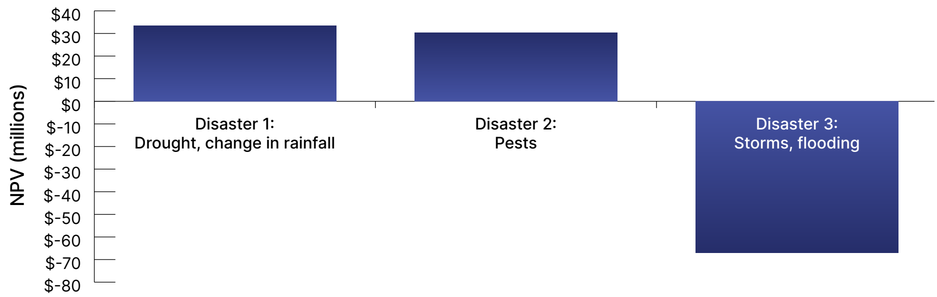
FIGURE E.3 • NPV map switching scenario (output of the RiST tool)



While project underperformance is unlikely when all the disasters are combined, the results of the analysis show that the project may be particularly vulnerable to floods. Based on hypothetical assumptions about the costs associated with severe flood damage to crop yields, storage, labor for rebuilding, and access to markets, as compared to the risk management measures in the project, the project NPV could fall below zero in a high climate impact, pessimistic project scenario. Figure E.4, an output of the RiST tool that shows the change in project NPV based on each individual disaster, highlights the disaster that the project may be most vulnerable to. Given that we applied extremely high out-of-system costs to this hypothetical analysis,[30] the likelihood of underperformance is low. Still, the task team should consider undertaking a more nuanced analysis and including further measures—for example, nature-based solutions such as agroforestry woodlots, grass bunds and watershed reclamation to control floods. During implementation, the project may also wish to explore further contingency measures that promote early warning systems, adaptive management, stormproof infrastructure, and a plan for assisting farmers in the event of a disaster.

Figure E.4 shows the change from each disaster compared to a project NPV that considers only non-climate impacts and the effects of change in average climate conditions. Depending on whether the project

FIGURE E.4 • Changes in project NPV, based on each disaster



incorporates risk management measures and the cost of climate impact, the NPV may rise or fall, highlighting which disaster the project is likely most vulnerable to and the benefits of risk management measures. Note: the main purpose of the RiST tool is a stress test, and the robustness of the analysis will depend on the robustness of the inputs/estimates.

Appendix F: Water Security in the Dry Corridor of Honduras Project

Country:	**Honduras**
Project name:	**Water security in the dry corridor of Honduras**
Project number:	**P169901**

Hypothetical reporting results of a climate and disaster risk stress test in project documents for a water security project in Honduras

Overview

This project aims to improve water service delivery and strengthen water governance in selected areas of Honduras's dry corridor. The project will finance the local water harvesting reservoir systems, Sistemas Integrados de Agua Segura (SIAS), basic sanitation units,[31] and infrastructure modernization in the middle Nacaome Basin's José Cecilio del Valle Dam and the downstream water supply system. The latter includes installing gates on the spillway to increase storage, improve reservoir operation, and increase the usable capacity of an existing hydropower plant; building a centralized water treatment plant and dedicated pipeline to increase water quality and supply for four municipalities downstream; and dam safety interventions.

The project will also support a community-based integrated micro-watershed management approach in the areas serviced by the SIAS, by strengthening community-driven water governance, climate-smart agriculture, and better-value chain practices.

Future changes in average temperature and precipitation patterns can impact some of the gains from irrigation and water supply and sanitation infrastructure. Extreme events—including tropical storms, flooding, and droughts—can also reduce benefits from infrastructure investments. Honduras has experienced 17 storms, 14 riverine floods, and 10 droughts since 1990.[32] The infrastructure for this project is in low-lying areas that are particularly vulnerable to flooding and high winds from storms.

Hypothetical excerpt from PAD economic analysis section that fulfills A-rating criteria (risk stress testing)

Including climate and disaster risks in the project's economic analysis shows the project is robust. Without including climate impacts, the NPV in the optimistic scenario is $67 million, while the NPV in the pessimistic scenario is $50 million. When climate impacts are added at a low level of impact, the NPV increases to $72 million (table F.1). This increase despite a reduction in crop yield and water supply is because the "without project" alternative is relatively vulnerable to climate impacts and OPEX costs are higher. Under a high-impact climate scenario, the project's NPV decreases to $55 million.

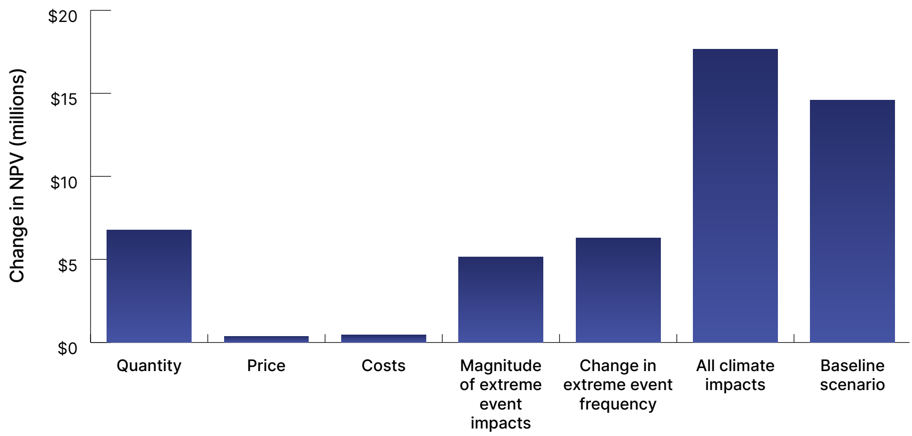
In the worst-case scenario—pessimistic scenario (OPEX costs overruns, only one

TABLE F.1 • Results under four extreme scenarios (climate impact and baseline pessimism)

Adjusted NPVs and BCRs		Level of climate impact			
		Low		High	
		NPV ($, millions)	BCR	NPV ($, millions)	BCR
Baseline scenario	Optimistic	72.4	1.86	54.5	1.64
	Pessimistic	55.9	1.61	39.9	1.43

Note: The numbers in green indicate that, in both low and high climate impact scenarios and optimistic and pessimistic project scenarios, the NPV and BCR remain above an acceptable threshold (NPV > 0 and BCR > 1).

FIGURE F.1 • Sensitivity analysis



crop per year instead of two, and no crop diversification) with high level of climate impacts—the NPV is about $40 million and the BCR is 1.43. This indicates that the project is highly robust to climate impacts. The climate impacts would have to be more than four times higher than the worst case to make the NPV fall below 0.

The sensitivity analysis (figure F.1) shows that the NPV is more sensitive to climate than other impacts. Changes in quantities of water and crops due to average climate conditions, disasters, and change in disaster frequency all have similar levels of impact on NPV, and there is little sensitivity to the price impacts of average climate conditions. Hence, measures to address impacts from both average conditions and disasters will further strengthen the project. Additional exploration at the local level would be beneficial in identifying opportunities to address specific risks to the infrastructure from extreme events. Using more heat- and drought-resistant crops, flood-resilient practices and implementing measures to reduce water quality degradation will also be beneficial.

Analysis of climate impacts: This assessment of the impacts of climate change on the outcomes of the project uses the RRS methodology for Resilience Rating A (World Bank Group 2021). This involves:

1. Selecting and reporting optimistic and pessimistic baseline scenarios that do not account for climate change

2. Assessing the impact of climate change on the project's reported costs and benefits in the optimistic and pessimistic scenarios. The impacts of climate change are measured by accounting for:

    - Projected changes in average conditions
    - Natural hazards most likely to impact the project location and assets
    - Projected changes in frequency and severity of the natural hazards.

This analysis includes the impacts of average changes due to climate change on the project and the impacts of natural hazards and disasters. For changes in average conditions, the impacts on the projects considered are: a decrease in potable water supply; a decrease in water available for irrigation; and the impacts on crop yields and crop prices from decreased water for irrigation and changes in temperature. OPEX costs are also expected to increase due to:

- Warmer temperatures, which will increase evapotranspiration rates and degrade water quality—for example, due to increased growth of algae, microbes, and invasive species
- Changes in precipitation patterns, with heavier rainfall leading to increased sedimentation, increased nutrient loads, and eutrophication.

The major natural hazards in Honduras—droughts, tropical storms, and flooding (World Bank 2012)—are all included in the analysis. Climate change scenario selection is based on RCP 2.6 and RCP 8.5 emission scenarios to reflect a range of low and high impacts. According to A-rating guidance, RCP 8.5 is considered excessively pessimistic. However, the analysis uses this scenario to provide a more conservative estimate of climate impacts.

Baseline scenario: The baseline economic analysis without climate impacts considers two future scenarios—one with and one without project infrastructure investment interventions. The NPV is estimated using the summary net incremental cost and benefits flows. This forms the "optimistic scenario" for the no-climate-change baseline.

A second baseline without climate impacts, the "pessimistic scenario," is also considered, in which the "with-project" scenario has 10 percent cost overruns and the number of crops per year falls to one instead of the two assumed in the optimistic scenario. There is no crop diversification with cassava and chilies, as assumed in the optimistic scenario.

Climate impacts from projected changes in average climate conditions: The analysis incorporates impacts of average conditions on crop yields and prices using estimates from literature (Hannah et al. 2017, Havlík et al. 2015). Impacts on potable water supply and OPEX costs were more challenging to estimate. Estimates for neighboring Nicaragua find that water balance in 2050 may fall by 36–64 percent (World Bank 2013). More conservative figures are used in the analysis for the impact on water supply, which assumes a reduction of 7–10 percent reduction in the "with-project" scenario and 10–15 percent in the "without-project" scenario. The baseline economic analysis uses a shadow price for water. Based on internal estimates, it is assumed this will increase by about 1–2 percent in 2050.

Climate impacts from natural hazards: The analysis considers and differentiates the impacts of drought, floods, and storms on yields, water supply, hydroelectricity generation, and repair and reconstruction costs with and without the project. Estimated impacts on yields and water supply are based on internal estimates. The impact of drought on hydroelectricity is based on a global study (van Vliet et al. 2016), since no regional estimates were available. Estimates of repair and reconstruction costs from floods are taken from a report prepared by Miyamoto—an earthquake and structural engineering firm—for the World Bank (Miyamoto International 2019). Estimates could be improved by conducting local hydrological studies to identify the level of flooding at the infrastructure site. Local studies can also inform specific measures (such as engineering improvements) to decrease vulnerability to floods.

Climate impacts based on changes in frequency of natural hazards: Changes in the frequency of natural hazards are estimated using CKKP indicators of projected change in annual drought likelihood and projected change in rainfall of very wet days. Changes in frequency of natural hazards have a significant impact on NPV (figure F1).

Summary: Overall, the "without project" alternative has high OPEX costs and is more vulnerable to climate impacts. The project has lower operating costs and higher benefits, and builds more resilience to climate impacts. The project remains "viable" under the stress test's worst-case scenario.

Endnotes

1. This analysis uses the estimated change in frequency as a proxy for incorporating estimated changes in severity/intensity of natural disasters and presents options for a more sophisticated approach that also considers change in severity.
2. Optimistic and pessimistic scenarios may be identical, depending on the project. In cases where the existing CBA has more than two scenarios, the team can either select the two most extreme scenarios or use all scenarios as possible baselines. Note, however, that the RiST tool can accommodate only two baselines, while the methodology presented in this guidance note can accommodate more. If an analysis includes many scenarios, it will require specific methodologies to extract manageable information from the set of scenarios. A review of existing approaches is available in Marchau et al. (2019).
3. Climate change is sometimes expected to bring benefits—for example, increasing yields in cold areas. In cases where benefits are possible, then the low-impact scenario is the most optimistic (highest possible benefits), and the high-impact scenario is the most pessimistic (lowest possible benefits or highest possible costs).
4. RCPs are greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change (see box 10.1 in section 10.2 for details). We recommend using RCP 2.6 to analyze low-impact scenarios and RCP 6.0 to analyze high-impact scenarios. RCP 8.5 can also be used, though emissions in RCP 8.5 are now considered unrealistic with recent progress in green technologies and the implementation of climate policies.
5. Note that the results and robustness of the analysis will depend on the quality of inputs and estimates. In the absence of specific country information, the *World Bank Discount Rate Technical Note* (World Bank internal resource, available at https://worldbankgroup.sharepoint.com/sites/ggs/SitePages/Detail.aspx/Blogs/mode=view?_Id=2892&SiteURL=/sites/ggs) suggests using 6 percent.
6. Note that the task team can still incorporate risk management measures and increase its NPV or BCR—especially for risks the project is particularly exposed to.
7. The graph shows the change from disasters, whereas a project NPV merely considers non-climate impacts to the project baseline and the effects of changes in average climate conditions.
8. There are many ways to define the "without project" scenario—for example, assuming a continuation of the present situation (with no additional investment) or assuming an alternative project is implemented with different characteristics. The choice of scenario, which ensures that the CBA can inform the decision to implement the project, will depend on the context.
9. BCR is a metric that needs to be used carefully, because it changes depending on how costs and benefits are defined. In practice, if a cost is relabeled as a negative benefit, then the ratio changes. NPV is more stable and is preferrable when deciding whether an investment is profitable.
10. https://worldbankgroup.sharepoint.com/sites/ggs/SitePages/Detail.aspx/Blogs/mode=view?_Id=2892&SiteURL=/sites/ggs (World Bank internal resource).
11. All numbers in table 4.2 are hypothetical, but the International Finance Corporation forestry tool offers a way to estimate impacts of climate change on forestry yield.
12. Use this GFDRR tool (https://www.gfdrr.org/en/100-year-flood) to calculate the likelihood of experiencing different hazard events in a given year.
13. Note that these would not be traditional "frequentist" probabilities, since only one scenario will eventually reveal "correct". Instead, they are "subjective" or Baysian probabilities, which represent our belief in the likelihood of various outcomes.
14. A first problem is that not all models are independent. They have been developed based on a unique knowledge base and there are only a few main architectures for them, so these models are likely to share the same biases—in a Baysian approach, for example, the additional information from models is dominated by the prior. In practice, experts usually disagree on the probability of various possible outcomes, making it very difficult to build a consensus.
15. For an illustration of this approach with the Thames Barriers, see Ranger et al. (2010).
16. https://www.rand.org/topics/robust-decision-making.html.
17. For guidance on impleaenting this, see Appendix 1 of World Bank Group (2021). For a review of methodologies, see Marchau et al. (2019).
18. Based on data from OasisHub (https://oasishub.co/) and the Open Data for Resilience Index (https://index.opendri.org/).
19. These were regions that were more susceptible to changes in climate (Mishra, Kumar, and Garg 2017).
20. https://thinkhazard.org/en/report/253-uganda.
21. Crops in the analysis include: sorghum, maize, cassava, Irish potato, sweet potato, millet, sim, ground nut, beans, banana, coffee, cotton, and rice.
22. Uganda ATAAS Economic and Financial Analysis.
23. Climate projections from Hallegatte et al. 2016 are based on the HadGEM2-ES, IPSL-CM5A-LR, GFDL-ESM2M, and MIROC-ESM-CHEM models (Rozenberg and Hallegatte 2015), while those from RegioCrop are based on IPSL-CM5A-LR; GFDL-ESM2M, MIROC5, and HadGEM2-ES models (http://regiocrop.climateanalytics.org/choices).
24. Note that for this EFA, we aggregated project benefits as a single stream of benefits, averaging out the data from 13 crops rather than itemizing them by crop or intervention. A more accurate analysis would use itemized flows of project benefits and present these in gross rather than net form.
25. See, for example, World Bank (2016) and GFDRR. Post Disaster Needs Assessments. https://www.gfdrr.org/en/post-disaster-needs-assessments.
26. "Severe drought" is based on the Standardized Precipitation Index (SPEI), which captures the cumulative balance between water gain and loss across an interannual timescale. Severe drought is likely once the SPEI drops below -2. CCKP uses the 12-month integrated SPEI to compute the annual likelihood of severe drought.

27. We assumed that negative impacts on yields were 15 percent lower *with* the project than *without* the project for weak and moderate intensity events, 10 percent lower for strong intensity events, and the same in the most extreme case of drought. A weak intensity event is defined as a 1-in-5-year occurrence; a moderate intensity event as 1-in-10-year occurrence; a strong intensity event as a 1-in-100-year occurrence; and an extreme intensity event as a 1-in-1,000-year occurrence.
28. For pest outbreaks, we assumed negative impacts on yields to be 20 percent lower with the project than without the project for weak and moderate intensity events, 10 percent lower for strong intensity events; and the same in the most extreme case.
29. For storms/flooding, we assumed negative impacts on yields to be 10 percent lower with the project than without for weak, moderate, and strong intensity events; and the same in the most extreme case.
30. The analysis assumed a tripling of labor costs per hectare on the final number of project hectares in a high-impact scenario.
31. The units will comprise a basic latrine, a septic tank, and a handwashing sink. The project will prioritize families living upstream of the local water reservoirs.
32. EM-DAT database. https://www.emdat.be/. Accessed November 4, 2020.

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The disaster and climate risk stress test methodology has been designed to highlight risks to project outcomes over long time horizons, accounting for risks along three dimensions:

» Changes in average climate conditions.

» Impacts from natural disasters, with current frequency and intensity.

» Changes in the frequency of disasters due to changes in average climate conditions.

The methodology is linked to the World Bank Group's Resilience Rating System and provides a tool and approach to obtain an A rating for resilience of a project, the first of two dimensions covered by the resilience rating methodology. The risk stress test methodology uses ranges for various impacts of climate change and disaster on a project's costs and benefits and identifies plausible risks for its viability and desirability.

The objectives of the risk stress test analysis are to:

» Support project developers in identifying possible risks to a project and incorporating risk mitigation measures where necessary.

» Better inform decision makers, investors, and other stakeholders on project robustness.

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