Compendium Volume:

Climate-Resilient Investment in Sub-Saharan Africa

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How to Use this Report

Underlined text will take you to its respective location, for instance, clicking on this hyperlink will jump you to Chapter 2

While **the focus of this note is on the project design level,** it remains **crucial to understand the particular policy, regulatory, and institutional context in which the project is situated.** Hence, all project design decisions should be taken with both the policy landscape and local capacity in mind, acting as either enablers or barriers for implementation. This note is part of a larger Compendium Volume , with these cross-cutting issues discussed in Chapter 2 of the Compendium Volume Chapter 1 of the Compendium provides a general introduction, with the remainder of the Compendium broken down into two parts: Part 1 houses sector-specific guidance notes (including this one), while Part 2 provides a series of more detailed technical notes.

The scope of this note covers development in the agricultural sector at large, with the sector categorized into the following sub-systems, all of which are part of the agricultural value chain, and interact and depend on each other:

- **Investments in agricultural water management:** This includes systems for irrigation and drainage, watershed management measures, water conservation measures, monitoring systems to track irrigation flows and water quality, monitoring of groundwater levels and well water quality, and development of water infrastructure for livestock. These are also covered in the accompanying water guidance note included in the Compendium Volume.

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Overview

01 Introduction

02 A Roadmap For Enhancing the Climate Resilience of Investment Projects in Sub-Saharan Africa

OVERVIEW:
Introduction

This Compendium Volume presents a series of *guidance notes* and more detailed complementary *technical notes* that offer practical insights in support of **enhancing the climate resilience of infrastructure investment projects in Sub-Saharan Africa.** This first introductory chapter starts with an overview of the investment conditions and climatic context in the region, followed by a description of the scope of this Compendium Volume and individual notes, target audiences, and a roadmap for users of the contents covered in this Volume.

1.1. Enhancing the Climate Resilience of Infrastructure Investment Projects in the Context of Sub-Saharan Africa

In 2020, Sub-Saharan Africa was home to over 1.1 billion people (World Bank 2020), with this population expected to triple to 3.1 billion by 2100 (Ezeh et al. 2020), potentially making the region one of the world's most dynamic growing economies. Even before the onset of the COVID-19 pandemic, it was estimated that Africa needs investments of $200 billion annually in order to meet its Sustainable Development Goals by 2030 (United Nations Conference on Trade and Development 2020). The region has enormous development potential and much-needed investments are influenced by a variety of factors, including

- A large funding gap and the need to make the best use of available funds.
- Local populations tend to live with narrower margins (e.g., fewer social safety nets, lower levels of savings and less redundancy in income options) as compared to wealthier regions of the world.
- Gaps and uncertainty in political oversight and governance systems.
- Low penetration of Information and Communication Technology services and limited data availability for the region.
- A large degree of climate variability in the region (see for example **Textbox 1.1**).

In spite of contributing less than 5 percent of total global greenhouse gas emissions (Climate Watch 2020), Sub-Saharan Africa's current already significant degree of climate variability is expected to become substantially worse given the impacts of future climate change. **Textbox 1.1** presents a brief introduction to regional variability and climate projections for Sub-Saharan Africa, drawing on examples from three major regions: Southern, East, and West Africa. Additionally, climate change often also acts as a multiplier for conflict and pre-existing fragility, exacerbating tensions, resource constraints, weak governance, and other socio-economic concerns.

Climate change uncertainty is a key issue that needs to be taken into account when developing and designing investment projects, particularly infrastructure projects, in Sub-Saharan Africa. Given these uncertainties, incorporating variable conditions in project evaluation is critical and the use

Textbox 1.1: Climate Variability and Climate Change Uncertainty in Sub-Saharan Africa

The geographic focus of these guidance notes is on Sub-Saharan Africa, a vast and diverse region. This textbox briefly examines key climatic characteristics, regional variability and projected changes due to climate change for Sub-Saharan Africa, by introducing key examples from three major regions:

East Africa: The majority of East Africa is drained by the White and Blue Nile Rivers. The White Nile originates in Lake Victoria, which has exhibited large fluctuations in water level, including a severe drop in the 1960s (Nicholson *et al.* 2000). Despite some disagreements among different climate projection models, the magnitude of precipitation during the wet season over Lake Victoria is expected to increase in the future (Akurut *et al.* 2014; Onyutha *et al.* 2016). The Blue Nile originates from Lake Tana, which is smaller than Lake Victoria and has maintained generally stable water levels for the last 50 years (Kebede *et al.* 2006). Floods and droughts in the Blue Nile are attributed to rainfall variability downstream of Lake Tana, associated with the changes in the Southern Oscillation Index (Conway 2000). In the Blue Nile basin, despite high uncertainty in precipitation projections, increases in both the frequency and severity of floods and droughts are expected in the future (Tariku *et al.* 2021).

West Africa: Precipitation in West Africa in the last century has been highly variable, characterized by a very wet period between 1950 and 1970, a dry period from 1970 to 1990 (Barbe *et al.* 2002) and a moderate increase in rainfall after the 1990s (Maidment *et al.* 2015). Correspondingly, surface runoff is also highly variable (Roudier *et al.* 2014). The natural climate variability in West Africa is so high that the climate change signal may not be distinguishable from natural variability until after 2050. Despite high precipitation uncertainty and disagreement amongst climate projections, a decrease of more than 10 percent in runoff in the Senegal, Gambia, and Guinea-Bissau River basins has been predicted, as opposed to an increase of more than 10 percent in runoff in Liberia and Côte d'Ivoire (Stanzel *et al.* 2018). Aich *et al.* (2016) similarly predicted an increase in flood magnitude in the Niger River basin given future climate change.

Southern Africa: In Southern Africa, the level of understanding of the effect of climate change is hampered by high interannual variability, complex oceanic-atmospheric dynamics, and an incomplete historical record of climate data (Ziervogel *et al.* 2014). Historically, the level of Lake Malawi, which feeds the Shire River and subsequently the Zambezi River, has fluctuated due to large precipitation variability (Nash *et al.* 2018). Precipitation in Malawi is projected to change between -20 and +20 percent from its historical levels by mid-century (Taner *et al.* 2017), a range that indicates a central value (i.e., median) of zero, or "no change." Bhave *et al.* (2020) simulated the variation of the level of Lake Malawi to the end of 2050 and reported that one-third of available climate projections predict a future with devastating floods, and about one-third of them a drier future in which lake levels are so low that there would be no outflow.

of a project development methodology that incorporates climate resilience in project evaluation is necessary. Resilience is defined as *the ability of a system and its component parts to anticipate,* absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner (Intergovernmental Panel on Climate Change 2012). Achieving such resilience to climate shocks in the design of infrastructure projects is not trivial, requiring a number of decisions on what sources of variability to include and to what extent, with these decisions ultimately affecting evaluation outputs and subsequent action plans. The benefits of pursuing climate resilient infrastructure investments (as compared to projects that do not explicitly seek to achieve improved climate resilience) have been widely documented – for instance, a 2015 study looking at enhancing the climate resilience of Africa's infrastructure examined investment in hydropower in six of Africa's major river basins. The benefit to cost ratio of climate resilient investments as compared to baseline (less resilient) investment plans were greater than one for five of the six basins, with values between 2.5 and 5.3 in four of the basins (Cervigni et al. 2015).

Ultimately, enhanced climate resilience can be achieved if uncertainty is appropriately accounted for during the project evaluation process and can result in significant economic benefits. The guidance notes introduced in the subsequent chapters of this Compendium Volume provide a structured and systematic approach to achieving such climate resilience, with the complementary technical notes offering a deeper dive into key issues such as climate model selection, economic analysis and decision-making under uncertainty, among other reference materials.

1.2. Objectives and Scope of this Compendium Volume

Funded through the Africa Climate Resilient Investment Facility, this Compendium Volume **presents a series of sector-specific guidance notes and complementary technical notes that provide direction on enhancing the climate resilience of investment projects in Sub-Saharan Africa.**[1]

Focusing on six climate-sensitive sectors, namely agriculture, energy, water, transport, ecosystems, and urban areas, the guidance notes presented in Part 1 of this Compendium synthesize the latest research and methods on achieving climate-resilient investment. Each individual note was developed by a team of multi-disciplinary researchers and practitioners, led by a sectoral expert as lead author. The notes build on a review of existing robust research, recent analytical methods and other established guidance documents, to provide practical "how to" guidance for enhancing the climate-resilience of infrastructure investments in African. Each note builds on practical and demonstrated projects, as described through a detailed case study, and complemented by diverse "resilience spotlights" and shorter in-text examples. The result is a set of guidance and technical notes that are pedagogically oriented to inform capacity building. The notes are not intended to serve as comprehensive texts nor exhaustive policy handbooks, but as brief, accessible guidance that highlights the most important principles to take into account when pursuing climate resilient investment projects. Extensive hyperlinked references are included within each note for those seeking further detail on a particular topic.

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[1] A partnership with the African Union, United Nations Economic Commission of Africa, Nordic Development Fund, African Development Bank, and the World Bank.

> Each individual note was developed by a team of multi-disciplinary researchers and practitioners, led by a sectoral expert as lead author

Each of the six guidance notes is built around **a common framework** (introduced in Chapter 2 of this Compendium Volume) **for evaluating project assets to ensure they meet project objectives in spite of possible future climate impacts**. While each individual note is focused on a particular sector, many projects include cross-sectoral components and depending on the different investment components included in a project, several of the individual guidance notes may be useful to consult, as facilitated by the use of one single overarching framework across all six notes. The complementary technical notes presented in Part 2 of the Compendium offer further technical information on key issues such as working with climate projections, economic analysis, decision-making under climate uncertainty, the Africa Climate Resilient Investment Facility's training program that builds on these notes, as well as things to consider when working with external consultants on project level resilience. While the focus of this document is on the project design level, **the particular policy, regulatory, and institutional context in which the project is situated all play a critical role in achieving successful project outcomes.** All project design decisions should thus be taken with both the policy landscape and local capacity in mind, acting as either enablers or barriers for implementation, with these key topics discussed in Chapter 2 of this Compendium Volume.

1.3. Target Audience

There are generally three primary audiences for these notes, each differing considerably in their technical focus, operational roles, and objectives:

- **Practitioners.** These are the groups/teams that conduct detailed project- and planning-level investment analyses (e.g., African consulting firms) and implement investment projects. These notes will help practitioners develop their staff and internal expertise to perform the necessary climate vulnerability and adaptation analysis.
- **Government Staff.** National governments not only have the long-term responsibility for owning and monitoring infrastructure investments, but also tracking and ensuring the resilience of such investments over the course of their lifetime. These efforts are often complemented by bottom-up planning by provincial and local governments, as well as by the work of specialized (government) bodies such as basin commissions and offices. Government staff typically lead and procure the analytical work needed to plan and design investments, but generally do not conduct those analyses themselves. These notes will give staff from all levels of government an understanding

of the steps involved in evaluating and enhancing the resilience of a proposed project, how to be prepared for creative and alternative investment packages, how to draft Terms of Reference for practitioners to develop climate resilient projects, as well as how to monitor existing projects.

- **Donors and Development Banks.** Ideally, donors and development bank staff would already possess a general understanding of global climate change and what analytical processes are available to incorporate climate change uncertainty into project designs. For this audience, the key focus of these notes is on how to bring resilience into their investment decision-making processes, and how to draft Terms of Reference for the analysts and practitioners that will actually conduct the climate resilience analyses for the planning/design of a project. These notes will help donors and development banks provide clear direction and guidance to consultants for how to make project designs more resilient to climate change.

Each of these three target audiences differ considerably in their technical focus, operational roles, and objectives. Typical investment projects will see the individual guidance notes used as high-level guidance by donors and banks, as well as the more detailed technical notes used within client countries. **The notes are incremental in nature, meaning that they offer guidance on assessing and incorporating climate resilience in infrastructure investment projects, and assume that individual users already possess expertise on project design, project management, and project evaluation generally, including meaningful stakeholder involvement.**

1.4. When to Use this Compendium Volume

While each of the above target audiences will use these notes in slightly different ways, within the overall project development process, climate resilience should generally be considered anywhere from the project's **conception** and **planning** stages, as well as during post-project completion **monitoring** (see the orange components of **Figure 1.1**). It is anticipated that in most cases, project teams will utilize these notes during the scoping, early design, and final design stages of the project planning process. That said, the earlier in the project lifecycle that climate resilience considerations (as described in this Compendium Volume) are incorporated, the greater the scope and opportunity to improve the performance of the project given climate uncertainty. Furthermore, attention should be paid throughout the project planning process to the policy and institutional landscape, as well as the role of policy shifts and improved local capacity in building resilience (see Chapter 2 in this Compendium Volume).

Figure 1.1. **Applicability of the Guidance Notes During a Typical Project Life Cycle**

1.5. Compendium Volume Roadmap

Following this general introductory chapter, this Compendium Volume contains a high-level roadmap for enhancing the climate resilience of infrastructure investment projects in Sub-Saharan Africa (Chapter 2). Chapter 2 first introduces the common framework that is used in all of the guidance notes to evaluate and improve the climate resilience of **project assets**. Chapter 2 then presents a discussion of key cross-cutting multi-sectoral considerations such as the critical role of policy and institutions, the need for nexus thinking and landscape-level solutions, as well as options for paying for resilience.

After Chapter 2, the remainder of the Compendium Volume is then broken down into two parts:

1) Part 1 **presents the six individual guidance notes (Chapters 3 through 8)** that describe the actual practical "how to" of enhancing the climate-resilience of investment projects focused on the following:

    - Agriculture Infrastructure Projects (Chapter 3)
    - Energy Infrastructure Projects (Chapter 4)
    - Water Infrastructure Projects (Chapter 5)

- Transport Infrastructure Projects (Chapter 6)
- Ecosystems Projects (Chapter 7)
- Urban Area Infrastructure Projects (Chapter 8)

This organization into six separate guidance notes (with each intended to function as a standalone document as well as an integrated part of this Compendium) belies just how complex and interconnected these different sectors really are. Many projects include cross-sectoral components and depending on the different investment components included in a project, it may be useful to consult several of the individual guidance notes as facilitated by the use of one single overarching framework.

2) Part 2 **presents five complementary technical notes (Chapters 9 through 13)** that offer further, more detailed technical information on key issues, including:

- A Primer on Working with Climate Projections (Chapter 9)
- A Primer on Economic Analysis (Chapter 10)
- Decision-Making Under Climate Uncertainty (Chapter 11)
- Overview of the Africa Climate Resilient Investment Facility's Training Program that Builds on these Notes (Chapter 12)
- Working with Consultants on Project Level Resilience (Chapter 13)

Lastly, this Compendium Volume is not intended to be read exhaustively from cover to cover by any single user. Each of the notes serve as stand-alone documents and it is envisioned that members of a project team read these introductory materials (Chapter 1 and Chapter 2) before then skipping to the specific sectoral or technical note(s) that best describe the project (e.g., a transport versus irrigation investment project) and match the user's role in the project (e.g., a technical analyst at a consulting firm versus a ministerial representative).

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OVERVIEW:

A Roadmap for Enhancing the Climate Resilience of Investment Projects in Sub-Saharan Africa

This second chapter in the Compendium Volume introduces a roadmap for enhancing the climate resilience of infrastructure investment projects in Sub-Saharan Africa. It first presents an overview of the process of developing a generally applicable framework that is used throughout the notes as a step-by-step guide to the evaluation of projects given climate change uncertainty (Section 2.1). An overview of the framework is provided in Section 2.2. The remainder of the chapter discusses key cross-cutting considerations applicable across all sectors, including the role of policy and institutions (Section 2.3), cross-sectoral investments (Section 2.4) and paying for resilience measures (Section 2.5).

2.1. Developing a Generally Applicable Framework for Enhancing the Climate Resilience of Investment Projects in Sub-Saharan Africa

Each sector-specific guidance note presented in Part 1 of this Compendium Volume is built on a generally applicable framework for evaluating project assets to ensure they meet project objectives in spite of possible future climate impacts. **The use of a common framework across all sectors is intended to enable easier coordination across different sectors**, so as to better take into account cross-cutting issues and inter-sectoral linkages.

This framework builds on a range of existing resources produced by the World Bank and others, complementing more general guidance on strategic planning and investment by providing practical methods for the improvement of the climate resilience of planned investment projects within Sub-Saharan Africa. Notably, in February 2021, the World Bank released its Resilience Rating System, a methodology for building and tracking resilience to climate change. The Rating System explains how to evaluate the resilience of a project, examining to what extent climate and disaster risks have been considered when designing the project's assets. The Rating System assigns individual projects a letter grade from A+ to C, which at a glance, provides a characterization of the extent to which the project has taken into account climate risks and is expected to be able to perform well given uncertainty about possible future climate conditions. Subsequently, a disaster and climate risk stress test methodology was released by the World Bank (Hallegatte et al. 2021), explaining how to obtain an A grade when assessing the resilience of a project. The guidance notes included in this Volume are complementary to the climate stress test methodology in that they build on the Resilience Rating System (which focuses on the resilience of the investment assessment process) and offer a broadly applicable, practical, step-by-step framework to identify climate resilient project alternatives that will score an A or an A+ grade under the Resilience Rating System (i.e., the focus is on improving the resilience of projects themselves). Furthermore, the framework presented below is broadly in line with new guidance developed by the World Bank to ensure that future Bank investment projects are in alignment with the climate targets set out in the Paris Agreement (United Nations 2015) as well as the country's own adaptation goals.

> While many investments can enhance both the resilience of and through projects, the framework presented in these notes predominantly focuses on enhancing the resilience of particular investment projects

The Resilience Rating System mentioned above distinguishes between two dimensions of resilience, namely **resilience of** the project and **through** the project (World Bank 2021):

- **Resilience of** the project is the extent to which a project's assets have considered climate and disaster risk in their design.
- **Resilience through** project outcomes reflects whether a project's objective is to enhance the target sector and beneficiaries' climate resilience through its interventions.

While many investments can enhance both the resilience of and through projects, **the framework presented in these notes predominantly focuses on enhancing the resilience of particular investment projects** (including the resilience of direct project outputs), with any improvements to the resilience of the community or sector that benefits from the project considered secondary.

2.2. Overview of the Framework

The general framework for enhancing climate resilience that underpins all the guidance notes is summarized in **Figure 2.1.** It consists of a series of sequential steps, with many of the steps linked through important feedback loops:

0) **Step 0: Initial Assessment of the Preliminary Situation**

In this critical preparatory step, the **institutional and project context** (including the existence of country-level development plans, support from relevant ministries, and the state of weather and climate change monitoring capabilities) are examined - Section 2.3 below revisits these considerations. In addition, during this initial assessment it is key to develop a plan for **stakeholder involvement** throughout the framework. This involves not just identifying relevant stakeholder groups (for instance, community groups and beneficiaries, technical experts and policymakers and non-governmental organizations), but also determining how stakeholders will be involved at each step. The World Bank's Environmental and Social Framework standard focused on stakeholder engagement (2016) offers a succinct overview of good practices for effective stakeholder engagement, while the United Nations

Development Program's technical note (2004) offers more detailed guidance on effective stakeholder engagement in the context of resilience and adaptation planning specifically,

1) **Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality**

In this first step, the proposed project's **exposure to climate hazards** is evaluated, and an analytical approach that is suitable for assessing the vulnerability of the project to the identified climate hazards is established.

2) **Step 2: Assess Project Vulnerability to the Identified Climate Hazards**

The purpose of this second step is to **assess the project's vulnerability to the climate hazards** identified in Step 1. This involves determining suitable performance indicators, establishing a climate baseline and an appropriate set of future climate scenarios to analyze project performance under current and future conditions and using a stress test to assess the vulnerability of the project to diverse climate futures.

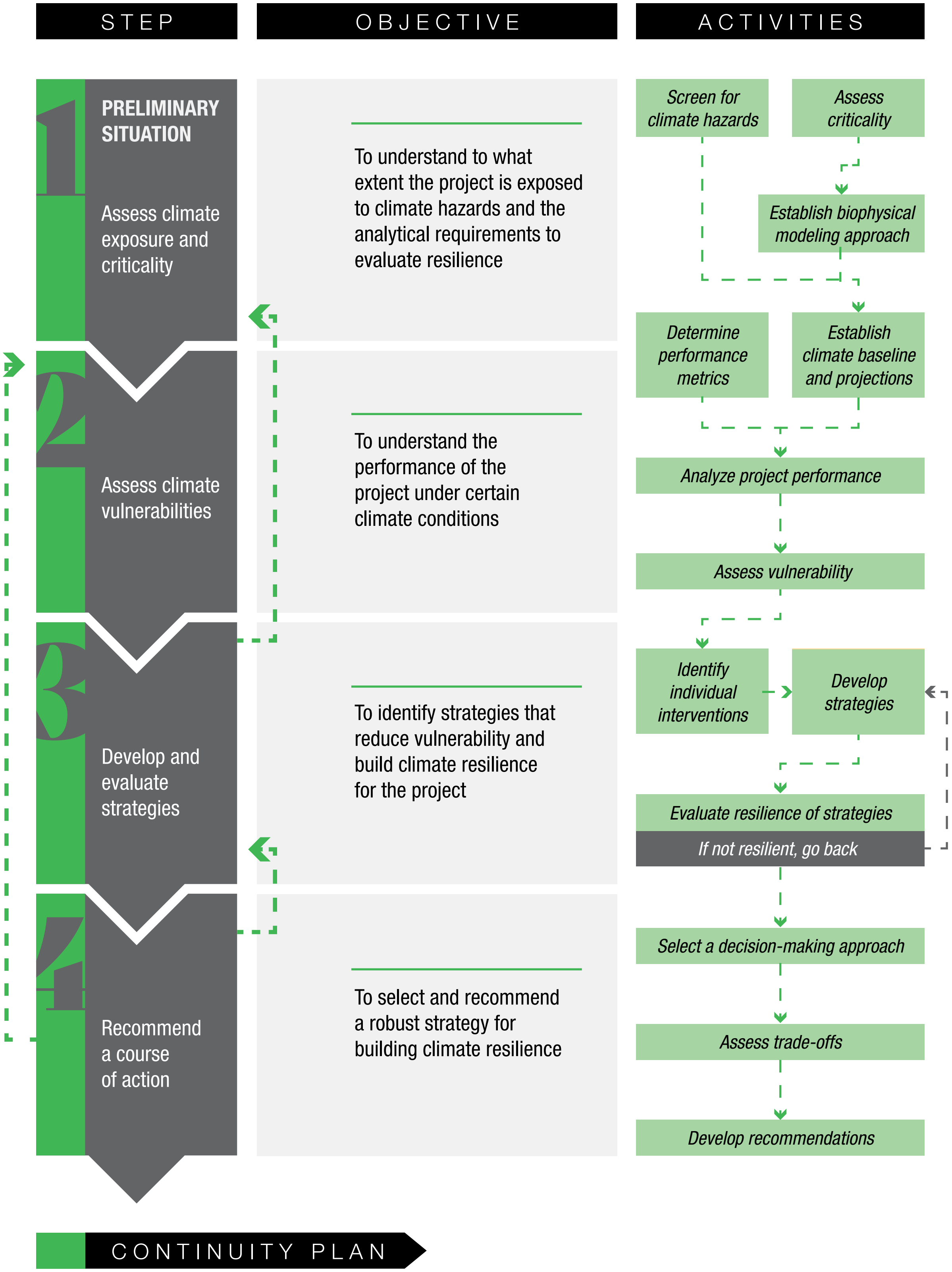
3) **Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience**

For those projects found to be vulnerable to climate change impacts, this next step in the framework **helps develop and evaluate a set of possible strategies by which to adapt the project to climate hazards so as to improve its resilience**. In this step, it is critical to understand any multi-sectoral elements of the project and assess cross-sectoral impacts of proposed strategies (see Section 2.4 below for further detail).

4) **Step 4: Recommend a Course of Action**

Finally, this fourth step identifies a suitable decision-making approach by which to select a recommended course of action from the adaptation strategies considered in Step 3, taking into account both trade-offs and the full economic lifetime of the project. The recommended adaptation strategy should be incorporated into a continuity plan that justifies the selection of the recommended course of action and describe a process for project evaluation, along with a clear schedule of activities and stakeholder responsibilities during and after implementation. Monitoring and evaluation should focus on assessing how progress toward vulnerability reduction will be measured, and how lessons learned can be used to improve current and future projects.

Figure 2.1. **Framework for Enhancing the Climate Resilience of Investment Projects**



Given that this general framework is intended to be used by three separate target audiences (practitioners, government staff, and donors and development banks, as described in Section 1.3 above), **Textbox 2.1** below offers some additional detail on who will typically be responsible for actually completing individual steps in the framework and who will rely on the output of previous steps to achieve eventual project implementation. Note that this classification into three separate target audiences is somewhat artificial and treats "practitioners" as those who are primarily responsible for completing technical project analyses and on-the-ground project implementation; "government staff" as those who initiate projects in line with the government's broader policy priorities; and "donors and development banks" as those who fund projects. In reality, these lines are often blurred, with some "practitioners" operating within government or development banks, for instance.

Textbox 2.1: Overview of how the different target audiences for these notes will typically be involved in each step of the framework for enhancing a project's climate resilience

Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality	**Practitioners**	**Government Staff**	**Donors and Development Banks**
Activity 1a. Screen for climate hazards	Lead	Kept informed & provide input	May influence activities through funding pre-requisites
Activity 1b: Determine the project criticality to establish the appropriate level of effort required to assess project resilience			
Activity 1c. Establish a biophysical modeling approach based on the project tier			

Step 2: Assess the Vulnerability of the Project to the Identified Climate Hazards	**Practitioners**	**Government Staff**	**Donors and Development Banks**
Activity 2a. Determine performance indicators and targets to assess climate vulnerability	Lead	Kept informed & provide input	May influence activities through funding pre-requisites
Activity 2b. Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions			
Activity 2c. Analyze project and system performance under the selected climate scenarios		Kept informed	
Activity 2d. Assess the vulnerability of the project in the form of a stress test			

Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience	**Practitioners**	**Government Staff**	**Donors and Development Banks**
Activity 3a: Identify individual interventions to enhance the climate resilience of the project	Co-lead		Kept informed; may influence strategies considered
Activity 3b: Develop adaptation strategies to enhance resilience	Co-lead		
Activity 3c: Evaluate the contribution to the resilience of the selected strategies	Lead	Kept informed & provide input	

Step 4: Recommend a Course of Action	**Practitioners**	**Government Staff**	**Donors and Development Banks**
Activity 4a: Select a decision-making approach	Provide input	Lead	Kept informed; may be required to pursue financing
Activity 4b: Assess the trade-offs of each strategy			
Activity 4c: Develop a recommendation and continuity plan			

2.3. The Role of Policy and Institutions

While the focus of the notes in this Compendium Volume is primarily on infrastructure investments at the project level, **broad supporting policies and strong, effective institutions are critical in creating the necessary enabling environment to successfully implement climate resilience efforts**.

Looking first at the policy context, **the absence of high-level climate-focused initiatives may hinder the pursuit of climate resilience at the project level.** For instance, the existence of and progress on implementing national climate initiatives such as climate change policies, national adaptation plans, and climate change adaptation strategies demonstrate a country's policy readiness for undertaking project-level climate resilience activities. National policy frameworks are often underpinned by further sector-specific initiatives, such as Climate Smart Agriculture Investment Plans, which can help to realize a country's climate goals and targets for example by establishing a necessary legal framework or allocating resources to capacity building. The existence of climate change financing frameworks can help mobilize and target finance in support of achieving a country's strategic climate goals.

Furthermore, **alignment between resilience actions and a country's development priorities can help enable investments in resilience**, especially in Sub-Saharan Africa where there are important synergies between climate action (both mitigation and adaptation) and development outcomes. For example, improved crop varieties can benefit farmer livelihoods and agricultural productivity regardless of whether the climate changes in the future or not. This means that climate resilience efforts should ideally be seen within the context of national development priorities and plans, over and above being only considered within a country's climate policy context. This joint focus enables the development of comprehensive adaptation strategies that help countries reach their socio-economic objectives and confront any trade-offs, all while enhancing their climate resilience. This alignment between climate action and socioeconomic development is often championed in high level policy forums such as the African Ministerial Conference on the Environment (United Nations Environment Programme n.d.) and the United Nations Environment Assembly (United Nations Environment Programme n.d.)

Additionally, in order for climate resilience considerations to be included in project planning, it is important that **the existing policy landscape not just acknowledges that the climate is changing but also takes a sufficiently long-term view of investments**. While climate is intrinsically variable, the effects of climate change are typically most important to consider in longer-lived projects. For instance, a country developing an irrigation master plan with a horizon of 10 years may not necessarily face significant climatic changes within this 10-year horizon. That said, even in a shorter-term project like this, it may be wise to briefly consider possible longer term climate impacts so that current investments can be undertaken in such a way that is aligned (or not in direct conflict) with likely future adaptation actions. This connecting of shorter-term actions within a longer term adaptive and flexible plan is discussed in greater detail in the technical note on decision-making under climate uncertainty.

Institutions are the rules, norms and enforcement mechanisms that guide, constrain and shape economic, social and political interactions and institutional frameworks drive how organizations and groups, from government to individual stakeholders develop, act and interact. **The existence of strong institutions is crucial to achieve long-term climate resilient development**. Institutional capacity and readiness at local, national, and sectoral levels can help reduce climate and disaster risks to a project, whereas low capacity and standards, weak policy and regulatory frameworks, and a lack of transparency can hamper a project's ability to effectively respond to identified threats.

In particular, **it is critical that all levels of government in a country are unified in their commitment to pursuing investments that are resilient in the face of climate uncertainty**. This commitment must span sector-specific ministries that are usually most directly involved in infrastructure spending, to those involved with finance and economic evaluation, to the president's office. It is of little use if a country's ministry of water and agriculture, for instance, is committed to assessing and improving the resilience of proposed investments if the government entities involved with the economic evaluation of proposed projects reject these projects because they do not consider the added costs of resilience to be worthwhile.

A further factor that can hinder the pursuit of climate resilience is **the need to fund the added costs of resilience, including improvements in the functioning of entities established for this reason.** While development agencies and funders are increasingly unified in their desire to support projects that are climate resilient, it often remains unclear who will provide the funds required to make projects more resilient. There is a need for easily accessible funding mechanisms that can cover resilience costs at the project level. Section 2.5 below examines the process of developing a financing roadmap and presents a shortlist of possible sources of climate funding for Sub-Saharan African countries.

Finally, **when looking at enablers for climate resilience, education and capacity building also play a critical role.** An example of this is documented in the technical note that describes the Africa Climate Resilient Investment Facility's training program. There is a need for concepts relating to climate, resilience and risk to be incorporated broadly into school curricula and the general public's awareness. Additionally, technical and design professionals should be trained not just in the traditional skills required for their work but be taught to think dynamically and creatively to design innovative projects that continue to perform even in the face of a significantly altered future.

2.4. Cross-Sectoral Investments and the Move Towards Sustainable Landscape Approaches

Many investment projects in Sub-Saharan Africa are **cross-sectoral**, meeting several development objectives at once. For instance, a multi-purpose reservoir project may provide water for irrigation (agricultural sector) and for hydropower (energy sector), as well as have downstream impacts on water resource availability (water sector), including for cities (urban sector). There has been a significant move in recent years away from a siloed, sectoral view of investments to a more integrated view of development.

While the decision to develop individual sector-focused guidance notes may seem counter to the prevailing trend to think in a more integrated fashion, this was a pragmatic choice driven primarily by a desire to keep each guidance note relatively short, accessible and user-friendly. The use of a single framework for evaluating and enhancing climate resilience allows users to read one guidance note fully and then jump to those steps in other sectoral notes that may be relevant to the project at hand. For instance, the team working on the same reservoir project introduced earlier in this section, may wish to consult specific sections (particularly Steps 1b, 1c, 2a, 3a and 3b) of the water, energy, agriculture, and cities notes. In many cases, it is likely that a cross-sectoral project will not just need to conduct quantitative assessment in several different sectors individually, but that **linkages and trade-offs between different sectors will need to be evaluated**, especially in cases where resilience in one sector may come at the expense of resilience in another. Returning to this same example, a model that captures key interactions within the water-energy-food nexus may be necessary in order to assess how increased water use by agriculture under future hotter and drier conditions may affect the resilience of hydropower generation or urban domestic supply. Ultimately, trade-offs should be guided by a country's development priorities.

Resilience Spotlight: Climate Action through Landscape Management in Ethiopia's Highlands

The Climate Action through Landscape Management program in Ethiopia is an example of how sustainable landscape approaches can be implemented at a large scale. The program focuses on increasing the adoption of sustainable land management practices across the country's highlands. The program provides results-based financing for the establishment of Watershed Users' Associations and the implementation of participatory watershed management plans, among other interventions. By operating at a landscape level, the project will produce cross-sectoral benefits including improved ecosystem services in support of agriculture, more reliable water flows from the highlands for use downstream, and reduced sediment flows improving reservoir lifespans and water quality, among other outcomes.

The program is helping Ethiopia reach its climate resilience and mitigation goals and promote the sustainable management of natural resources. **Furthermore, by providing performance-based financing, the program is helping establish national capacity in sustainable land management, which will help enhance the resilience of the program itself and the long-term sustainability of the program's outcomes.**

One step beyond capturing the complex interactions and linkages between different sectors is the desire to work towards a **sustainable landscape approach to development**. Such a landscape approach not only recognizes the linkages between food, water, and energy security, but acknowledges that none of these can be achieved without safeguarding the natural capital base and ecosystem services provided by the environment. In practice, such an approach is a social process that continuously makes choices on the protection, use, and development of existing natural capital. An example of a sustainable landscape approach that benefits numerous sectors could be to pursue catchment and landscape management: not only will this reduce erosion (which has benefits for agriculture) and reduce sediment (which has benefits for hydropower generation), floods will be better attenuated (benefitting urban areas) and more water will be available in total (benefitting water supply for all users, including ecosystems).

Finally, when looking at any investment project, but in particular those that are cross-sectoral in nature, it is important to **consider the regional context when exploring possible resilience-building measures.** Resources such as rivers are often shared between multiple countries (for instance the Zambezi is shared by eight Riparian states) and it is often the case that issues faced in one location can be best addressed by taking elsewhere in the basin (for instance flooding downstream in a flat delta region may be most effectively addressed by pursuing storage upstream). With improved regional integration and deeper regional cooperation, African countries could rally around collective climate adaptation solutions (African Development Bank Group 2022).

2.5. Financing Resilience

Crucial to achieving improved climate resilience in Sub-Saharan Africa is getting projects financed (e.g., through a loan) or funded (e.g., through grants or donations). Before considering specific sources of funding, it is often useful to first develop an overarching financing strategy roadmap. The development of such a roadmap is generally structured around three main steps:

- **Estimating the cost of interventions:** thorough climate screening of the projects under consideration should be conducted, to determine the anticipated scope and cost of the identified interventions.
- **Identifying possible financing and funding solutions:** identifying the various sources of relevant climate finance, as well as their funding requirements and conditions. Where co-funding is required, the type and level should be ascertained.
- **Developing a monitoring, evaluation, and reporting framework**

When exploring possible options, advantage should be taken of the existence of different financing and funding sources, combined in such a way as to best manage climate risks. Sources can include **African governments through domestic funding** (including from carbon taxes, environmental levies, and green bonds)**, foreign country investments, multilateral development institutions and initiatives, private donors** and **private sector funding**.

Different sectors are often characterized by being more or less reliant on particular sources of funding:

- In the **agricultural** sector in Sub-Saharan Africa, the majority of investments generally originate from private domestic sources, with a significant burden on individual farmers. Other sources include local institutional funding, private sector funding (either in the form of direct investment in infrastructure or risk reduction through the provision of insurance for climate-related risks), as well as external funding.
- In the **energy, water** and **transport** sectors, the majority of investments generally originate from African governments through domestic funding (e.g., taxes, private equity market, etc.), with some intergovernmental transfers (funding from regional/national government that might be earmarked for specific purposes). Outside funding is primarily from foreign country investments, with China being the largest single funding source. Additional funding to a lesser degree is provided by multilateral institutions, the private sector and private donors.
- When it comes to **ecosystem and biodiversity projects** in Sub-Saharan Africa, it is a challenge to track funding for these projects because terms like "nature-based adaptation" and "ecological infrastructure" have several definitions and can cover a broad range of projects. There are unique challenges in funding ecosystem and biodiversity projects in Africa because very little climate finance is directed at ecosystems (outside of agricultural systems). As a result, financing for projects in the ecosystems sector often requires creativity in finding and leveraging appropriate funds.

Lastly, financing options at the sub-national level, especially for growing **urban areas**, continue to be a substantial blind spot in the infrastructure dialogue in sub-Saharan Africa. In general, the financing mechanisms used in urban areas include external funding (e.g., through bi- or multi-lateral agreements), Public-Private Partnerships (which are on the rise in the region), private investment, and equity for urban projects with the support of local governments. While a large share of climate financing for urban infrastructure investment in Sub-Saharan Africa is domestically financed by central government budget allocation, African efforts at decentralization of fiscal authority seriously lag behind other regions of the world. Most countries in sub-Saharan Africa still depend heavily on national government transfers, instead of permitting local governments to raise their own revenues.

Across all these sectors, multilateral climate funds are generally the main source of funding for **adaptation** projects. A challenge is that many project developers often do not take advantage of adaptation funds when developing projects as methodologies to demonstrate adaptation benefits are not as well developed as those used for climate mitigation meaning that developers often only focus on concessionary finance associated with a project's climate mitigation potential. Furthermore, many projects in the region are limited in scope and therefore do not meet the thresholds for larger fund financing.

Table 2.1 lists multilateral climate funds and initiatives that support investment projects in different sectors in Sub-Saharan Africa - further information is available via the hyperlinks, with the Climate Policy Initiative serving as an additional source of information on climate finance. (Sources of climate funding are evolving constantly and while the contents of **Table 2.1** are up to date at the time of writing, it is recommended to look more broadly than just this list as new options may have become available). When it comes to external funding sources, it is important to ascertain whether funding is available as a grant in whole or in part, and where applicable, the interest rates that apply. Cooperation between public and private sector financiers is key as the public sector shapes the enabling environment (i.e., through policy and other measures that improve the bankability of projects). Furthermore, funds from private sources may be increased through initiatives like the Adaptation Benefit Mechanism (through the African Development Bank).

Other sources of information that may be helpful to consult include:

- The United States Agency for International Development's Financing Climate Resilience in African Cities (2019)
- The Global Impact Investing Network (2018)
- The Infrastructure Consortium for Africa's Infrastructure Financing Trends in Africa 2017 report (2018)
- The World Resources Institute's Public International Funding of Nature-based Solutions for Adaptation: A Landscape Assessment provides guidance on the mechanisms used to fund nature-based adaptation projects (Swann et al. 2021)

Finally, it is important that any financing roadmap is underpinned by a reliable and dependable institutional framework that allows efficient and effective disbursement of both local and external funds. It is worth noting that accreditation of national institutions (both public and private) is usually required to access multilateral climate finance - this is an involved process that requires extensive capacity building at the individual and institutional levels. Local funding should ideally be subjected to the same level of scrutiny as external funding, indicating the need for due diligence in the determination of the institutions that are mandated to disburse the funds.

Table 2.1. Summary of Relevant Climate Funds and Initiatives

United Nations Framework Convention on Climate Change Financial Mechanisms	Agriculture sector	Energy sector	Water sector	Transport sector	Ecosystems sector	Cities sector
Global Environment Facility						
Least Developed Countries Fund	X	X	X	X	X	X
Special Climate Change Fund	X	X	X	X	X	X
Green Climate Fund						
Green Climate Fund	X	X	X	X	X	X
Adaptation Fund						
Adaptation Fund	X	X	X	X	X	X

Multilateral & bilateral	Agriculture sector	Energy sector	Water sector	Transport sector	Ecosystems sector	Cities sector
African Development Bank						
ClimDev Special Fund	X	X	X	X	X	X
Africa Climate Change Fund	X	X	X	X	X	X
Urban & Municipal Development Fund for Africa		X	X	X	X	X
Agriculture Fast Track Fund	X				X	
Africa50 Infrastructure Fund			X	X		X
Climate Investment Funds						
Clean Technology Fund	X	X	X	X		X
Pilot Programme for Climate Resilience	X	X	X	X	X	X
Scaling-up Renewable Energy Program	X	X	X	X		X
Forestry Investment Programme	X				X	
Private Infrastructure Development Group						
Emerging Africa Infrastructure Fund		X	X	X		X
International Fund for Agricultural Development						
Adaptation for Smallholder Agriculture Programme	X					
United Nations						
Millennium Development Goal Achievement Fund	X	X	X	X		X
United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation	X	X	X	X	X	X

Multilateral & bilateral	Agriculture sector	Energy sector	Water sector	Transport sector	Ecosystems sector	Cities sector
Global Fund for Ecosystem-based Adaptation					X	
Cities Alliance		X	X	X		X
World Bank						
Africa Infrastructure Resilient Facility	X	X	X	X	X	X
Biocarbon Fund	X			X	X	
European Funds						
Global Climate Change Alliance Plus	X	X	X	X	X	X
British International Investment	X	X	X	X		X
C40 Cities Finance Facility		X	X	X		X
North American Funds						
Canada's Partnering for Climate Fund					X	
Rockefeller Foundation's 100 Resilient Cities		X	X	X		X

Regional	Agriculture sector	Energy sector	Water sector	Transport sector	Ecosystems sector	Cities sector
African Union						
African Risk Capacity	X	X	X	X	X	X
African Heads of State						
Africa Adaptation Initiative	X	X	X	X	X	X
Adaptation of African Agriculture Initiative	X					
African Minister's Council on Water						
African Water Facility	X	X	X	X		X

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PART 1:

Climate Resilience Sector Guidance Notes

03 **Guidance Note:** Enhancing the Climate Resilience of **Agriculture** Infrastructure Projects in Sub-Saharan Africa

04 **Guidance Note:** Enhancing the Climate Resilience of **Energy** Infrastructure Projects in Sub-Saharan Africa

05 **Guidance Note:** Enhancing the Climate Resilience of **Water** Infrastructure Projects in Sub-Saharan Africa

06 **Guidance Note:** Enhancing the Climate Resilience of **Transport** Infrastructure Projects in Sub-Saharan Africa

07 **Guidance Note:** Enhancing the Climate Resilience of **Ecosystems** Projects in Sub-Saharan Africa

08 **Guidance Note:** Enhancing the Climate Resilience of **Urban** Infrastructure Projects in Sub-Saharan Africa

GUIDANCE NOTE:

Enhancing the Climate Resilience of Agriculture Infrastructure Projects in Sub-Saharan Africa

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Acronym List

AFRI-RES	Africa Climate Resilient Investment Facility
GCM	General Circulation Model (or Global Climate Model)
IPCC	Intergovernmental Panel on Climate Change

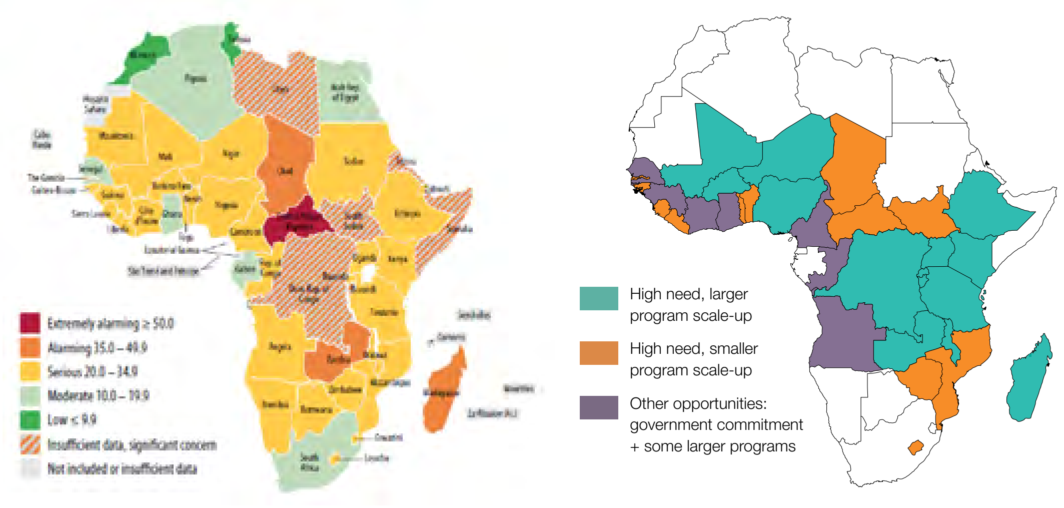
3.1. Introduction and Background

3.1.1. Problem Statement

Agricultural production in Sub-Saharan Africa is dominated by smallholder farming, accounting for 80 percent of all farms and 80 percent of food produced in the region, with production largely rainfed. The average land holding is less than 5 hectares and is typically accessed through family and customary traditions based on use rather than formal property rights. Farmers in Sub-Saharan Africa have limited access to agricultural finance and rely heavily on family labor and capital, thereby facing increased risk from a lack of existing damage mitigation measures (such as crop insurance and other critical support services). For these reasons, past **increases in agricultural growth and output have generally been achieved by increasing the area under cultivation** rather than improving agricultural productivity (which is the lowest in the world).

Agricultural production in the region tends to be subsistence-oriented, with many rural villagers depending on their local food production for both household food security, and for generating income from local markets. In times of drought (and occasionally, floods), crop yields are restricted, and villagers experience reduced incomes, driving them further into poverty. Due to the rainfed nature of agriculture in Sub-Saharan Africa, production is limited during the dry season, with farmers normally obtaining only one crop per year. The poor performance of agricultural activities has a negative impact on the socio-economic well-being of the 70 percent of the population who depend on agriculture for food security, livelihoods, and employment. Consequently, as many as 18 of the world's 20 poorest countries are found in Sub-Saharan Africa, with 40 percent of the region's population living in extreme poverty and 70 percent living in poverty (the left panel of **Figure 3.1** shows the regional breakdown of food insecurity).

Figure 3.1. **Global Hunger Index (Left) & Agriculture Investment Needs (Right) in Africa**



Source: von Grebmer et al (2021)

Source: World Bank (2018)

As such, **the full potential of the agricultural sector in Sub-Saharan Africa is still to be realized**. The region accounts for more than 60 percent of the world's uncultivated arable land that has rainfed crop potential, capable of adding two to three times more cereals and grains, horticultural products, and livestock to global agricultural production. Only 5 percent of the arable land is currently irrigated as compared to 37 percent in Asia. To fully exploit the agricultural potential of the region, significant investments are required not just in irrigation, but in improved seed and fertilizer, in basic storage facilities, and in basic infrastructure such as roads, ports, and electricity (see the right panel of **Figure 3.1**).

Food security and poverty in the region are inextricably linked to climate change, which has the potential to directly and indirectly impact the agricultural sector. The scientific consensus, as encapsulated in the most recent generation of General Circulation Model (GCM) projections of the Intergovernmental Panel on Climate Change (IPCC), indicates a high likelihood of higher than optimal growing temperatures and shortened growing seasons in the future, which may reduce rainfed crop yields by as much as 50 percent. Additionally, projected declines in water availability and increases in crop evapotranspiration would reduce irrigation potential and productivity. Livestock production and productivity are projected to be negatively affected by changes in feed availability and quality, reduced water availability, and heat stress. Warmer temperatures are likely to cause increases in the prevalence of crop and animal vectors and diseases; and warmer water temperatures, high evaporation rates, decreased nutrient concentration, and reduced water inflow are likely to reduce fish production and productivity. As a result, **current scientific understanding indicates that climate change poses a risk for food security in the region, including a potential increase in the proportion of undernourished people.**

> The region accounts for more than 60 percent of the world's uncultivated arable land that has rainfed crop potential, capable of adding two to three times more cereals and grains, horticultural products, and livestock to global agricultural production.

While there is general consensus on the broad range of impacts that climate change is already causing and can be expected in the near-term, there remains significant uncertainty about future climate impacts due to the varied output from existing climate models, the absence of downscaled model outputs, and data limitations, not to mention other non-climate uncertainties such as demographic changes, the political and policy environment, and macroeconomic factors. As such, this document presents a guidance note that offers **practical suggestions for enhancing the climate resilience of agriculture infrastructure projects in the Sub-Saharan African context**, where resilience is *the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner* (Intergovernmental Panel on Climate Change 2012). Adaptive capacity in the agricultural sector is limited and there is also a need to improve the capacities of scientific institutions, local governments, stakeholders, and civil society in the region to help them understand the implications of climate change on droughts and water scarcity, flooding, food scarcity, and health. This should be further complemented by the development of appropriate tools to support adaptation and damage mitigation (including advanced early warning systems), integrated management strategies and cross-sectoral cooperation, as well as sharing of experiences and policies.

3.1.2. Objectives and Scope of this Guidance Note

Funded through the Africa Climate Resilient Investment Facility (AFRI-RES), this document provides guidance on enhancing the climate resilience of agriculture infrastructure investment projects in Sub-Saharan Africa.[2] It is pedagogically oriented and draws on extensive experience and robust research and analytical methods. This guidance note provides **a framework for evaluating infrastructure project assets to ensure they meet project objectives in spite of possible future climate impacts**. As a result, this note is primarily relevant for climate adaptation, with climate mitigation benefits only considered if they are an explicit objective of the project being considered. The focus of this note is on guidance, serving

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[2] A partnership with the African Union, United Nations Economic Commission of Africa, Nordic Development Fund, African Development Bank, and the World Bank. This note is part of a series of guidance and technical notes funded by AFRI-RES that focus on climate resilient investment in Sub-Saharan Africa.

neither as a comprehensive technical text nor an exhaustive policy handbook, but as brief direction on the most important principles to take into account when seeking to enhance the climate resilience of infrastructure projects in the face of future climate uncertainty. (While the note focuses on uncertainty as it relates to future climate conditions, the principles presented here could be extended to include other sources of uncertainty.) In addition, this note focuses on enhancing the resilience of projects that have been at least roughly scoped in terms of their location and the type of investment to be made, being less relevant for very early-stage projects where the location and type of project are as of yet unknown.

These notes build on a range of existing resources produced by the World Bank and others, notably including the Resilience Rating System (World Bank Group 2021) and the disaster and climate risk stress test methodology (Hallegatte et al. 2021). Furthermore, the framework presented in these notes also complements new guidance developed by the World Bank to ensure that future Bank investment projects are in alignment with both the climate mitigation targets set out in the Paris Agreement (United Nations 2015) as well as the country's adaptation goals.

The Resilience Rating System mentioned above distinguishes between two dimensions of resilience, namely **resilience of** the project and **through** the project (World Bank 2021):

- **Resilience of** the project is the extent to which a project's assets have considered climate and disaster risk in their design e.g., large-scale irrigation infrastructure that includes water storage facilities to account for increasing precipitation variability in the future.
- **Resilience through** project outcomes reflects whether a project's objective is to enhance the target sector and beneficiaries' climate resilience through its interventions e.g., a capacity-building community-level project aimed at improving agricultural yields.

The scope of this note is focused on the **resilience of** projects, including the resilience of direct project outputs (e.g., food production or total revenues). While many investments in agricultural systems can enhance both the resilience of and through projects, **the framework presented in this note focuses on the resilience of particular investment projects** and not on how those investments enhance the resilience of a community or sector that benefits from it.

While **the focus of this note is on the project design level**, it remains **crucial to understand the particular policy, regulatory, and institutional context in which the project is situated.** Hence, all project design decisions should be taken with both the policy landscape and local capacity in mind, acting as either enablers or barriers for implementation. This note is part of a larger

> While the note focuses on uncertainty as it relates to future climate conditions, the principles presented here could be extended to include other sources of uncertainty.

Compendium Volume, with these cross-cutting issues discussed in Chapter 2 of the Compendium Volume. Chapter 1 of the Compendium provides a general introduction, with the remainder of the Compendium broken down into two parts: Part 1 houses sector-specific guidance notes (including this one), while Part 2 provides a series of more detailed technical notes.

The scope of this note covers development in the agricultural sector at large, with the sector categorized into the following sub-systems, all of which are part of the agricultural value chain, and interact and depend on each other:

- **Investments in agricultural water management:** This includes systems for irrigation and drainage, watershed management measures, water conservation measures, monitoring systems to track irrigation flows and water quality, monitoring of groundwater levels and well water quality, and development of water infrastructure for livestock. These are also covered in the accompanying water guidance note included in the Compendium Volume.
- **Improved agronomy practices:** Agronomy practices focus on both soil and crop systems. Soil systems include soil and land management measures, soil conservation measures, erosion control measures, and practices that improve carbon sequestration. Crop systems focus on drought tolerant seeds, crops, and farming practices (including Climate-Smart Agriculture practices), manure incorporation in the soil, investment in appropriate light farming equipment and building up resilient cropping systems which replenish soil nutrients.
- **Livestock and fisheries projects:** Livestock and fishery projects generally include investments in improved breeds, feed/fodder production for livestock, infrastructure for managing livestock waste, livestock production facilities and shelters, providing water and shade for the animals, and health and veterinary service facilities.
- **Optimization of post-harvest and off-farm value chains:** This system includes storage facilities, materials for the safe storage of crops, processing facilities related to agricultural, livestock and fisheries products, and local processing machinery for all the agricultural products noted above. Both the quantity and quality of agricultural production impact post-harvesting and value chain outputs.

These four systems represent a pragmatic categorization of agricultural production processes, but these systems are often interdependent. **The note is not specific nor prescriptive regarding development in the agricultural sector, but rather presents principles that can be applied to the evaluation of infrastructure investment projects of any kind.** Improved adaption to climate change will depend on comprehensive and inclusive policies and strategies that are inter-sectoral, underpinned by a unified framework such as the one presented in this note that allows meaningful coordination and provides adequate climate information services.

3.1.3. Target Audience

There are three primary audiences for this guidance note:

- **Practitioners.** The note will help practitioners develop their staff and internal expertise to perform the necessary climate vulnerability and adaptation analyses.
- **Government Ministerial Staff.** The note will give staff from government ministries an understanding of the steps involved in evaluating and enhancing the resilience of a proposed project, how to be prepared for creative and alternative investment packages, and how to draft Terms of Reference for practitioners to develop climate resilient projects.
- **Donors and Development Banks.** The note will help donors and development banks provide clear direction and guidance to consultants for how to make project designs more resilient to climate change.

Each of these three target audiences differ considerably in their technical focus, operational roles, and objectives. Typical investment projects will see this note used both as high-level guidance by donors and banks, as well as more detailed technical guidance for use within client countries. This note was developed to be accessible to these different audiences, with the general framework presented here supplemented by further detail in the technical notes included in Part 2 of the Compendium Volume.

3.1.4. When to Use This Note

While each of these target audiences will use the note in slightly different ways, within the overall project development process, this guidance note is intended to be used anywhere from the project's **conception** and **planning** stages, as well as during post-project completion **monitoring** (see the orange components of **Figure 3.2**). It is anticipated that in most cases, project teams will utilize this guidance note during the scoping, early design, and final design stages of the project planning process. That said, the earlier in the project lifecycle that climate resilience considerations (as described in this guidance note) are incorporated, the greater the scope and opportunity to improve the performance of the project given climate uncertainty. Furthermore, while not the focus of this note, attention should be paid throughout the project planning process to the policy and institutional landscape, as well as the role of policy shifts and improved local capacity in building resilience.

Figure 3.2. Applicability of this Guidance note during a typical project life cycle

3.1.5. Structure of and Roadmap to Using This Note

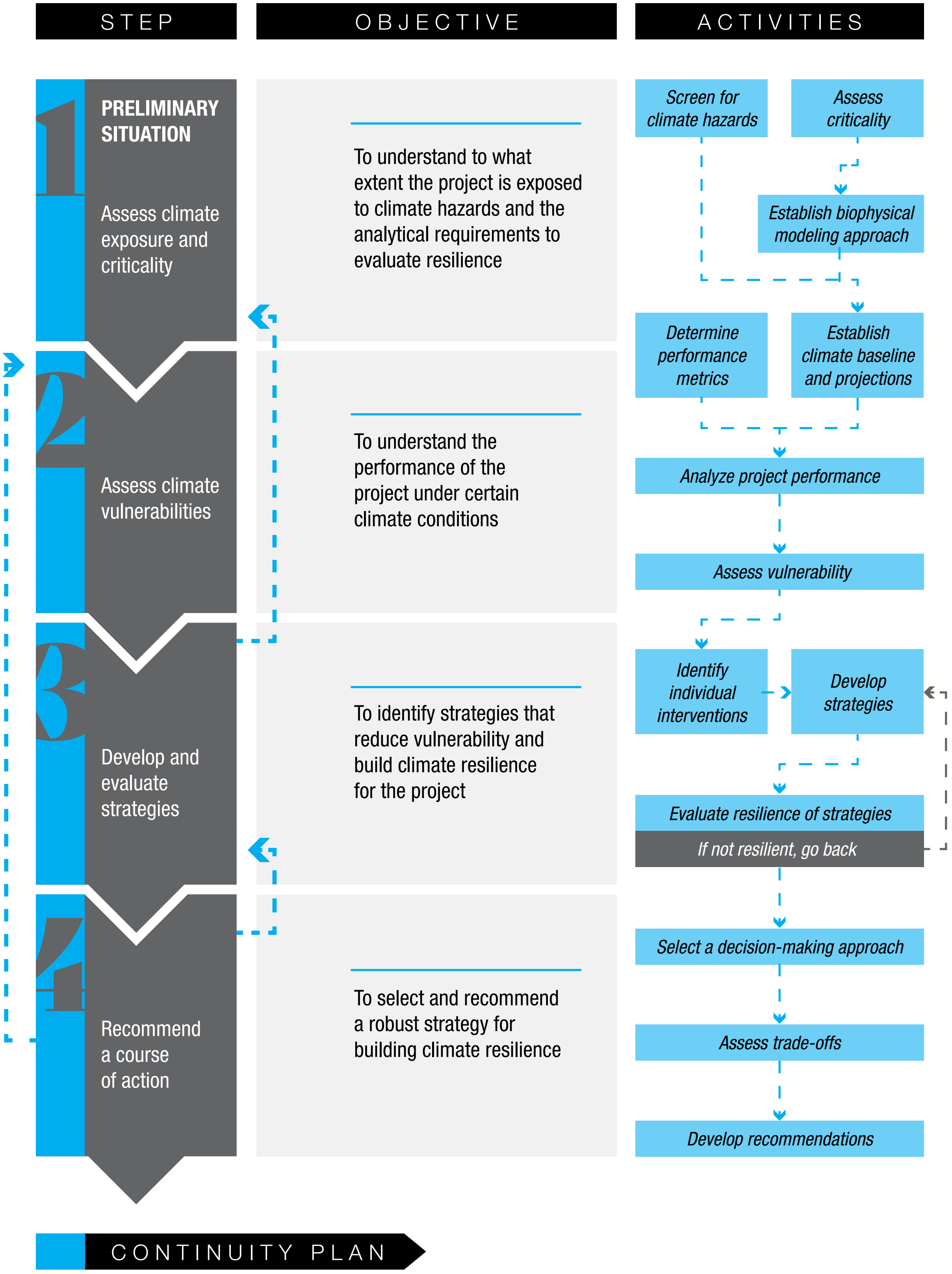
The remainder of this document is structured as follows: Section 3.2 describes a step-by-step framework used to enhance the resilience of projects in the agricultural sector to climate hazards. This section is subdivided into four steps, each containing different activities to carry out the analysis. Rigorously completing each activity requires a non-trivial amount of resources in terms of time, data, and analytical know-how. Where these resources are not available, completion of a more rapid qualitative assessment is still useful to undertake in order to provide a high-level understanding of the situation, but such high-level insights alone should not form the basis for recommendations. A case study is provided to illustrate the framework and is intended to be consulted by all users of the note. Lastly, Section 3.3 offers brief concluding remarks.

Finally, while the focus of this note is specifically on agriculture-focused infrastructure investments, many projects include cross-sectoral components and depending on the different investment components included in a project, several of the individual guidance notes beyond this one may need to be consulted. When using this note, **project leads should look beyond their particular project to consider both the broader system as well as any possible inter-system effects in their evaluation process.** For instance, those involved in a proposed agricultural water storage project would benefit from also consulting the water, energy and cities notes; a team working on an irrigation project should consider also consulting the water note; and efforts to advance forest restoration in agricultural areas should additionally review the ecosystems note, with all these notes included in the Compendium Volume.

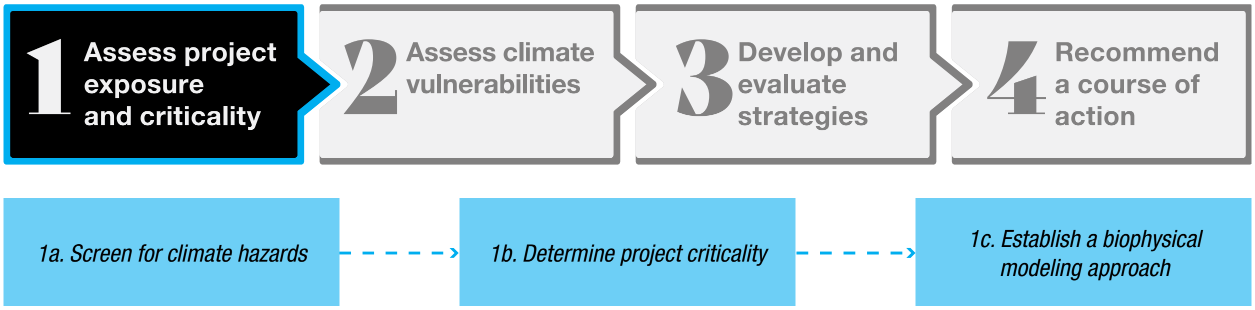
3.2. A Framework for Enhancing the Climate Resilience of Agriculture Infrastructure Projects in Sub-Saharan Africa

The guidance for developing climate-resilient investments presented in this note builds on a broadly applicable, multi-step framework, summarized in **Figure 3.3**. The framework consists of a series of four steps, each explained in further detail below, with many of the steps linked through important feedback loops. As noted in Chapter 2 of the Compendium Volume, the framework is founded on an initial assessment of the preliminary situation, which examines the **institutional and project context** (including the existence of country-level development plans, support from relevant ministries, and the state of weather and climate change monitoring capabilities) as well as identifies **relevant stakeholders** (including community groups, beneficiaries, technical experts, policymakers, and non-governmental organizations).

Figure 3.3. **Framework for Enhancing the Climate Resilience of Investment Projects**



3.2.1. Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality



Objective: The purpose of the first step is twofold. One, the process evaluates whether the project is exposed to any climate hazards, both now and over the course of the project's expected lifespan. And two, the process seeks to determine the level of complexity required for the analysis based on the project criticality.

Activity 1a. Screening for climate hazards. A climate hazard is any climate-driven event that may result in damage and loss to the project. These can be a product of:

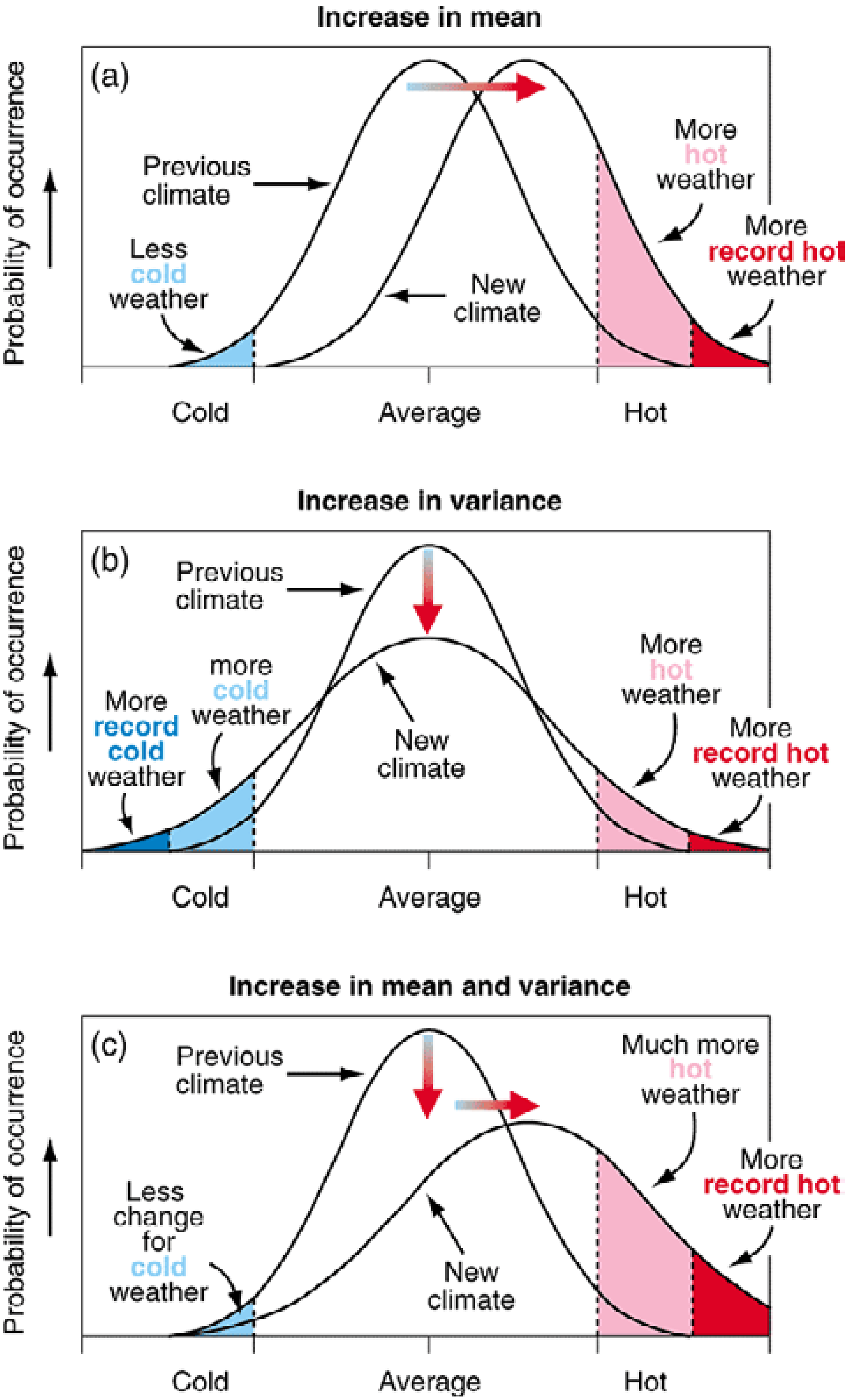
- **Extreme weather events:** low-probability but high-impact climatic phenomena (such as floods, droughts, or heat waves), as well as more frequent, lower-intensity events which can also cause significant impacts
- **Long-term changes to normal climate conditions:** changes relative to the historic baseline

Resilience Spotlight: Climate Resilience Benefits from Pairing Crops with Solar Power Production

Malawi recently invested in a 60-megawatt solar photovoltaic plant in Salima, which will add a new source of energy supply in the country, offering greater resilience to the country's climate-vulnerable hydropower sector. Emerging research from the United States suggests that **crops planted under solar arrays may experience more moderated ground temperatures, reduced water use and improved carbon uptake, with food production doubling under this kind of novel agrivoltaic system.** In addition, the performance of the solar system during hot summer months also improved, with water evaporating from the crops cooling the panels, resulting in three percent more electricity generated. While further research is needed, particularly in a Sub-Saharan African context, these remarkable findings suggest that **combining food and solar production results not just in increased resilience to possible future hotter conditions, but overall better performance of both systems.**

As **Figure 3.4** shows, taken together, climate change can impact both the mean conditions to which a project will be exposed (e.g., higher temperature on average in the future), as well as the frequency and intensity of extreme weather events (e.g., more record hot weather). Exposure to climate hazards refers to whether the hazard is present at the project's location, either because of natural conditions or the absence of protective systems. When considering future exposure over the course of the project's useful lifespan, understanding the uncertain nature of future climate hazards is essential for evaluating the climate resilience of a project.

Figure 3.4. **Illustration of Climate Change Impacts**



Source: Intergovernmental Panel on Climate Change (2001).

Textbox 3.1: Key Climate Hazards that Impact Agriculture in Sub-Saharan Africa

Temperature: changes in temperature leading to heat stress in common crops can shorten the growing season, leading to plant damage due to prolonged high temperatures and excessive heat and potentially no marketable crop yield; some crop types are more susceptible to heat (e.g., vegetables); extreme temperature can reduce or stall crop productivity, contribute to aridity and drought conditions.

Precipitation: changes in precipitation can affect the suitability and performance of crop types and livestock breeds as well as rain-fed and irrigated farming systems. Furthermore, it can lead to new pest and disease outbreak because of joint changes in total, seasonal distribution, and intensity of rainfall.

Drought: dry days impact soil moisture and can increase the stress on water resources, which may lead to crop failure and poor livestock performance. Analysis should look across all types of droughts –meteorological, agricultural, hydrological, and socio-economic.

Flooding and storms: can cause harm to crops and livestock, increase soil erosion, and damage agricultural and social infrastructure.

Strong winds: strong winds can increase evapotranspiration, decrease soil moisture, and exacerbate drought conditions.

Sea level rise: can induce soil erosion and reduce land availability for crops, pastures, and fisheries.

Screening for climate hazards will help the project team identify the types of hazards that threaten the performance of the project, given the project's location and expected useful lifespan. Climate hazard impacts are transmitted throughout the agricultural value chain, ultimately contributing to food insecurity, supply chain failures, and poverty traps for rural households in Sub-Saharan Africa.

Typical climate variables to consider for agriculture projects are temperature, precipitation, and evapotranspiration. These variables can constitute a hazard when their magnitude and/or duration affect the performance of the project. **Textbox 3.1** summarizes key climate hazards for agriculture in Sub-Saharan Africa.

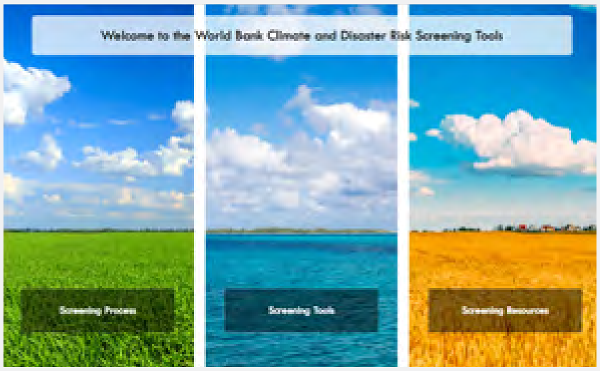
To screen the various climate hazards for a given location, the frequency and severity of historic events are first analyzed. However, it is important to consider the future exposure over the course of the project's useful lifespan. Generally, projects with a short useful lifespan may only need to focus on the impact of extreme weather events consistent with those experienced historically. In contrast, projects with longer lifespans should carefully inspect whether the project is exposed to new hazards and the increased frequency and severity of existing ones. Given the significant degree of uncertainty about future climate conditions, it is recommended to consider the broadest possible

range of climate hazards, including those considered less likely, rating the severity of each threat to identify those most relevant for the project.

Various tools exist that can be used to screen a project's exposure to climate hazards; **Textbox 3.2** shows a selection of tools that could be used. Note that the individual outputs from these different tools may not be directly comparable to each other due to differences in the design of the tool and the assumptions it makes. In addition, these tools are not designed for detailed asset-level risk analysis but rather offer broad insights about the hazards present at the location of a proposed project. Subject-matter experts and local stakeholders should further supplement the climate risk screening results from these tools, as a mechanism to both validate the identified threats and reduce the risk of omitting relevant hazards.

Textbox 3.2: Climate Hazard Exposure Screening Tools

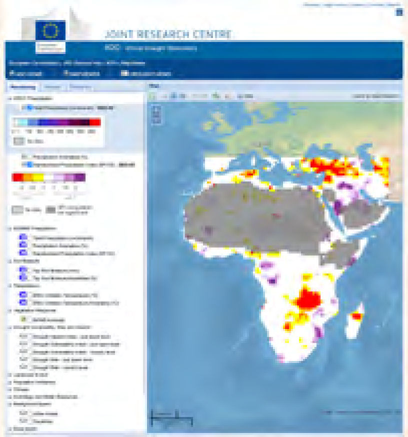
Climate and Disaster Risk Screening Tool (**World Bank)**. This tool provides a guided method to identify climate hazards and levels of risk to project evaluators at an early stage in the project design process. It focuses on physical and non-physical components of the project, and ranks the threat between low to high, including a no risk and insufficient understanding category. It has a “rapid” (about 30 min) and “in-depth” (about 2 hours) version for multiple sectors, the latter being highly recommended unless the evaluator is familiar with climate science and the project context. The tool relies on the World Bank’s Climate Change Knowledge Portal, which is a web tool that provides processed and synthetized historical and projected climate information from the Intergovernmental Panel on Climate Change. The tool considers extreme temperatures, extreme precipitation, flooding, drought, winds, sea level rise, and storm surge. Users would ideally be in possession of a project concept or design, as well as subject matter expertise for the country and project context. In terms of strengths, the tool guides the user on how to perform the screening and how to use data from other tools. It provides an assessment that includes the hazards at the project location as well as the potential impacts on the project’s infrastructure and service delivery, as well as how institutional and contextual factors interact with hazards and the project’s physical components.



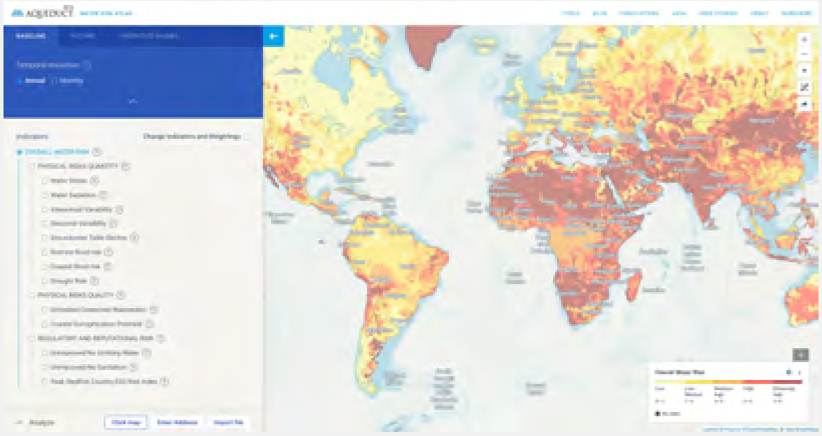
ThinkHazard! (**Global Facility for Disaster Reduction and Recovery)**. A web tool that provides a general assessment of climate hazards at a sub-national scale. The tool covers 12 different hazards including flooding (river, urban, and coastal), extreme heat, water scarcity, and cyclones. The tool presents a qualitative assessment of the level of a particular threat (i.e., low to high) both now and in the future given potential impacts of climate change, describing general impacts of the hazard along with generic recommendations for planning and evaluation. The tool also includes additional local and/or regional online resources when available. All that is required to run the tool is a general project location. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining a list of the relevant hazards to consider in a particular area, without requiring project specific information. It can help place climate hazards in context with other non-climate threats.

Textbox 3.2 (continued): Climate Hazard Exposure Screening Tools

African Drought Observatory **(European Commission Joint Research Centre)**. A web map service to identify potential drought hazard and risk levels in Africa. It offers access to recent drought monitoring data, as well as probabilistic forecasts for near term precipitation. A general project location is required to run the tool. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining an overview of historic climate hazards to consider in a particular area, without requiring project specific information.



Aqueduct Water Risk Atlas **(World Resources Institute)**. A global web map service that provides an assessment of coastal and riverine flood risks. The tool allows the customization of water hazards by time horizon, climate scenario and projection model, and return period. A general project location is required to run the tool. In terms of strengths, it easily allows users to explore how water risks change under different future climate scenarios.



ClimateLinks Screening and Management Tools **(United States Agency for International Development)**. The screening and management tool provides a sectoral toolkit for self-screening and rating of climate risks in the early stages of project design. The risk profiles consist of short briefs for countries and regions that assess the potential impacts of climate change on key economic sectors, including an overview of historical and future climate trends, the policy context, and existing adaptation projects.

Textbox 3.2 (continued): Climate Hazard Exposure Screening Tools

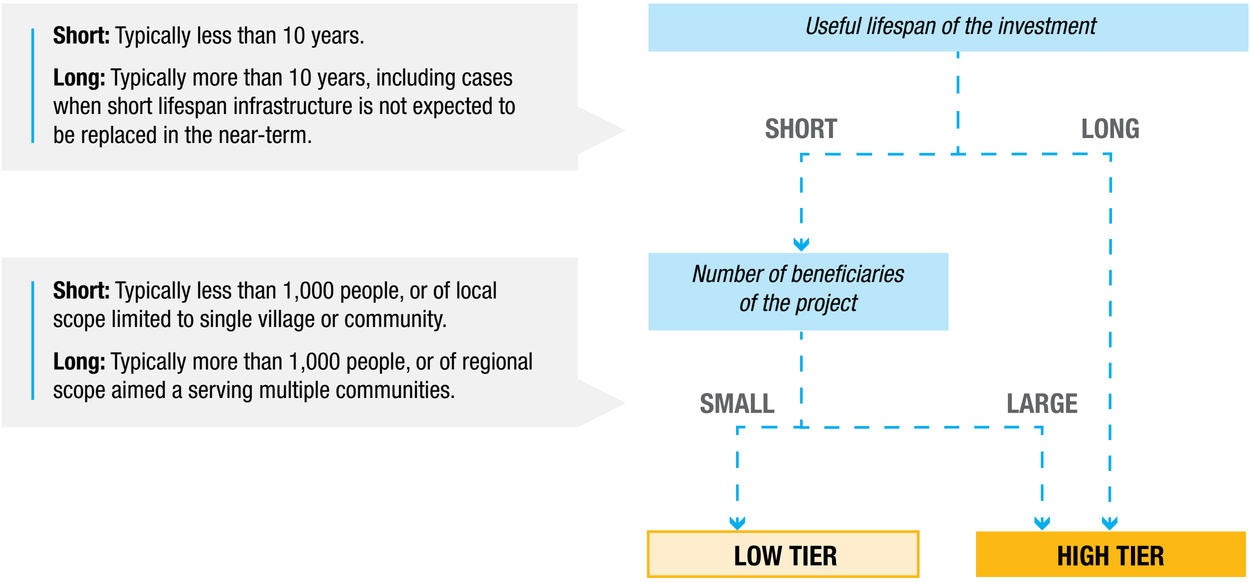
Additional non-web-based tools that could be consulted include:

The CRiSTAL (**International Institute for Sustainable Development**). A project planning tool for identifying climate risks and design components to enhance resilience. It incorporates stakeholder consultation and expert interviews, as well as guidance notes for internal evaluation developed by the African and Asian Development Banks. The tool includes an initial screening step that can be used to understand the potential impacts of climate hazards on the project and local livelihoods in the area. It expands beyond a cursory screening tool, offering guidance for project design and evaluation through a participatory process. A project concept or design is necessary in order to run the tool. In terms of strengths, it guides the user to perform a screening following a questionnaire and provides a community-based perspective of the project, as opposed to the perspective of funders only. It additionally puts climate hazards in context with social, political, and cultural conditions and provides a framework for incorporating local and expert knowledge through consultation.

Activity 1b: Determine the project criticality to establish the appropriate level of effort required to assess project resilience. Evaluating the impacts of the climate hazards identified to be relevant to the project can be complex, data-intensive, and expensive. However, not every project requires the same level of analytical complexity, and to ensure the framework is practical and accessible, projects are classified into two tiers. A low tier method is less data-intensive and simpler than a high tier method, which is generally treated as being able to more accurately model the project's response to climate hazards. For example, construction of a low-level water crossing for livestock would likely be considered a low tier investment, whereas a diversion weir for flood control of a peri-urban area is likely a high tier investment. Distinct components within a large project that require separate analysis or modeling could be analyzed separately and may be classified into different tiers. **While the focus of this guidance note is on the project design level, it is crucial to understand the development setting in which the project is situated.** All project design decisions should be mindful of local conditions, including the policy landscape, as well as technical and institutional capacity (see Compendium Volume Chapter 2 for a discussion of these kinds of cross-cutting factors that can enable or hinder a project).

The tier of a project can be determined using the sample process shown in **Figure 3.5**, which assesses criticality based on the useful lifespan and number of beneficiaries of the project. **Note that this framework is qualitative and flexible in nature, with Figure 3.5 providing guiding principles** (i.e. project lifespan and number of beneficiaries) and suggested cutoffs to determine short/long lifespan and small/large number of beneficiaries to judge the project under evaluation. However, **project teams and stakeholders should consider a more flexible set of criteria, carefully assessing which guiding principles and cutoff values are appropriate for their particular project and inspecting whether using the selected criteria results in an appropriate level of criticality**. For example, when looking at agricultural investments, high tier projects could also include those that address critical food security risks or offer significant enhancements in gender equity. These examples highlight that context is required to appropriately determine the criticality of a project.

Figure 3.5. **Sample Tier Determination Process**



Short: Typically less than 10 years.

Long: Typically more than 10 years, including cases when short lifespan infrastructure is not expected to be replaced in the near-term.

Short: Typically less than 1,000 people, or of local scope limited to single village or community.

Long: Typically more than 1,000 people, or of regional scope aimed a serving multiple communities.

Activity 1c. Establish a biophysical modeling approach based on the project tier. The results of the tier determination process serve as the basis for establishing a biophysical modeling approach that simulates the physical behavior of the project under different climatic conditions (e.g., translating changes in future precipitation to altered crop yields or water supply reliability). These models (i.e., simplified, conceptual, mathematical representations of a system) require climate variables as inputs and produce outputs of interest that are later used for the socio-economic evaluation. The kind of climate and other input variables required will vary based on the biophysical modeling approach selected.

Selecting a model for a particular analysis always depends on the specifics of the project. For example, when estimating irrigation water requirements for water resources planning and water allocation, a crop-water model such as AquaCrop may be a suitable choice, while a model like DRAINMOD may be a more appropriate choice when designing drainage/sub-irrigation systems. Models should be determined based on their capacity to inform and improve the design of the project, particularly from changes in climate inputs. **Figure 3.6** below provides guidance for the selection of a tier-specific modeling approach to be utilized for biophysical evaluation of the project, with **Table 3.1** presenting further detail on these models. (Additional details and modeling alternatives can be found in this report by the United Nations Framework Convention on Climate Change (2008). Many of these models are interconnected, with some outputs becoming inputs for another model, and different assessments can require the linking of different individual tools. For instance, an area's water runoff could be modeled using a water resource model, with these outputs then used to simulate crop yields under different irrigation regimes.

Figure 3.6. Possible Modeling Approaches by tier

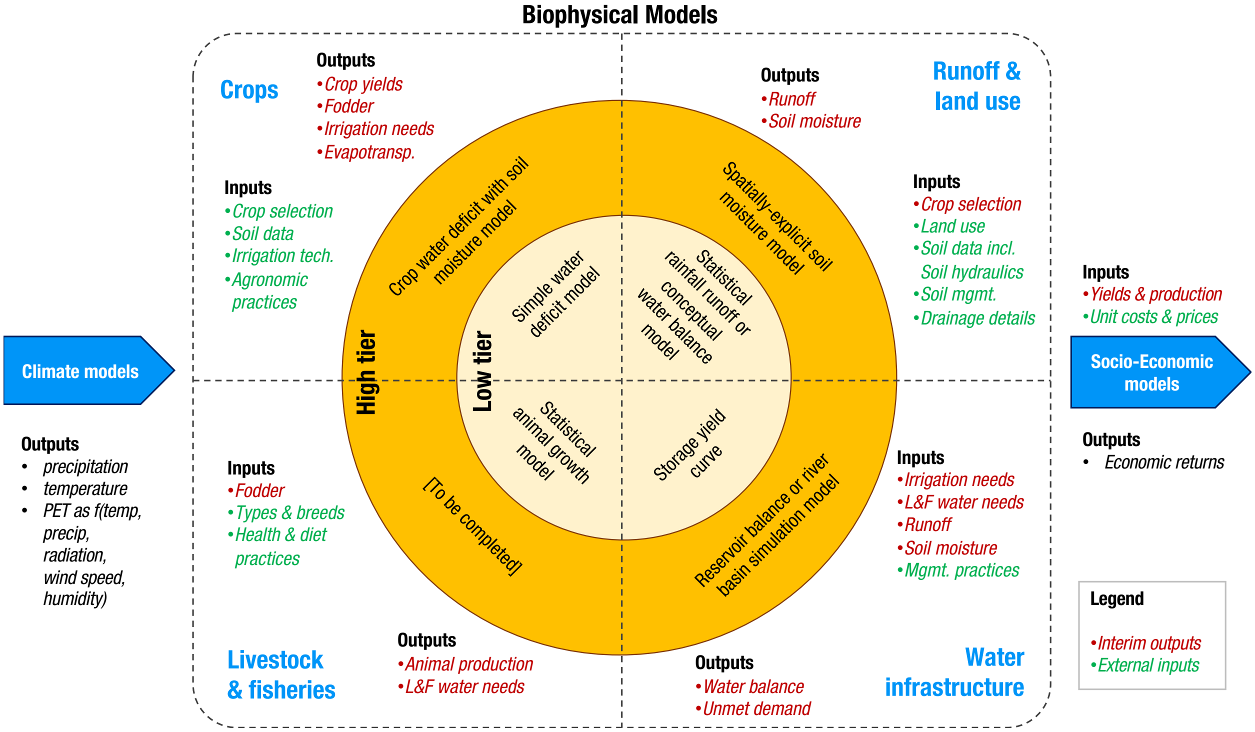


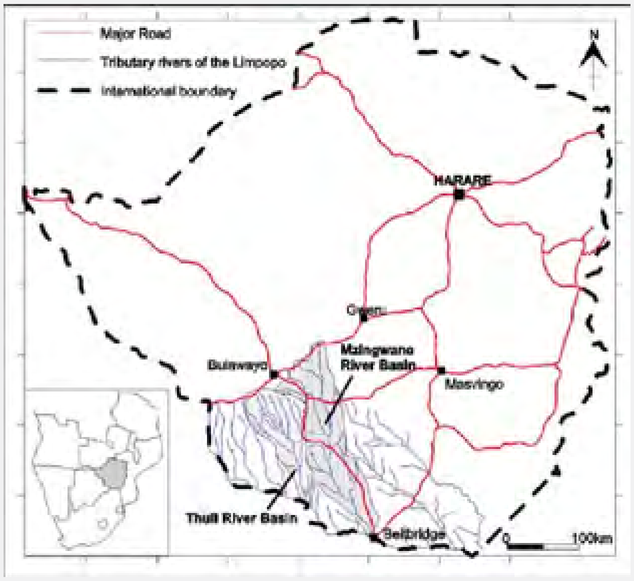
Table 3.1. Example of Classes of Models Within Each Tier

Tier	Crops	Livestock & Fisheries	Runoff & Land Use	Water Storage Yield
Low	Monthly model that considers precipitation and potential evapotranspiration effects only	Statistical relationship between annual temperature and precipitation, and resulting livestock/ fisheries yields	Reduced form monthly or annual relationship between precipitation, potential evapotranspiration, and runoff. Land use based on geospatial techniques.	Stylized excel-based approach such as the sequent peak algorithm
High	Daily biophysical/ process crop model that also considers direct temperature effects	Biophysical/process model of climatic effects on yields, considering water availability feedbacks	Calibrated daily or monthly rainfall-runoff model, and spatially explicit land use model evaluating erosion and water quality effects	A water systems model that routes runoff through a network of reservoirs and water demands

When selecting a modeling approach, it is not just important that the model relates climate variables to outcomes of interest, but also to consider which individual climate variables the model is sensitive, as well as possible interaction effects among multiple variables. External inputs, such as soil data or agronomic practices, may have increasing levels of detail for higher tiers. Furthermore, it is important to consider whether system-wide modeling is necessary to understand the risks to or benefits from a project, and in these cases, system-wide modeling would need to be undertaken. **Ultimately, model selection should be conducted considering the scope, functionality, availability and processing capacity of a particular model, experience utilizing it, knowledge of its caveats and limitations, and data availability.** That said, where existing models and analytical tools already exist for a project that are more analytically rigorous and detailed than the identified tier, these existing tools should be preferentially used.

Outcome: At the end of this step, the project team should have acquired a high-level understanding of the climate hazards the project is exposed to as well as the analytical requirements to adequately conduct a climate impact assessment of the project. Depending on the identified tier, an appropriate modeling approach should be established in consultation with modeling experts. Where a project is composed of separate investment components that are exposed to a different set of hazards, all the activities in Step 1 should be completed for each individual project component in turn.

Case Study Demonstration of Step 1: Rehabilitation of the Sebasa Smallholder Irrigation Scheme in Zimbabwe



Map showing project location. (Source: Love and Moyce 2006)

Background: Between 2017 and 2021, the Government of Zimbabwe, in collaboration with co-operating partners, took steps to rehabilitate the Sebasa smallholder irrigation scheme. Located in semi-arid south-west Zimbabwe, the scheme was originally constructed in 1968. The primary objective of the scheme was to enhance household and community food security of people living in Zimbabwe's Agro-ecological Region V, a region that receives annual rainfall averaging between 300 and 400 mm. The area experiences periodic seasonal droughts and severe dry spells to such an extent that under rainfed conditions, farmers are only able to realize good crop harvests two out of every five agricultural seasons. The Tuli River provides water for the scheme via a diesel-powered sand abstraction system. The scheme had previously been rehabilitated at a much smaller scale before the major rehabilitation works conducted between 2017 and 2021, with these most recent works the focus of this case study.

1 **Assess project exposure and criticality**

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

1a. Screen for climate hazards

1b. Determine project criticality

1c. Establish a biophysical modeling approach

Climate hazards: At the project's inception in 1968, 65ha were irrigated by 100 farmers but the total irrigated area has progressively decreased over time. By 2005, irrigation within the scheme had ceased

Case Study Demonstration of Step 1 (continued): Rehabilitation of the Sebasa Smallholder Irrigation Scheme in Zimbabwe

entirely due to an insecure water supply, with this insecurity largely attributable to climate-related phenomena, including:

- Cyclone Eline in 2000, which widened the river and caused the collapse of three pumping stations
- Cyclone Japhet in 2007, which caused flooding that destroyed irrigation infrastructure
- The 2015/16 El-Nino, which caused drying up of the Tuli River, and destruction of boreholes and the water delivery system.

The cumulative effects of these extreme climatic events caused widespread food, nutrition, health, livelihood and income insecurity in the scheme and its environs.

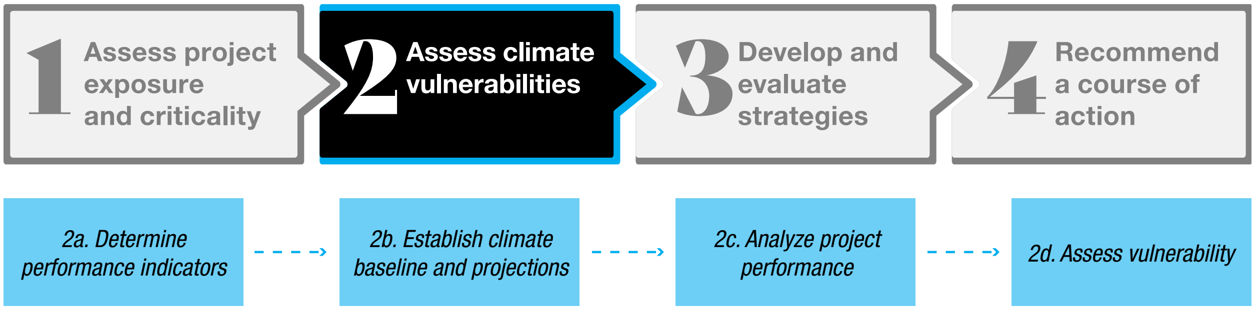
During planning, it was realized that successful rehabilitation of the scheme would need to take into account past climate extreme events (whose frequency and intensity are likely to increase), looking in particular at anticipated future changes in precipitation, runoff and potential evapotranspiration.

Project criticality: The criticality of the rehabilitation project was assessed based on the longevity of the proposed investments and the number of beneficiaries. Given the relatively short lifespan of the investments, the limited number of direct beneficiaries of the project (from 50-120 plot holders, depending on the size of the plot) and the local scope of the project, it is classed as being a low tier project. This means less data-intensive methods can be used to adequately assess the project's response to climate hazards.

Biophysical modelling approach: The project's classification as a low tier project means that a relatively simple crop model coupled with a basic water infrastructure model would suffice to quantify the expected impacts of project investments. Such a biophysical modelling approach could, for instance, translate altered future precipitation values given climate change into changes in the average yields of key crops. The changes in yields of rainfed crops versus crops that are irrigated can also be computed to estimate the benefits of expanding the area irrigated under the Sebasa scheme.

Condition of infield canals at Sebasa Irrigation Scheme (Source: International Fund for Agricultural Development no date)

3.2.2. Step 2: Assess the Vulnerability of the Project to the Identified Climate Hazards



Objective: After the project screening and assessment of the necessary analytical complexity, the next step is to **assess the project's vulnerability to climate hazards**. This process seeks to identify how a project performs under extreme climate conditions and, incrementally, under a future with climate change (which can further impact the frequency and intensity of extreme events), as compared to current conditions. This same framework will also be used later to assess the performance of possible adaptation options to build climate resilience. The process involves four different activities, each described below.

Textbox 3.3: Performance Indicators in Agriculture

- Stability of crop yields
- Types of crops planted that are drought resistant and heat tolerant
- Area under production
- Availability of seeds suited to the climate
- Reduced food deficit or increased dietary energy supply
- Increased water availability
- Number of irrigation systems in operation
- New market opportunities developed
- Farmer income levels
- New economic and poverty reduction strategies.

Activity 2a. Determine performance indicators and targets to assess the climate vulnerability of the project. On the one hand, these metrics would include the economic return of the project measured as net present value, benefit-cost ratio, or internal rate of return, and minimum acceptable returns or hurdle rates as targets (e.g., a net present value above zero, an economic rate of return above a minimum return). On the other hand, indicators that characterize and assess the success

> The climate baseline describes the default conditions applicable to the initial design of the project, representing the reference point for the analysis.

(or failure) of the project and its contribution to food security should be considered. **Textbox 3.3** provides a sample list of possible indicators for agriculture-focused investments. Depending on their nature, some may be quantitative outputs from the biophysical or socio-economic models, while others may require additional calculation assumptions. For instance, estimating food deficit requires an assumption on average caloric intake. When feasible, performance indicators should incorporate metrics established by the broader policy environment and development strategy, particularly when those address climate resilience already.

Whereas typical project evaluation methods consider means and weighted averages as performance metrics, given the large degree of uncertainty associated with future climate conditions, an evaluation of climate resilience should look at a range of expected values across different potential future climate scenarios (for instance, as defined in reports from the IPCC), as well as thresholds that cause a project to fail, in order to identify project designs that perform well across a range of different future conditions.

Activity 2b. Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions. The climate baseline describes the default conditions applicable to the initial design of the project, representing the reference point for the analysis. During later stages in this step, a subset of baseline conditions will be perturbed, and performance between baseline and future conditions will be compared for assessing vulnerability.

Resilience Spotlight: Enhancing the Climate Resilience of the Mwache Multi-Purpose Dam Project in Kenya

The Mwache Dam water resources development project, located in the Coastal Province of Kenya, is designed to provide 220,000 cubic meters per day for domestic water use in the greater Mombasa area as well as for irrigation of around 2,000 hectares of agricultural land in Kwale County. This project is expected to significantly reduce existing water deficits in the region, with current deficits as high as 60 percent of the total demand.

Several studies have been conducted to assess the risks to the current Mwache Dam design due to climatic change (see for instance, Taner, et al. 2019). In terms of enhancing the climate resilience of the project, possible adaptation options could include **increasing the design volume of the reservoir, or implementing a comprehensive sediment management plan to help maintain long-term reservoir storage. On-farm options to safeguard the project's resilience given uncertain future precipitation regimes could include reducing demand for water by utilizing drip-irrigation systems (versus flood irrigation for instance).**

In order to generate a baseline, the project team must first evaluate the availability and quality of historical data (possibly using statistical tools to fill in any data gaps), keeping in mind the expected lifetime of the project. An appropriate time frame for establishing a climate baseline from observed data in the agricultural sector would be 30 years of historic records. In cases with limited data, a baseline of the last 10-20 years could be acceptable, however, the shorter the period used the greater the possibility that the period used is not representative of the long-term climate. Depending on the project, baseline climate data would include historical hydro-meteorological records such as temperature, rainfall, low flows, high flows, and wind speed. The World Bank's Climate Change Knowledge Portal is a good place to start to obtain existing historical data for a particular area.

When considering investments in the agriculture sector, of special note is the role of natural climate variability particularly as it relates to water availability for rainfed and irrigated agriculture. Precipitation and thus river discharge are strongly seasonal in Sub-Saharan Africa, with the impacts of variability made more pronounced by the relatively limited water storage available. Furthermore, within some parts of Sub-Saharan Africa, the climate manifests low frequency variability due to El Nino Southern Oscillation phenomena and other factors that cause significant periods of anomalous climate as compared to long term means.

When considering investments in the agriculture sector, of special note is the role of natural climate variability particularly as it relates to water availability for rainfed and irrigated agriculture.

As such, for projects with lifespans of approximately 10 years or less, natural climate variability is the dominant concern, over and above the long-term impacts of changes to mean conditions as caused by climate change. For example, a project investing in unlined irrigation canals and small capacity siphons may take climate variability as well as any observed trends attributed to climate change into account at the outset, while managing further impacts from climate change adaptively in the medium term. Projects with longer time horizons (such as irrigation/drainage pumping stations and pressurized irrigation pipelines), however, are subject to greater uncertainty and should consider a wide range of future climate conditions.

There is a great deal of uncertainty about future climate conditions, particularly for long time horizons, which makes the question of which climate futures to consider a non-trivial decision point in the evaluation process. Future climate is uncertain not just because of natural stochastic variability in the climate (i.e., one rainy season can be wetter than another), but also because of uncertainty about how future greenhouse gas emissions will grow, and uncertainty about how the climate system

> Future climate is uncertain not just because of natural stochastic variability in the climate (i.e., one rainy season can be wetter than another), but also because of uncertainty about how future greenhouse gas emissions will grow, and uncertainty about how the climate system will respond to future emissions levels.

will respond to future emissions levels. One way of exploring these various sources of uncertainty is through the use of different future scenarios or pathways. While tempting to focus in on just one or a few individual climate futures, there are compelling reasons to consider a broader range of possible conditions: a single climate future describes only one possible version of the future, with many other possibilities going unexamined, making it difficult to draw well-substantiated conclusions.

Detailed, quantitative simulations of future climate can be obtained from projections modeled through GCMs. Recent World Bank guidance (2022) focuses specifically on the selection of future climate projections and recommends considering **an optimistic and a pessimistic scenario of greenhouse gas concentrations** as driven by global greenhouse gas emissions trajectories and climate mitigation policies, as well as **several scenarios that represent a "dry and hot" and a "wet and warm" future**. The first set of scenarios allows one to assess the impact of uncertain global climate mitigation efforts on project outcomes, whereas the second set helps assess local climate risks and overall uncertainty in climate model outputs on project outcomes. The latter is important because different models simulate different climate outcomes for the same emissions scenario due to their reliance on different modeling approaches. In addition, as a general rule, an analysis should consider different GCMs in order to capture the range of possibilities predicted by climate scientists. Attention should be paid to the range of future conditions described by these model ensembles (by considering confidence intervals, for example) rather than just their averages. **Textbox 3.4** provides guidance on where to obtain climate projections, with further details presented in the technical note on working with climate projections included in the Compendium Volume.

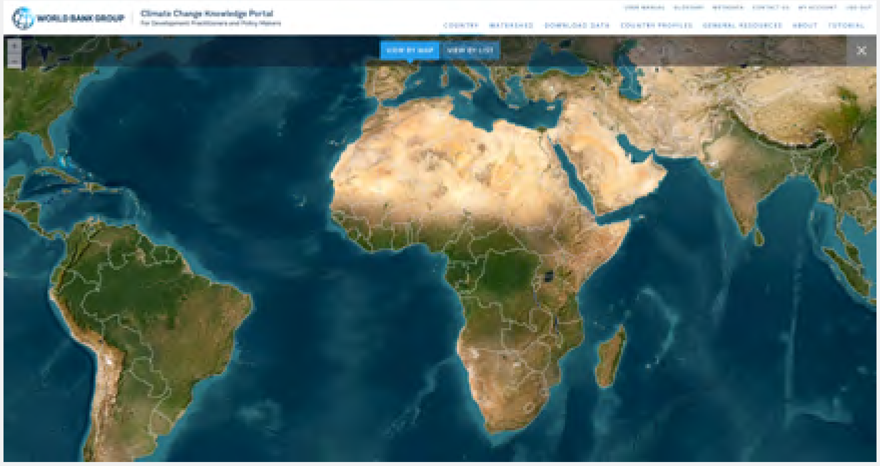
An even more rigorous analysis suitable for high tier projects would include considering the full range of future climate uncertainty (as compared to selecting a number of individual climate scenarios) through stochastic estimations of climate variables from a weather generator. The Decision Tree Framework (Ray and Brown 2015) provides additional guidance on how to use a weather generator in project evaluation.

Finally, through stakeholder consultation and expert advice, the project team should assess the degree of uncertainty suggested by the range of climate scenarios considered, as well as to what extent these uncertainties are tolerable and/or should be mitigated.

Textbox 3.4: Where to Obtain Climate Projections

The output of future climate simulations can be obtained from various sources:

The World Bank's Climate Change Knowledge Portal has both historical data and future climate simulations available for every country/sub-national unit/drainage basin in the world. All information contained within the Knowledge Portal is consistently produced and thus directly comparable. As well as being free of charge, it is well-suited to project teams who are not used to working with raw, unprocessed output from climate models and it saves time on data searches and data processing.



National meteorological agencies often also provide localized climate information, which can be accessed through the World Meteorological Organization's website.

Global observations and computer simulations from the Intergovernmental Panel on Climate Change's various assessment reports, can be obtained from their Data Distribution Centre. Similar information can also be collected from the KNMI/World Meteorological Organization Climate Explorer. These latter two sources provide raw, unprocessed model outputs, which require significant time and expertise to process and bias correct, before they can be utilized in project analyses.

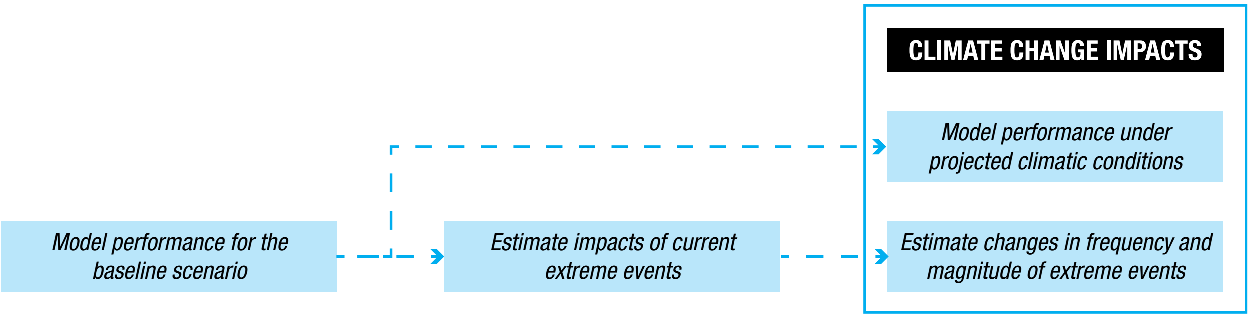
Activity 2c. Analyze the project's performance under the selected climate scenarios. The output of Activity 2b is then directed into socio-economic models that convert biophysical outputs into costs and benefits, identifying the performance of the project for both baseline and future scenarios. For instance, a project considering the use of drought resistant crops for different climatic regions and the development of a cropping calendar for drought prone regions, would see the results of a biophysical model feed into an econometric model and cost-benefit model. This chain of models would include data on crop prices, market demands and costs of inputs and supplies and labor, all to quantify the likely profits resulting from the project. These results, along with the performance in the metrics established in Activity 2a, serve as the basis for the evaluation.

In cases when the socio-economic evaluation is self-contained (typically within the farm's economy), standard investment evaluations practice follows either a Cost-Benefit or Cost-Effectiveness analysis. Economic analysis takes the view of a social (e.g., government) planner, and ideally considers all changes in welfare in the assessment. The technical note on economic modeling included in the Compendium Volume provides a primer on these models and the quantification of externalities, as well as on approaches required for cases in which the project's performance results in changes in macroeconomic variables further down the value chain (e.g., changes in commodity prices).

Following the analytical approach determined in Step 1, the analysis should model the impacts of climate hazards following the process in **Figure 3.7.** Climate change impacts should be modeled for all the future scenarios considered in the previous activity and compared against the baseline. Hallegatte et al. (2021) and Asian Development Bank (2015) provide further guidance on how to incorporate the effects of climate change and extreme weather events in cost-benefit analysis. For projects with long time horizons, it is recommended to look at the result at multiple timestamps (e.g., midcentury and end of century).

When conducting the assessment of a new development, a counterfactual representing a no-investment scenario, would be appropriate to assess whether the investment is better than a no-action scenario, as well as to measure the overall contribution (i.e., benefits minus costs) of the investment.

Figure 3.7. **Evaluation Process for Climate Hazards**



Activity 2d. Assess the vulnerability of the project in the form of a stress test. The analysis should then explore the performance of the project under the range of possible climate futures selected in Activity 2b to assess whether the project fails under those conditions based on the results from Activity 2c. This stress test will help the project team identify thresholds for failure, as well as failure scenarios (e.g., when the project does not meet the minimum economic returns) and the extent of the failure (i.e., difference between the results and a target measure). The vulnerability of the project is then assessed by looking at all the results generated in the previous activity for each future scenario. The following questions guide the vulnerability assessment:

- **Does the project meet the minimum performance targets?** When looking at economic return metrics, these generally require the project to have a positive Net Present Value and/or meet an Internal Rate of Return hurdle rate (see the technical note on economic modeling included in the Compendium Volume for a primer on economic evaluation). A project can also be vulnerable to a climate hazard when minimum performance in other metrics is not met under at least one scenario. For example, a project may fail if does not deliver a minimum number of dietary calories.
- **To what degree does the project meet the minimum performance targets?** The extent of the failure can be measured through the range of results across different climate futures. This analysis may indicate the presence of scenarios with results below an acceptable threshold, which may render the project vulnerable if consequences can be catastrophic.

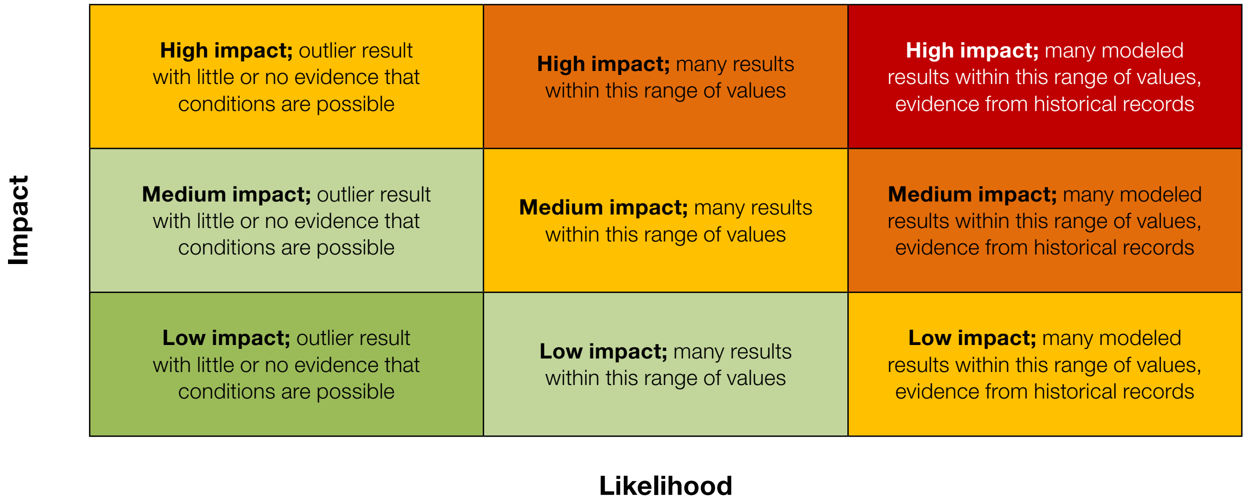
On the basis of these questions, a project can be considered vulnerable to climate change impacts if in the future (i) the results for individual climate scenarios are worse than the baseline, (ii) there is a greater number of failure scenarios than in the baseline, (iii) the potential range of results worsens, or (iv) a combination of these situations. For example, the analysis may find that for a single GCM scenario, the irrigation water provided by a new surface water investment is insufficient to support the expected enlargement in cropped area, and many of the GCM scenarios show a decline in irrigation water available, while some also show an increase or little change. Those that

show the problematic outcome (i.e., insufficient water) or worse results, indicate that the project is vulnerable should those futures occur. By using a large number of scenarios, the project team can have more confidence in the level of concern associated with the vulnerability (i.e., large number of problematic scenarios versus few).

A practical framework to summarize the results of the vulnerability analysis, particularly for high tier projects with a large number of results, is to generate a risk matrix that considers impact and likelihood. Impacts refer to the effects of the climate hazard on the project's performance. Likelihood can be thought of as a "weight of evidence" that provides insights as to the level of concern associated with the vulnerabilities. Likelihoods can be assessed in relative terms, based on whether the results of each GCM run fall within the general range of all results or is an outlier, and whether the climatic conditions have been observed in the historical baseline.

Figure 3.8 presents an illustrative example of a risk matrix adapted from Ray and Brown (2015), where higher impacts and higher likelihoods lead to higher levels of risk. All projects found to be vulnerable, particularly those at higher levels of risk, should advance to the next step of the framework to examine whether the project's resilience can be improved.

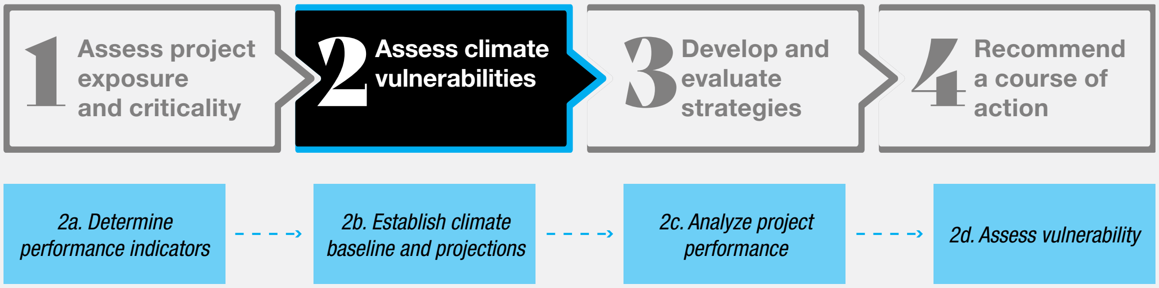
Figure 3.8. Sample Risk Matrix



Impact	**High impact;** outlier result with little or no evidence that conditions are possible	**High impact;** many results within this range of values	**High impact;** many modeled results within this range of values, evidence from historical records
	Medium impact; outlier result with little or no evidence that conditions are possible	**Medium impact;** many results within this range of values	**Medium impact;** many modeled results within this range of values, evidence from historical records
	Low impact; outlier result with little or no evidence that conditions are possible	**Low impact;** many results within this range of values	**Low impact;** many modeled results within this range of values, evidence from historical records
	Likelihood		

Outcome: The result of this step is an understanding of the climate vulnerability of the project as currently designed. Comparison between the performance of the project under a historical baseline and under various climate futures provides an estimate of the degree of vulnerability of the project to climate change. It is possible that some project designs may be found to already be climate resilient in their performance given climate uncertainty and these projects can exit the framework here.

Case Study Demonstration of Step 2: Rehabilitation of the Sebasa Smallholder Irrigation Scheme in Zimbabwe



Performance indicators: The Sebasa project falls under a broader program of work known as the Smallholder Irrigation Revitalisation Programme. In total, 16 performance indicators were defined for the programme (a full list is available in Appendix A of Government of Zimbabwe 2018), including

- Area of irrigation schemes rehabilitated
- Effectiveness of irrigation: incremental hectares of crop grown throughout different seasons
- Improved agricultural production: average yield increases (kg/ha) of main crops, including maize, beans, tomatoes, sorghum and groundnuts
- Gross total value of marketed commodities per year
- Annual household income on irrigation schemes
- Number of people benefiting from project services, by gender
- Gross total value of marketed commodities per year
- Number of people trained in soil and water conservation, nutrition education and organization

For each indicator, a baseline value was established, as well as midterm and end-of-project targets.

Climate baseline and projections: As identified in Step 1, it had been determined that successful rehabilitation of the scheme would need to take into account anticipated changes in precipitation, runoff and potential evapotranspiration. Specifically, climate change modelling show that in the medium to long term (2040 and 2080), the Mzingwane River basin (in which the scheme is located) is expected to experience the following:

- precipitation changes of between -40 percent and +20 percent
- runoff changes of -70 percent to + 100 percent
- potential evapotranspiration increases of 50 percent

Analyze project performance: An analysis of project performance given possible future climate impacts would ideally be based on a quantitative assessment that converts the biophysical impacts of investing in the project into costs and benefits, for both baseline and future climate conditions. In the case of Sebasa, the technical, organizational and socioeconomic conditions of the scheme were assessed through a Rapid Appraisal conducted in 2017 and a Feasibility Study completed in 2019. These studies sought to assess both scheme performance as well as formulate action plans to improve scheme performance. They relied predominantly on stakeholder consultation, and utilized focus group discussions, in-depth interviews and questionnaires as well as secondary data collection.

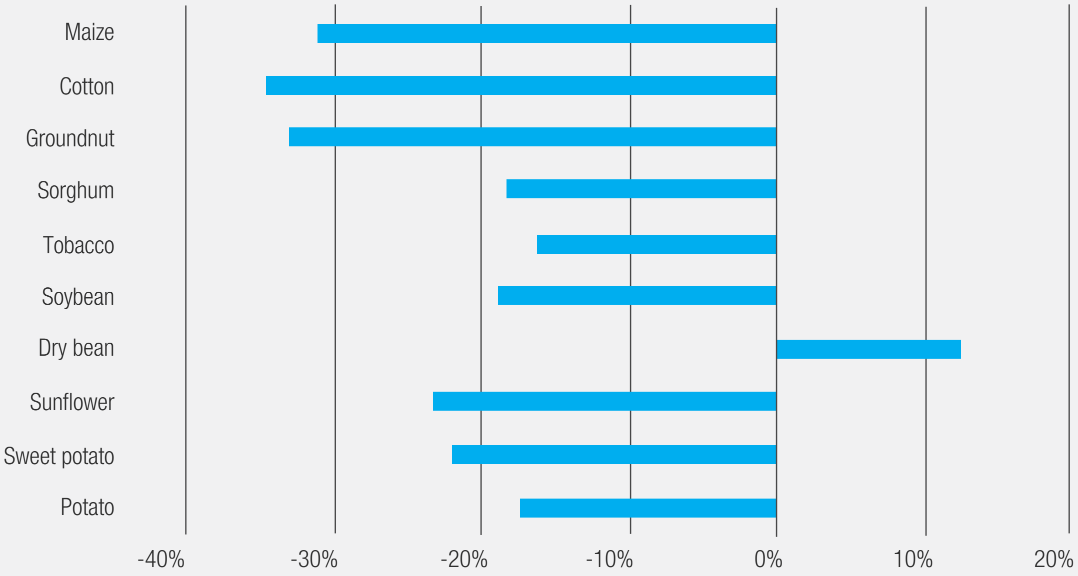
Case Study Demonstration of Step 2 (continued): Rehabilitation of the Sebasa Smallholder Irrigation Scheme in Zimbabwe

The appraisal targeted potential beneficiaries and stakeholders of the Smallholder Irrigation Revitalisation Programme, including dryland and irrigating farmers, key informants and service providers. Key informants included representatives from the Agricultural Technical and Extension Services, the Irrigation, Mechanisation, District Development Fund, the Zimbabwe National Water Authority, and the Ministry of Health and Child Care.

Assess vulnerability: Given the qualitative nature of how project performance was assessed, the climate vulnerability of different possible project investments was also assessed qualitatively. There was an awareness among stakeholders that climate factors (e.g., Cyclone Eline and Japhet and the 2015/16 El-Nino) had historically reduced performance of the scheme and would continue to do so in the future. As such, the successful achievement of the project performance indicators described above was considered vulnerable to climate change impacts. Furthermore, farmers identified "climate change-related issues" as a priority training gap to be addressed.

These findings are in line with the results of detailed quantitative modeling conducted as part of Zimbabwe's Climate Smart Agriculture Investment Plan (2019): under a changing climate, maize, the staple food crop in Zimbabwe, is expected to see a 33% yield reduction by the 2030s, with a range of expected yields from +35% to -50% across three different climate scenarios considered (a dry/hot, a medium and a wet scenario). Expanding this assessment to 10 different crops, all but one of the 10 show an expected decline in yield, with declines ranging from -15% to -36%.

While the results presented in the Climate Smart Agriculture Investment Plan are not tailored to Sebasa specifically, they do provide additional quantitative evidence that supports the conclusions of the qualitative vulnerability assessment conducted as part of the Sebasa project itself.



Projected change in crop yields in Zimbabwe by the 2040s for a medium climate projection (Source: World Bank 2019)

3.2.3. Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience

Objective: This next step in the framework develops a set of possible strategies by which to adapt the project to climate hazards to improve its resilience. The analysis seeks to provide insights about the performance of the project given climate change as compared to the adapted project given climate change, and considers three activities.

Activity 3a: Identify individual interventions to enhance the climate resilience of the project. Building resilience involves strengthening the capacity of agricultural system to cope with climate hazards. As such, the assessment should start from the results of the analysis in Step 2, and search for interventions that can mitigate the project's vulnerabilities by decreasing the magnitude and recurrence of failure scenarios. In general, these practices to enhance resilience fall into four different categories (adapted from the Food and Agriculture Organization 2010):

- **Structural:** structural modifications to the project in terms of its capacity, dimensions, materials used, etc. and the inclusion of protective infrastructure. For example, the addition of a sediment monitoring system to safeguard the storage of a reservoir that supplies water for irrigation.
- **Technology:** use of technology to improve the resilience of a project. For example, weather and soil moisture monitoring and information systems, land leveling, drought resistant crops, early warning systems, or using satellite-based remote sensing to estimate water demand.
- **Management and planning:** water, land use, and maintenance planning. For example, developing planning protocols that consider robustness to climate variability and change.
- **Knowledge:** capacity building and training, establishment of training programs for farmers and extension service workers in concepts of robustness and ecosystem services. For example, building capacities in methodologies that address issues related to assumptions of Climate-Smart Agricultural practices.

Table 3.2 lists some measures that can be used to enhance resilience in Sub-Saharan Africa's agriculture sector. A wide range of actions can also be found as part of Climate-Smart Agriculture Country Profiles and Investment Plans, developed to provide insights about the challenges of and opportunities for Climate-Smart Agriculture within analyzed countries. Practices tend to be aligned with common-sense productivity measures, with ample room for co-benefits and few trade-offs, and include a wide portfolio that is very adaptable to farmers' needs and context-specific considerations (Sova et al. 2018).

In addition, it may be useful to think of adaptation practices as they relate to the specific vulnerabilities identified in Step 2 above. For example, if natural climate variability is found to be the dominant concern, then monitoring, forecasting and risk transfer programs can be helpful to consider; if changes in temperature are found to be of concern, then the choice of agricultural cultivars or resilient agronomic practices could be pursued.

Finally, it is important to highlight the role of **nature-based solutions**, which harness biodiversity and ecosystems services (for example, a lake or wetland providing water purification or nursery functions) to reduce vulnerability and build resilience to climate change. The ecosystems note included in this Compendium Volume provides additional guidance on incorporating such measures into a project.

Table 3.2. Agricultural Practices to Enhance Climate Resilience

System	Frequent / prioritized practices
Agricultural water management	• Precision and micro irrigation (drip, sprinklers) • In situ and ex-site water-harvesting techniques • Groundwater irrigation and use of shallow wells and hand pumps
Agronomy practices	• Conservation and regenerative agriculture (permanent soil cover, minimizing soil disturbances, crop rotation) • Intercropping, replenishment of organic matter, and increasing carbon sequestration • Integrated soil fertility management (organic inputs, green manures, improved fertilizer management) • Land restoration • Develop/switch to stress-tolerant crop types and varieties (to drought, heat, acidity/salinity, and low soil fertility) • Adjust timing of planting/harvesting etc. based on observed seasonal shifts • Integrated pest management • Mulching for moisture conservation
Livestock and fisheries	• Drought and heat tolerant types and breeds • Diseases management and animal health monitoring, including vaccines for livestock health • Animal housing and watering systems • Improved fodder species for nutrition and improved pastures • Grazing and diet management

System	Frequent / prioritized practices
Post-harvest and value chains	• Cold chain storage system • Weather index-based agricultural insurance • Improved on-farm storage and food processing • Improved market access and partnerships for smallholders • Biofortification of crops' nutrients • Traceable product systems • Sustainably sourced and fair-trade products
Cross-cutting	• Digital agriculture and big data analytics • Climate information services

Sources: World Bank (2018); Sova et al. (2018)

Textbox 3.5: Resilience Attributes for Agriculture

Key capacities to build climate resilience in infrastructure investments in Sub-Saharan Africa's agriculture sector include (adapted from Ospina and Rigaud 2021):

Robustness: the ability to withstand the impacts of climate extremes and variability, maintaining agricultural production and functioning of the supporting processes and infrastructure, while minimizing variability in performance.

Redundancy: the availability of additional or spare resources that can be accessed in case of an extreme, for instance irrigation water from a secondary source.

Rapidity: the speed at which critical resources such as agricultural inputs (e.g., fertilizer), supporting systems (e.g., irrigation systems or pumps), or supply chain assets (e.g., wholesale buyers) can be assessed.

Learning: the ability to develop knowledge and skills to innovate, adapt, and improve performance, leveraging existing knowledge to develop resilience mechanisms.

Inclusion: building on diversity and inclusion, ensuring that women and vulnerable groups have the necessary tools and resources, both in normal conditions and during crisis. For example, empowering women through climate-smart irrigation technologies.

Activity 3b: Develop adaptation strategies to enhance resilience. Once a set of promising and feasible adaptation measures has been identified for the project, more comprehensive and integrated strategies to build resilience should be developed by combining individual measures. Strategies should consider different sets of interventions, as well as different degrees of implementation, timing, or locations as appropriate, and should be part of a participatory consultation with stakeholders to identify and validate solutions. For example, one strategy could consider both upgrading irrigation infrastructure to improve water use efficiency as well as developing new reservoir storage to increase supply. Moreover, project evaluators should also pay attention to possible interactions between measures.

Ultimately, which interventions become part of a strategy will depend on what attributes of resilience need to be enhanced to reduce climate vulnerability, as well as how stakeholders and users define resilience for the particular project in question. **Textbox 3.5** presents a list of key attributes for agricultural systems, which can guide the development of adaptation strategies to enhance resilience, with these attributes ideally to be tailored to local circumstances. While these attributes are introduced here as guidelines to consider when developing possible adaptation strategies, they are a powerful tool to strengthen project design, especially when integrated as key resilience concepts into the project narrative from the outset and then used to track progress towards achieving greater resilience. Additional guidance can be found in the note for practitioners titled Integrating Resilience Attributes into Operations (Ospina and Rigaud 2021). In the face of climate uncertainty, it is appropriate that strategies consider a portfolio of measures to mitigate the impacts from multiple climate hazards, along with insurance and contingency plans for when conditions exceed the capacity of the adapted system to cope.

Climate-Smart Agricultural Investment Plans provide a helpful example of how to combine solutions for addressing the interlinked challenges of food security and climate change by focusing on three pillars: (i) sustainably increasing agricultural productivity, (ii) adapting and building resilience to climate change, and (iii) reducing greenhouse gas emissions when appropriate. Though this guidance note focuses predominantly on climate adaptation (with adaptation considered the priority at present for Sub-Saharan Africa), it is important that adaptation and climate mitigation goals and activities are not treated in isolation, as the resilience of a project can also be impacted by climate mitigation-related considerations. For instance, Climate-Smart agricultural practices can improve climate resilience while also contributing to reducing agricultural greenhouse gas emissions. The focus of this note on adaptation should not detract from the identification and quantification of any co-benefits that may accrue from climate mitigation.

Resilience Spotlight: Sustainable Food Systems in West Africa

The West Africa Agricultural Productivity Program is striving to make agriculture more climate-smart in thirteen countries in West Africa. Agriculture remains a critical contributor to gross domestic product and livelihoods in the region and this program will help ensure that the agriculture sector remains sustainable even under altered future conditions. By investing in national research centers, the program has seen the development of climate-smart varieties of staple crops including rice in Mali, plantains in Cote d'Ivoire and maize in Benin. **To help ensure the advances made at these research centers translate into improved climate resilience of on-farm activities, the program has supported implementation of climate-smart post-harvest and food processing technologies, and trained farmers on climate-smart practices such as composting, agroforestry and water harvesting.**

Activity 3c: Evaluate the selected strategies' contribution to the resilience of the project. Having identified a feasible portfolio of individual adaptation measures, the next step involves using the same modeling framework established in the vulnerability assessment described in Step 2 to evaluate the performance of the different adaptation strategies being considered.

Depending on the specific interventions, it is possible that new model parameters or assumptions may need to be defined (looping back to Step 2) before being able to estimate the costs and benefits of different interventions, which may require the gathering of additional data. Comparing the performance of the strategies to the project as originally designed (in Step 2) in terms of how much they reduce the magnitude and recurrence of project failure provides a sense of the degree of climate resilience that different strategies offer. In other words, an adaptation strategy that increases climate resilience is one that results in fewer cases of failure, a reduced impact in the failure scenarios, or both. For example, the planting of trees within an agroforestry food cropping system can reduce heat stress on the lower grown food crops, conserve soil moisture, increase water infiltration to the soil, as well as sequester carbon from plant residue, all contributing to both fewer and less severe cases of harvest failure. The extent of these improvements can be tracked using the Risk Matrix previously shown in **Figure 3.8.**

Outcome: At the end of Step 3, the project team will have identified promising portfolios of interventions that enhance the climate resilience of the original project design evaluated in Step 2. The output of this step is an updated set of results showing the project's performance for each adaptation strategy and climate scenario. This output will be the input for the following decision-making step.

Case Study Demonstration of Step 3: Rehabilitation of the Sebasa Smallholder Irrigation Scheme in Zimbabwe

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

3a. Identify individual interventions → *3b. Develop strategies* → *3c. Evaluate resilence of strategies*

Identify individual interventions to improve project resilience and develop adaptation strategies: Prior to the rehabilitation efforts undertaken between 2017 and 2021, a variety of piecemeal attempts to improve water supply and water distribution had been undertaken, over the course of a decade. In 2006-7, the Government of Zimbabwe tried to service and repair all the diesel engines. They did not succeed because the engines needed a complete overhaul, which could only be done in neighboring South Africa at a very high cost. Between 2015 and 2017, local Non-Governmental Organisations, assisted farmers to clear 10 hectares in block A of the scheme, drill 3 boreholes, partially install 3 sand abstraction systems in the Tuli River (but the work could not be completed due to financial constraints), install submersible pumps and attempted to extend the Mashaba solar grid system to the scheme. The limited success of these efforts underlined the need for a more comprehensive intervention plan, even if a comprehensive package of interventions required significant injection of capital. As such, the main rehabilitation scope of works includes i) replacement of diesel pumps with a solar powered system; ii) rehabilitation of canals; iii) repair of boundary fences; and iv) drilling and equipping boreholes.

Having identified that the successful achievement of project performance targets associated with the above scope of work was quite vulnerable to climate change (see Step 2 above), measures to improve the project's climate resilience were identified. These resilience measures include

- ensuring a reliable power supply for irrigation pumps;
- adoption of Good Agricultural Practices and Climate Smart Agriculture practices and technologies;
- conservation works to minimize the impacts of flooding, destruction of irrigation infrastructure and development of gullies; and
- focusing on small stock in any livestock projects.

Evaluate the resilience of the different strategies: Having identified a number of possible resilience-building measures above, a detailed quantitative assessment was carried out for different possible strategies to ensure a reliable power supply for irrigation pumps. This is a good example of an instance where cross-sectoral factors come into play, with this analysis incorporating not just the methods presented in this agricultural guidance note, but also the energy and water guidance notes as well. Three different energy systems were ultimately assessed for the Sebasa Irrigation Scheme, namely mini-hydro, wind, solar. Ultimately, seasonal fluctuations in flow in the Tuli River (on which a mini-hydro scheme would be installed) as well as the need for a back-up energy source during low wind months (7 months of the year), indicated that a solar power system would offer the most climate resilient power supply for the irrigation pumps.

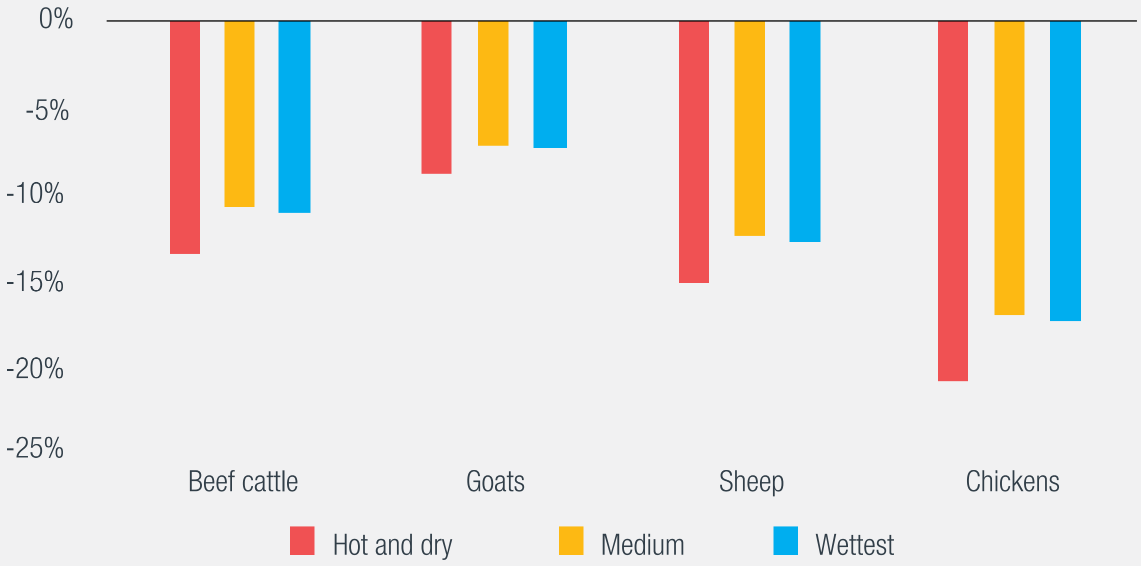
Case Study Demonstration of Step 3 (continued): Rehabilitation of the Sebasa Smallholder Irrigation Scheme in Zimbabwe

Additionally, the resilience benefits of Good Agricultural Practices and Climate Smart Agriculture practices and technologies in the Zimbabwean context have been widely documented.

For instance, Zimbabwe's Climate Smart Agriculture Investment Plan (2019) explored the ability of Climate Smart Agriculture investments to achieve a more resilient agricultural sector under various uncertain climate futures. Crop-switching to drought and heat tolerant crop varieties was estimated to increases yields by 3-12% across all crops. While investment in irrigation has high initial capital costs, it provides estimated yield increases of between 50 and 140%. The combination of investment in irrigation and fertilizer is expected to increase yields by 100-210%.

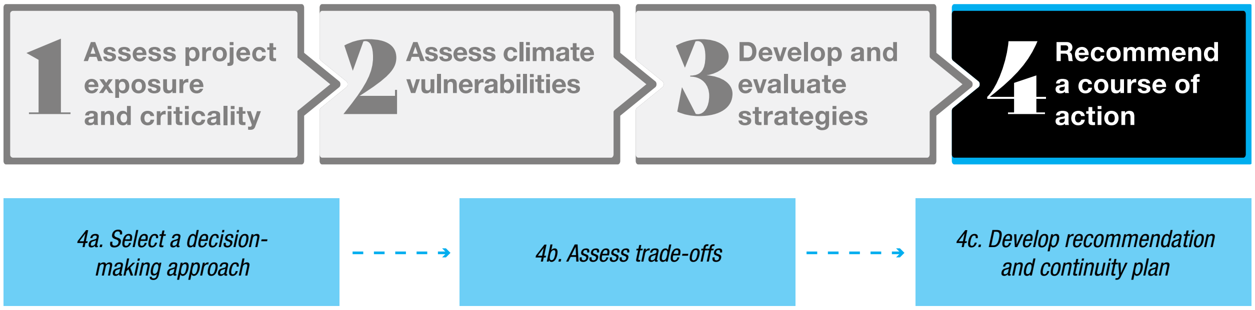
Similarly, Zimbabwe's Climate Smart Agriculture Investment Plan (2019) also evaluated the impact of switching from cattle to smaller livestock. Switching to smaller livestock increases protein production, provides a more climate resilient food source, and significantly reduces greenhouse gas emissions.

For example, modeling indicates that goats produce 74% less emissions per unit of protein produced than communal cattle in Zimbabwe. In addition, goats are less susceptible to heat impacts: while climate change drives reductions in the income from beef cattle by 11-13% (depending on the climate scenario) by 2040, income from goats only decreases by 7-9%.



Impact of hotter temperatures on income from livestock by species (using differences in temperature from the 2000 mean to a mean centered around 2040 (Source: World Bank 2019)

3.2.4. Step 4: Recommend a Course of Action



Objective: Finally, this step will lay out a decision-making approach to identify a course of action from the adaptation strategies considered in Step 3 that considers trade-offs and looks at the full economic lifetime of the project. Three activities are involved.

Activity 4a: Select a decision-making approach that is able to help identify a strategy (from the set developed in Step 3) that is well-suited for a broad range of uncertain conditions. This requires assessing and trading off project performance across a variety of uncertain future conditions, rather than simply maximizing the expected results from averaged future conditions. While the focus in this note is on uncertainty about future climate conditions, resilience analyses in Sub-Saharan Africa are faced with a variety of different uncertainties, including from inadequate historical climate data, the divergence of existing climate projections, as well as changing political and policy environments, external market conditions, or levels of technology adoption. In this context, traditional decision-making methods often fall short because they typically strive to identify an optimal design for an average or most likely set of future conditions. (This group of methods is often described as being founded on **predicting and then acting** – see the technical note on decision making under climate uncertainty included in the Compendium Volume for an overview of these traditional decision analysis methods.)

Given the significant degree of uncertainty associated with future climate conditions, a new group of decision-making methods has been developed that focus on **preparing and adapting,** rather than predicting and acting. This class of methods emphasizes **the identification of flexible decisions that enable ongoing adaptation, or robust decisions that will prove wise across a wide range of future climate conditions.** In general, these methods involve framing the analysis and conducting an exploratory assessment, choosing initial and contingent actions to iterate and perform re-examination, and allowing participation of stakeholders. **Table 3.3** provides a summary of some of these decision-making approaches, grouped based on whether they emphasize the robustness or flexibility of the decision. (See the technical note on decision making under climate uncertainty included in the Compendium Volume for further details.)

Table 3.3. Summary of Approaches for Decision-Making Under Climate Uncertainty

Emphasis of Framework	Description	Examples
Robustness	These approaches focus on achieving acceptable project performance across a wide range of possible future conditions. The emphasis is on the investment decision to be made now and generally follows a conservative approach when incorporating future conditions that are significantly different from the baseline.	• Decision Scaling • Robust Decision Making
Flexibility	These approaches prioritize identifying a design that can adapt in the future given different climate conditions. In general, these value the agility of a design more than its robustness and include consideration of "tipping points" for climate variables that will indicate a change from one set of actions to another.	• Engineering Options Analysis • Adaptation Pathways

The selection of a decision-making framework should be informed by the preference either to account for future uncertainty now through measures that enhance the robustness of the decision or leave options open for future adaptation. This choice should be informed by the available resources today and in the future, the capacity of the project team to control or influence changes in the future, and the optimism that future information will help to clarify the adaptation decision and will arrive in a timely way. For instance, while a large-scale commercial irrigated agriculture enterprise may choose to pursue a robust approach that ensures reservoir infrastructure is sized so as to provide sufficient storage for even low-probability extreme drought events, smaller-scale farmers may choose to pursue more drought resistant crops, while waiting to observe how the climate evolves over the coming decade before making a decision as to whether to pursue any additional, more costly adaptation strategies.

As mentioned before, the framework for enhancing the climate resilience of projects that is presented in this note is circular: it is possible that after selecting a decision-making approach, the activities completed during earlier steps in the framework may need to be revisited and adjusted. For instance, having prioritized the flexibility to make incremental adaptation decisions and delay large investments till later (as compared to prioritizing system robustness now), this decision may necessitate returning to Step 3 and identifying additional adaptation interventions that enable flexibility, as well as returning to Step 2 and selecting a few additional uncertainty scenarios to explore if particular climate futures are concerning to decision makers.

Activity 4b: Assess the trade-offs of each strategy. Generally, there is no perfect adaptation strategy, and more beneficial strategies tend to be more expensive. Strategies that are good for mitigating the impacts of one climate hazard, for instance drought, may also fail at properly addressing others such as flooding. Furthermore, strategies that benefit one sector may cause negative downstream impacts to other stakeholders. In this context, the decision-making process must also look at minimizing trade-offs. The starting point of this activity requires identifying, and if possible, quantifying, the trade-offs of each strategy. An example of a typical trade-off that occurs when considering agricultural investments is the use of scarce water resources for irrigation of crops versus allocating water for in-stream flows to support fisheries, waterfowl, wildlife and biodiversity. It is often unclear whether significant capital expenditures made today may not be needed in the future due to climate change, or due to anticipating climate changes that ultimately do not occur. Thus, there are difficult questions as to whether to act or not to address climate vulnerabilities.

The quantitative analysis performed during Steps 2 and 3 can produce two kinds of results: a point estimate of an economic performance indicator (e.g., internal rate of return or net present value) and information related to the variability (i.e., distribution of uncertainty) around the point estimate. Under uncertain future conditions, the point estimate may be no more likely to occur than the wide range of other possible outcomes around it. For this reason, when assessing trade-offs, the project team should consider the distribution of uncertainty around point estimates to promote better decision-making.

Resilience Spotlight: Climate Resilience for East Africa's Livestock Farmers Through Index Based Livestock Insurance

In East Africa, poultry and pigs already face heat stress challenges, and even under relatively optimistic climate scenarios, large-scale adaptation of livestock farming practices will be necessary to maintain livestock productivity in the face of hotter temperatures caused by climate change. Adaptation is already underway in some areas: pastoralists in Ethiopia are shifting from large to small ruminants, which are typically more resilient to climate extremes. In Kenya's rift valley, dairy farmers are experimenting with different feed production strategies to be better prepared for feed shortages during droughts.

The resilience of these efforts can be further bolstered by the so-called Index Based Livestock Insurance **program**. Operating in drought-prone regions of Kenya and Ethiopia, **the program offers resilience against climate-related livestock losses.** While traditional insurance programs pay when an animal is lost, this program is linked to climatic conditions over the course of a season. **By considering the amount of rainfall or the distribution of pasture available, the program provides farmers with financial resources to help their livestock survive during prolonged periods of extreme weather.**

In order to weigh the importance of different strategies, the project team should develop a hierarchy of all consequences that result from project failure. These causes of failure correspond to all the reasons why the project does not meet the performance metrics in the face of extreme weather events and climate change, as identified from the vulnerability assessment and addressed through adaptation strategies. This list will indicate the order of priority and urgency and should be produced in consultation with and validated by stakeholders of the project.

The project team should then carry out the decision-making process, with the benefits of the strategy (i.e., the performance metrics defined in Step 2 and evaluated in Step 3, considering the distribution of uncertainty of estimates), its direct costs and associated trade-offs, and the hierarchy of priorities as inputs. As mentioned, this process may require revising the analysis done in previous steps as new information is obtained and inputs are gathered from stakeholders. Decisions then could fall into three categories, namely:

1) **Investing in climate-proofing the project at the time the project is being designed or implemented**, which can result in low-regret, no-regret and/or win-win options depending on the projected costs and benefits;
2) **Deferring from investing in climate-proofing but designing the project in such a way it can be more easily climate proofed in the future**, if deemed necessary; Or
3) **Deciding that the project design and monitoring should not take account of climate variables and their impacts at the present time**, and that investment in climate-proofing will be undertaken at a later point, if needed.

The first option sees more substantial investments in climate resilience at the project outset than the latter two options. The second option is commonly referred to as **adaptive management**, where proactive and incremental adaptation investments are introduced over the project's lifetime. The third decision making approach embodies **a wait-and-see mindset** – while this latter approach maximizes flexibility and adaptability, minimizes the hardening of infrastructure today, and may be preferred when funds are limited, and uncertainty is high, it is only suitable for situations where baseline risk is considered acceptably low.

An example of adaptive management can be found in the development of post-harvest storage facilities, which are crucial to extend the marketability and shelf life of perishable commodities. While the design of such storage facilities is very much dependent on ambient temperature, relative humidity and solar radiation data, this data may not be available at the time of design. Knowing the importance of these facilities to the supply chain, a decision may be taken to build the facility based on the best available data, knowing that future modification may be necessary when further climatic data becomes available. A more proactive approach would not just wait-and-see what changes need to be made to the facility over time but would make up-front design decisions that enable the kinds of adaptations that are expected to be needed in a hotter future.

The recommendation of a preferred course of action should cover all components of the project cycle, starting with project identification, focusing on risk screening and identifying critical stakeholders and their roles and responsibilities. The recommendation should focus on those adaptation solutions that are technically feasible to address projected climate vulnerabilities, taking into account the related costs and benefits. In this context, the trade-offs analysis should also inspect the feasibility of a strategy in terms of technical capacities, policy environment, and financial constraints, with particular attention to the extent to which the environment supports or limits their implementation. Potentially, the analysis may require returning to Step 3 and revising the strategies proposed. Project implementation should identify stakeholders with the capacity to implement the preferred adaptation option(s) and include necessary capacity building at the individual and institutional levels. Lastly, the recommendation works best if it draws and builds upon existing country-level plans that identify priority areas, such as Climate Smart Agricultural Investment Plans (World Bank 2019). Such plans have been developed for Cote d'Ivoire (2019), Mali (2019), Zambia (2019), and Zimbabwe (2019), with more underway.

Activity 4c: The development of a recommendation and continuity plan should provide a narrative that justifies the selection of a course of action from the process in the previous activity. Moreover, the continuity plan should describe how project evaluation will be conducted, along with a clear schedule of activities and stakeholder responsibilities into the future, both during and after the implementation phase, including how resources for maintenance and/or continued adaptation will be mobilized, to ensure the investment continues to perform over the course of its life.

Both the narrative and continuity plan should discuss residual climate risks not addressed in the proposed project design that are still material to the project. Since it is not always economical or preferred to address all risks under all potential future conditions, there will generally be a residual risk. However, since the future is uncertain, it is possible for residual risk to grow over time in unanticipated ways to a point where it would be appropriate to address, and should be the basis for a monitoring and evaluation plan. For example, precipitation-related risks may not be considered relevant today if most climate scenarios point to a drier future but may become significant if the climate evolves differently than predicted. Monitoring and evaluation should focus on assessing how progress toward vulnerability reduction and changes in residual risk will be measured in terms of indicators, tipping points, and thresholds, and how lessons learned can be used to improve current and future projects underpinned by a fit-for-purpose monitoring, evaluation and reporting framework.

This plan should include which actors will be responsible for each action and when, and should cover the full economic life of the project. Developing such a plan is fundamental when selecting a wait-and-see type of strategy that requires future actions. Even when interventions are prioritized in the near-term, as (climate and non-climate) uncertainties resolve over time, the continuity plan provides critical milestones for revising the resilience of the project.

Outcome: After completing these four steps, the project team should be capable of providing an assessment of the vulnerability of the project as initially proposed and developing a narrative on how much a particular strategy (or set of alternative strategies) can enhance its resilience and, therefore, reduce its vulnerability. The assessment, moreover, should enable the team to understand whether the improvements (and corresponding trade-offs) are acceptable, as well as the costs of following each course of action.

This plan should include which actors will be responsible for each action and when, and should cover the full economic life of the project.

Case Study Demonstration of Step 4: Rehabilitation of the Sebasa Smallholder Irrigation Scheme in Zimbabwe

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

4a. Select a decision-making approach → *4b. Assess trade-offs* → *4c. Develop recommendation and continuity plan*

Select a decision-making approach: Having identified a number of different adaptation strategies (in Step 3 above) that could be pursued to improve the climate resilience of the Sebasa project, investment decisions were ultimately made on the basis of stakeholder input and a financial analysis.

Project records suggest that robustness was implicitly prioritized in project decision-making as there was significant emphasis placed on achieving acceptable project performance across a wide range of possible future conditions (e.g., irrigation pumps had to continue to be operational in the face of possible power supply disruptions). A decision-making approach that instead prioritized flexibility could have focused on the ability to make incremental adjustments in the future (e.g., mapping out the tentative locations of future irrigation pumps if additional pumping capacity becomes necessary in hotter, drier periods).

Participants at a focus group discussion (Source: International Fund for Agricultural Development no date)

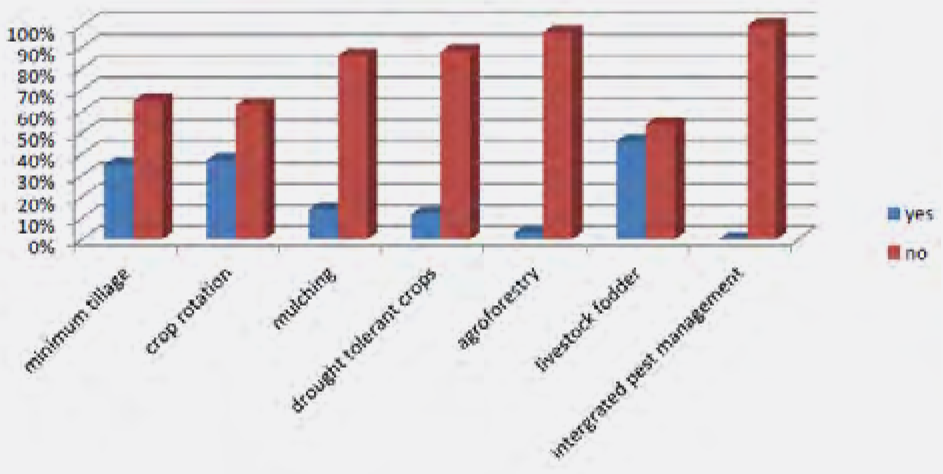
Case Study Demonstration of Step 4 (continued): Rehabilitation of the Sebasa Smallholder Irrigation Scheme in Zimbabwe

Assess trade-offs: Some of the underlying trade-offs that were considered between different investment actions included

- up-front capital costs
- impact on performance indicators of interest
- long-term maintenance costs and the ability of the local population to pay for/provide the necessary maintenance services
- environmental impacts

Develop recommendation: Ultimately, a solar system was installed to replace the diesel engines that formerly provided power for the irrigation pumps, as well as replacing/improving the main pipeline and the in-field canals. The emphasis was on putting in place climate-proof infrastructure that is secure from flooding, siltation and is water efficient. Works to minimize the impacts of flooding, destruction of irrigation infrastructure and development of gullies included the construction of weirs and gabions as well as the rehabilitation of bridged points (barrages).

Climate Smart Agriculture practices were also pursued to enhance the climate resilience of the project by promoting efficient water management, focusing on small stock in any livestock projects and establishing a comprehensive climate information system to facilitate access to tailored information. While conservation agriculture practices had previously been promoted to local farmers, uptake rates remained low, as shown in the graph below.



Percentage of farmers on irrigated plots at Sebasa who previously already practiced conservation agriculture

Other components of the project that more generally enhanced the resilience of the local community (over and above the resilience of the project itself) included strengthening community structures for effective operations and maintenance through training in management, leadership, marketing, conflict resolution and other skills.

Ultimately, the cost for rehabilitating the irrigation scheme was around US$400,000.

3.3. Concluding Remarks

Crop and livestock production is critical to Sub-Saharan Africa's agricultural sector. Aquaculture is also a growing source of protein and income in some areas, where water in canals, ditches, ponds and rivers is available. These production enterprises are all vulnerable to a changing climate. Both climate adaptation and mitigation measures will be required to support the income and livelihoods of this important segment of the rural population, and to provide food security to climate vulnerable populations. It is crucial that resilience to climate extremes, whether floods, droughts, or extreme heat be built into agriculture projects at all scales.

This guidance note presents a practical framework for enhancing the climate resilience of infrastructure development projects in agriculture in Sub-Saharan Africa. The framework includes four steps: (1) assessing the exposure to climate hazards and determining the criticality of the project; (2) assessing the vulnerability of the project to the identified climate hazards; (3) developing and evaluating strategies to enhance the project's resilience; and (4) recommending a course of action. For each step, the note provides illustrative examples, along with references to additional technical notes for issues that expand beyond the scope of the guidance note and are common to the other sectors covered in the Compendium Volumes.

There is no single approach for assessing climate hazards in project evaluation, and this guidance note is based on the authors' understanding of the most appropriate methods available for the agricultural sector in Sub-Saharan Africa. Future climate conditions are uncertain in nature, and the proposed framework was designed for incorporating the vast and evolving field of study in climate science by way of a practical and flexible approach that can adapt to new emerging knowledge.

This note is of an incremental nature: it seeks to inform how to incorporate climate-related uncertainties and the assessment of resilience over existing project evaluation methodologies. Only the fundamentals of economic, climate, and biophysical modeling, as well as of decision-making under uncertainty are covered in this note, and extensive references to external resources are provided to those seeking further detail. The note does not address other uncertainties in project performance such as demographic changes, political and policy environment, or macroeconomic factors. However, although the principles presented in this note can be extended to other uncertainties, specific guidance on these is preferable.

The framework presented in this note will always benefit from further refinement through widespread application in Sub-Saharan Africa, for a wide range of geographies, socio-economic, and climatic conditions. As conditions in the region change, and climate knowledge advances become more accessible, periodic updating of this note will ensure that users continue to be provided with the best guidance possible for enhancing the climate resilience of much-needed infrastructure investments in the region.

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GUIDANCE NOTE:

Enhancing the Climate Resilience of Energy Infrastructure Projects in Sub-Saharan Africa

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Acronym List

AFRI-RES	Africa Climate Resilient Investment Facility
GCM	General Circulation Model (or Global Climate Model)
HVAC	Heating, ventilation, and air conditioning
kWh	Kilowatt-hour
IPCC	Intergovernmental Panel on Climate Change
NDC	Nationally Determined Contribution

4.1. Introduction and Background

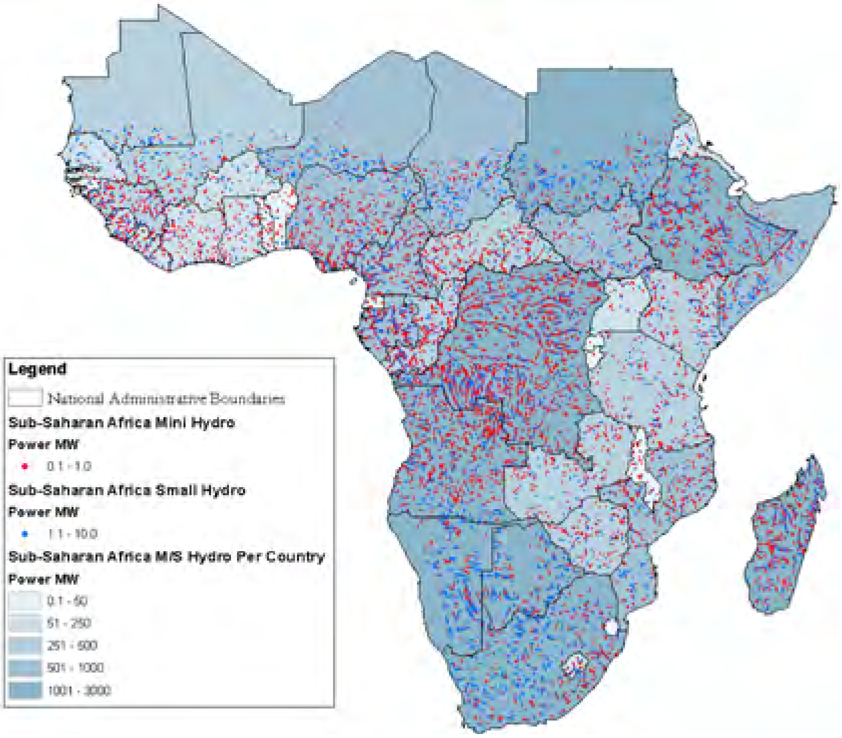
4.1.1. Problem Statement

Africa's development is accelerating. As Sub-Saharan Africa modernizes, the growth potential is staggering. While per capita consumption of energy in the region (excluding South Africa) is 180 kWh, consumption in the United States reaches as high as 13,000 kWh and 6,500 kWh in Europe (African Development Bank 2019). Appropriate forms of energy (electricity in particular) are increasingly being demanded for overall development (Howells and Roehrl 2012). As an example, of the 169 targets included in the United Nations' Sustainable Development Goals, 113 require appropriate energy to be available (Fuso Nerini et al. 2018). Hence, **in Sub-Saharan Africa, advancing development includes the development of an energy system (composed of integrated supply chains) that is robust and adaptive to climate change.**

At present, however, Africa's energy consumption is dominated by wood fuel (which is often collected freely, but with high time and health costs). Its burning – particularly indoors - results in high levels of pollution and respiratory disease. **While electricity is required for almost all modern economic activity, access to power is limited**: over 640 million Africans are not connected to power supplies (African Development Bank 2019). Furthermore, an estimated 600,000 people (mostly women and children) die annually due to indoor air pollution associated with the use of fuel wood for cooking. Children underperform compared to global averages since over 90 percent of Africa's primary schools lack electricity (African Development Bank 2017). Moreover, in places where there is access to electricity, supply is often poor and failures can be exacerbated by changes in climate. For example, unusual recent extended droughts in the Zambezi River basin have resulted in prolonged periods of power shortages from its hydropower plants, which causes heavy economic losses. There has been accelerating demand for power services due to increasing economic growth, which has in turn strained energy supply chains as they struggle to meet demand. Thus, **as demands for energy accelerate, it is essential that bulk supplies (especially of electricity) are not only increased, but that these supplies are healthy, environmentally compliant, low-cost, and reliable.**

Further, the political economy in which these systems are to expand is complex and diverse. In some regions, the sector is leapfrogging fast where new mobile technologies are deeply embedded with energy supply and demand technologies. While the primary supplies of the African energy sector are dominated by biomass, followed by oil, gas, and coal, much of its potential growth is in hydro and micro-hydro power, which often provide cheaper more reliable power than other low-carbon renewable energy options. **Figure 4.1** shows the potential sites for hydropower investment across the region. While this source is potentially vulnerable to impacts of climate change from changes in future precipitation regimes, the inclusion of hydropower in a country's energy portfolio can help absorb large amounts of intermittent renewable energy technologies, even in times of low water availability.

Figure 4.1. **Potential Hydropower Investment Sites Across Sub-Saharan Africa**



Source: Korkovelos et al. (2018)

The range of expected climate change risks to the energy sector in Sub-Saharan Africa relates to the loss of energy supplies in one form or another. This has consequential effects on the economy, as those energy supplies are used for services that are critical for the function of those sectors. This is often measured in a metric called the 'cost of energy not served'. **The hazards that affect the energy sector include changes in air temperature, precipitation, radiation, wind speed, humidity, and in turn runoff, cloudiness, wind density, biomass yield, water temperature, and air temperature.** These may occur over short high intensity events. A hailstorm may destroy solar panels for example. At the same time, they may occur over prolonged periods, such as the gradual increase of temperature over decades.

While exposure to climate hazards can occur in various components of the sector directly, indirectly, or via system interactions, there are **specific vulnerability-exposure combinations that will result**

in different effects and risks. For instance, during hot-dry weather, more water and cooling may be needed for safe coal-mining operations. The power plants using this coal for electricity generation may themselves also require more water for cooling. Moreover, hot-dry weather will increase direct electricity demands due to the increased cooling or refrigeration needs that will be felt in industry, transport, residential, commercial, and public services, as well as in agriculture, forestry, and fishing. These sectors will increase indirect demands as more energy will be used for water pumping, desalination, or increased purification needs.

Furthermore, **energy systems and their constituent supply chains can be impacted not only by their physical construction but also by how the system is operated and managed.** Typically, integrated power system chains are designed to include 'reserve margins', which help increase their ability to withstand hazards. Market rules are developing as the integration of cheap, but intermittent renewable energy introduces new design and operational challenges. However, these margins, as well as their design and operation, can struggle under current climatic change and geopolitical conditions. Improvements will be needed to ensure that climate, among other hazards, is contained or adapted for.

Meanwhile, the **delivery of energy almost always results in greater adaptive capacity in the sector to which it is delivered.** If appropriately delivered, the energy supply chain and the sector are far less vulnerable than they would otherwise be. Against this backdrop, this document presents a guidance note that offers practical suggestions for achieving climate-resilient energy infrastructure projects (at component, sub-system or integrated-chain level) in the Sub-Saharan African context, where resilience is understood to mean *the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner* (Intergovernmental Panel on Climate Change 2012).

> While exposure to climate hazards can occur in various components of the sector directly, indirectly, or via system interactions, there are specific vulnerability-exposure combinations that will result in different effects and risks.

4.1.2. Objectives and Scope of This Guidance Note

Funded through the Africa Climate Resilient Investment Facility (AFRI-RES), this document provides guidance on enhancing the climate resilience of energy infrastructure investment projects in Sub-Saharan Africa.[3] It is pedagogically oriented and draws on extensive experience and robust research and analytical methods. This guidance note provides **a framework for evaluating infrastructure project assets to ensure they meet project objectives in spite of possible future climate impacts.** As a result, this note is primarily relevant for climate adaptation, with climate mitigation benefits only considered if they are an explicit objective of the project being considered. The focus of this note is on guidance, serving neither as a comprehensive technical text nor an exhaustive policy handbook, but as brief direction on the most important principles to take into account when seeking to enhance the climate resilience of infrastructure projects in the face of future climate uncertainty. (While the note focuses on uncertainty as it relates to future climate conditions, the principles presented here could be extended to include other sources of uncertainty such as demographic changes, the political and policy environment, and macroeconomic factors.) In addition, this note focuses on enhancing the resilience of projects that have been at least roughly scoped in terms of their location and the type of investment to be made, being less relevant for very early-stage projects where the location and type of project are as of yet unknown.

These notes build on a range of existing resources produced by the World Bank and others, notably including the Resilience Rating System (World Bank Group 2021) and the disaster and climate risk stress test methodology (Hallegatte et al. 2021). Furthermore, the framework presented in these notes also complements new guidance developed by the World Bank to ensure that future Bank investment projects are in alignment with both the climate mitigation targets set out in the Paris Agreement (United Nations 2015) as well as the country's adaptation goals.

The Resilience Rating System mentioned above distinguishes between two dimensions of resilience, namely **resilience of** the project and **through** the project (World Bank 2021):

- **Resilience of** the project is the extent to which a project's assets have considered climate and disaster risk in their design e.g., a power plant with improved cooling to account for increasing temperatures in the future.
- **Resilience through** project outcomes reflects whether a project's objective is to enhance the target sector and beneficiaries' climate resilience through its interventions e.g., the introduction of wind or solar sources of generation to system dominated by hydropower can provide improved climate resilience in the face of more variable future precipitation.

The scope of this note is focused on the **resilience of** projects, including the resilience of direct project outputs (e.g., electricity generation or total revenues). While many investments in energy

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[3] A partnership with the African Union, United Nations Economic Commission of Africa, Nordic Development Fund, African Development Bank, and the World Bank. This note is part of a series of guidance and technical notes funded by AFRI-RES that focus on climate resilient investment in Sub-Saharan Africa.

systems can enhance both the resilience of and through projects, **the framework presented in this note focuses on the resilience of particular investment projects** and not on how those investments enhance the resilience of a community or sector that benefits from it.

While **the focus of this note is on the project design level**, it remains **crucial to understand the particular policy, regulatory, and institutional context in which the project is situated.** Hence, all project design decisions should be taken with both the policy landscape and local capacity in mind, acting as either enablers or barriers for implementation. This note is part of a larger Compendium Volume, with these cross-cutting issues discussed in Chapter 2 of the Compendium Volume. Chapter 1 of the Compendium provides a general introduction, with the remainder of the Compendium broken down into two parts: Part 1 houses sector-specific guidance notes (including this one), while Part 2 provides a series of more detailed technical notes.

The scope of this note covers development in the energy sector at large, with the sector categorized into energy systems, including both supply and demand sides, as well as transmission components. In this note, an energy 'project' embedded in the overall energy system can include a component, sub-system or tightly integrated chain (such as a connected grid and its assets). There are **direct, indirect,** and **induced vulnerabilities** in the energy sector, as well as **compound vulnerabilities** that result from systems interactions. This note presents an approach critical to uncover those diverse vulnerabilities. From the supply side, the note underscores how to enhance resilience in energy sources such as hydropower, solar, wind, as well as thermal power plants. From the demand side, the note emphasizes heating, ventilation, and air conditioning (HVAC) demands and agriculture demands. Across the energy system as a whole, flexible operation and resilience in transmission infrastructure is also emphasized. **The note is not specific nor prescriptive regarding development of particular sources of energy, but rather presents principles that can be applied to the evaluation of infrastructure investment projects of any kind.** Improved adaption to climate change will depend on comprehensive and inclusive policies and strategies that are inter-sectoral, underpinned by a unified framework such as the one presented in this note that allows meaningful coordination and provides adequate climate information services.

4.1.3. Target Audience

There are three primary audiences for this guidance note:

- **Practitioners**. The note will help practitioners develop their staff and internal expertise to perform the necessary climate vulnerability and adaptation analyses.
- **Government Ministerial Staff**. The note will give staff from government ministries an understanding of the steps involved in evaluating and enhancing the resilience of a proposed project, how to be prepared for creative and alternative investment packages, and how to draft Terms of Reference for practitioners to develop climate resilient projects.
- **Donors and Development Banks**. The note will help donors and development banks provide clear direction and guidance to consultants for how to make project designs more resilient to climate change.

Each of these three target audiences differ considerably in their technical focus, operational roles, and objectives. Typical investment projects will see this note used both as high-level guidance by donors and banks, as well as more detailed technical guidance for use within client countries. This note was developed to be accessible to these different audiences, with the general framework presented here supplemented by further detail in the technical notes included in Part 2 of the Compendium Volume.

4.1.4. When to Use this Note

While each of these target audiences will use the note in slightly different ways, within the overall project development process, this guidance note is intended to be used anywhere from the project's **conception** and **planning** stages, as well as during post-project completion **monitoring** (see the orange components of **Figure 4.2**). It is anticipated that in most cases, project teams will utilize this guidance note during the scoping, early design, and final design stages of the project planning process. That said, the earlier in the project lifecycle that climate resilience considerations (as described in this guidance note) are incorporated, the greater the scope and opportunity to improve the performance of the project given climate uncertainty. Furthermore, while not the focus of this note, attention should be paid throughout the project planning process to the policy and institutional landscape, as well as the role of policy shifts and improved local capacity in building resilience.

Figure 4.2. Applicability of this Guidance Note During a Typical Project Life Cycle

4.1.5. Structure of and Roadmap to Using this Note

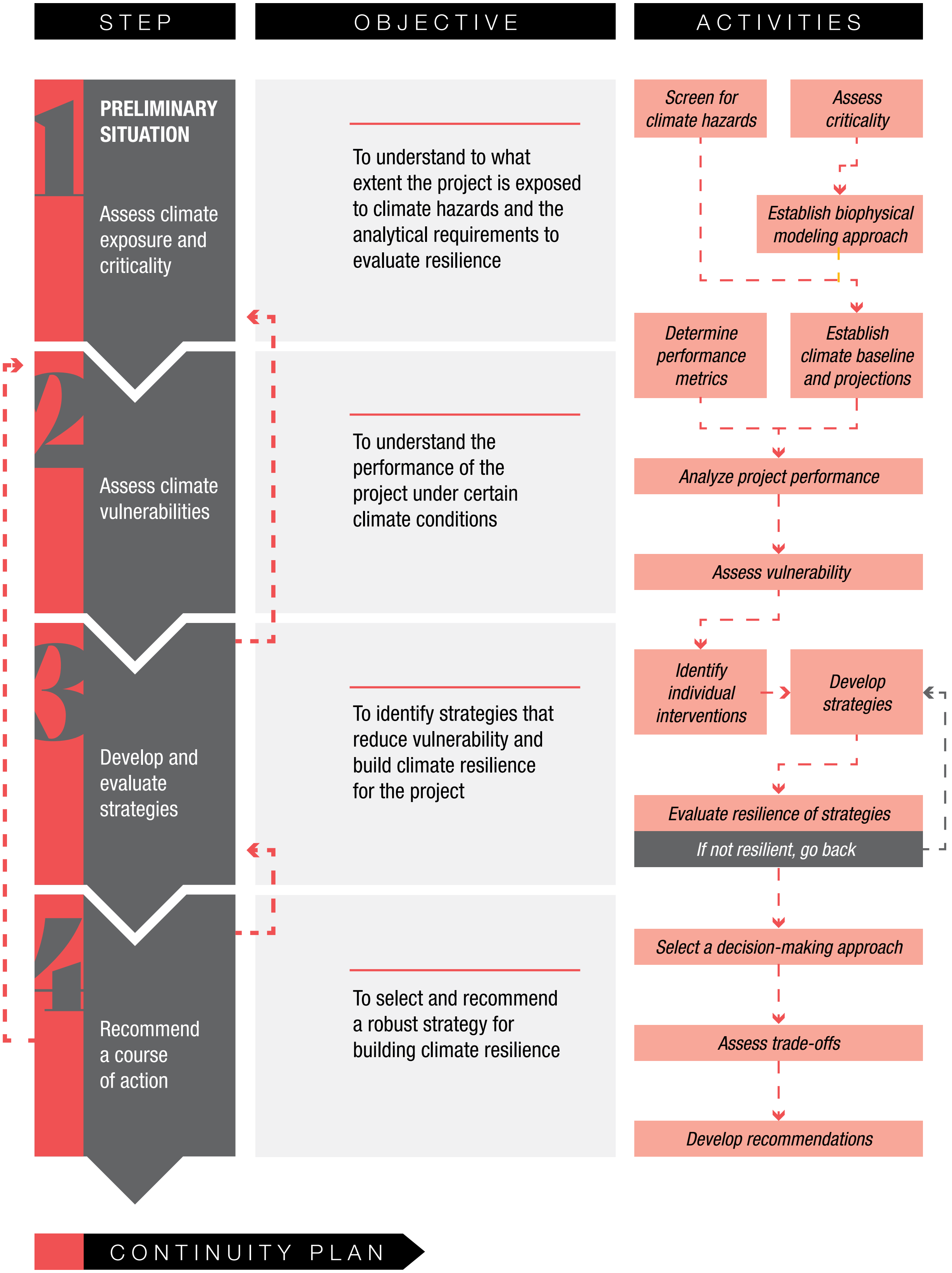
The remainder of this document is structured as follows: Section 4.2 describes a step-by-step framework used to enhance the resilience of projects in the agricultural sector to climate hazards. This section is subdivided into four steps, each containing different activities to carry out the analysis. Rigorously completing each activity requires a non-trivial amount of resources in terms of time, data, and analytical know-how. Where these resources are not available, completion of a more rapid qualitative assessment is still useful to undertake in order to provide a high-level understanding of the situation, but such high-level insights alone should not form the basis for recommendations. A case study is provided to illustrate the framework and is intended to be consulted by all users of the note. Lastly, Section 4.3 offers brief concluding remarks.

Finally, while the focus of this note is specifically on energy-focused investments, many projects include cross-sectoral components and depending on the different investment components included in a project, several of the individual guidance notes beyond this one may need to be consulted. **Project leads should look beyond their particular project to consider both the broader system as well as any possible inter-system effects in their evaluation process.** For instance, those involved in a proposed hydropower plant that supplies energy to irrigation operations would benefit from also consulting the water and agriculture notes; a team working on an HVAC project should consider also consulting the cities note; and efforts to reduce biomass dependency for cooking and heating should additionally review the ecosystems note, with all these notes included in the Compendium Volume.

4.2. A Framework for Enhancing the Climate Resilience of Energy Infrastructure Projects in Sub-Saharan Africa

The guidance for developing climate-resilient investments presented in this note builds on a broadly applicable, multi-step framework, summarized in **Figure 4.3**. The framework consists of a series of four steps, each explained in further detail below, with many of the steps linked through important feedback loops. As noted in Chapter 2 of the Compendium Volume, the framework is founded on an initial assessment of the preliminary situation, which examines the **institutional and project context** (including the existence of country-level development plans, support from relevant ministries, and the state of weather and climate change monitoring capabilities) as well as identifies **relevant stakeholders** (including community groups, beneficiaries, technical experts, policymakers, and non-governmental organizations).

Figure 4.3. Framework for Enhancing the Climate Resilience of Investment Projects



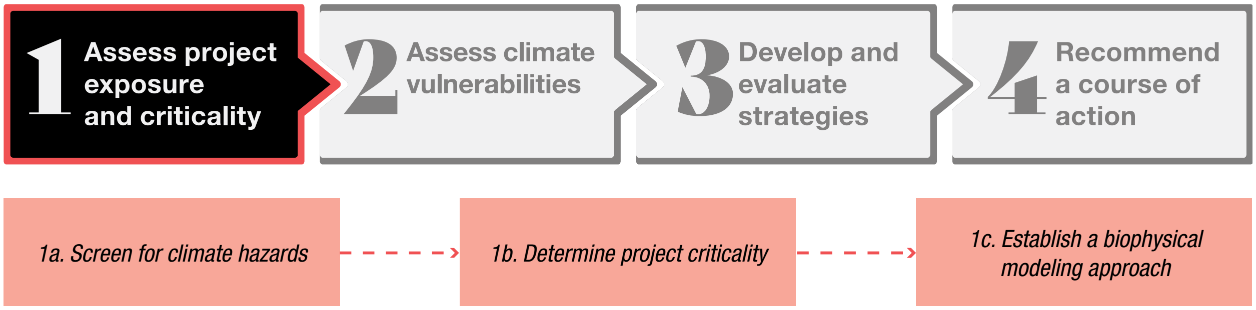
To understand to what extent the project is exposed to climate hazards and the analytical requirements to evaluate resilience

To understand the performance of the project under certain climate conditions

To identify strategies that reduce vulnerability and build climate resilience for the project

To select and recommend a robust strategy for building climate resilience

4.2.1. Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality



Objective: The purpose of the first step is twofold. One, the process evaluates whether the project is exposed to any climate hazards, both now and over the course of the project's expected lifespan. And two, the process seeks to determine the level of complexity required for the analysis based on the project criticality.

Activity 1a. Screening for climate hazards. A climate hazard is any climate-driven event that may result in damage and loss to the project. These can be a product of:

- **Extreme weather events**: low-probability but high-impact climatic phenomena (such as floods, droughts, or heat waves), as well as more frequent, lower-intensity events which can also cause significant impacts
- **Long-term changes to normal climate conditions**: changes relative to the historic baseline

As **Figure 4.4** shows, taken together, climate change can impact both the mean conditions to which a project will be exposed (e.g., higher temperature on average in the future), as well as the frequency and intensity of extreme weather events (e.g., more record hot weather). Exposure to climate hazards refers to whether the hazard is present at the project's location, either because of natural conditions or the absence of protective systems. When considering future exposure over the course of the project's useful lifespan, understanding the uncertain nature of future climate hazards is essential for evaluating the climate resilience of a project.

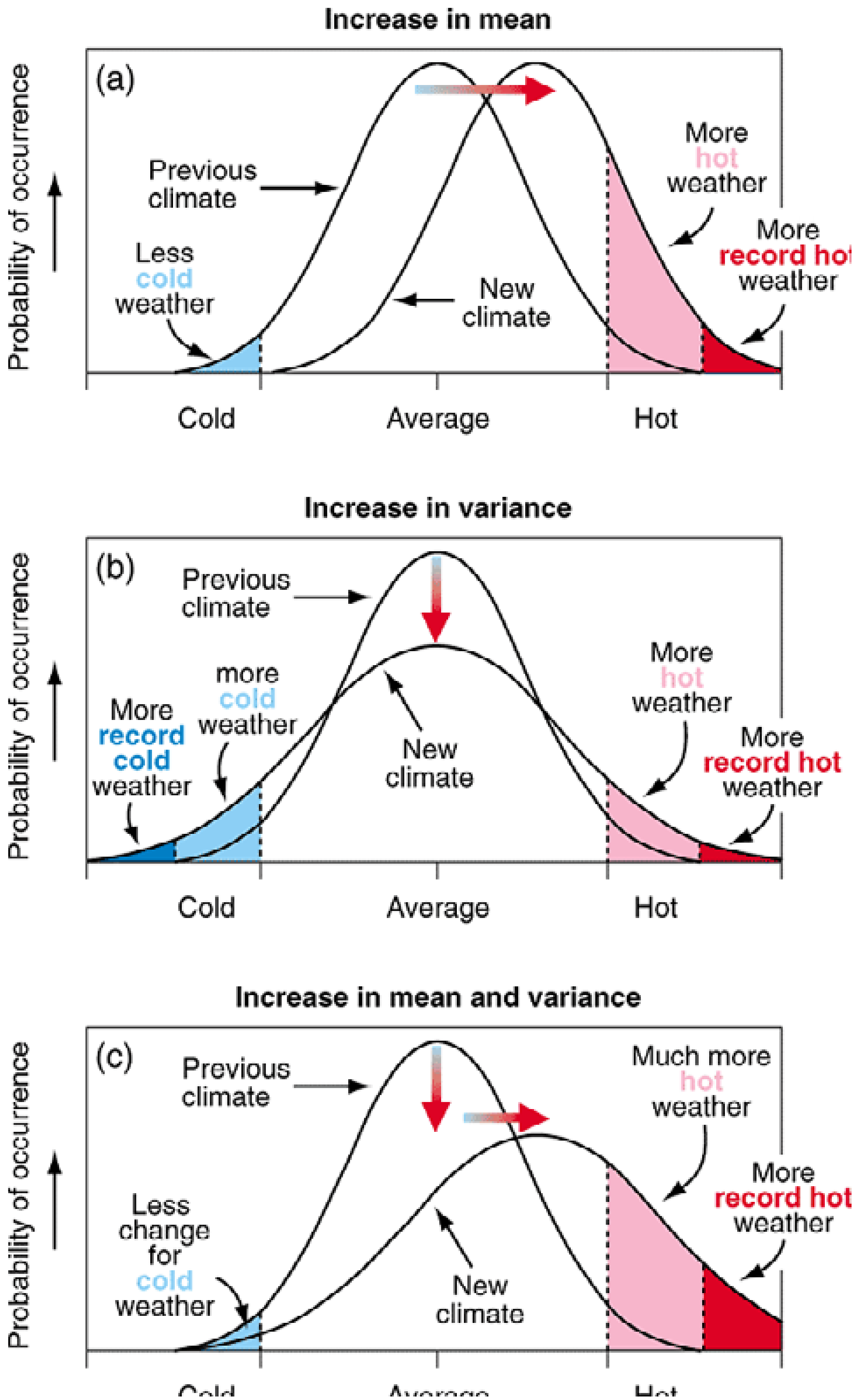
Resilience Spotlight: Climate Resilience at the Kribi II Power Project in Cameroon

The Kribi II Power Project looks to expand the operational capacity of the natural gas-powered plant from 216 MW to 330 MW. The project design takes climate resilience of the infrastructure into account by **including a functional drainage network to prevent the occurrence of floods on the project site.** In addition, the project uses internal combustion engines that are **air radiator cooled which require a minimal amount of cooling water and the demand for cooling water does not vary with weather conditions or load, making the plant more resilient to climatic fluctuations in future water availability.**

Screening for climate hazards will help the project team identify the types of hazards that threaten the performance of the project, given the project's location and expected useful lifespan. Climate hazard impacts are transmitted throughout the energy system, ultimately contributing to energy insecurity, supply chain failures, and poverty traps for rural households in Sub-Saharan Africa.

Typical climate variables to consider for energy projects are temperature and precipitation. These variables can constitute a hazard when their magnitude and/or duration affect the performance of the project. **Textbox 4.1** summarizes key climate hazards for energy in Sub-Saharan Africa.

Figure 4.4. **Illustration of Climate Change Impacts**



Source: Intergovernmental Panel on Climate Change (2001).

Textbox 4.1: Key Climate Hazards That Impact Energy Systems in Sub-Saharan Africa

Temperature: higher temperatures reduce the performance of compressors and refrigeration in commerce and industry, increasing demand for electricity. Further, heating, ventilation and air-conditioning demands are temperature sensitive. Hence, temperature increases or decreases can result in increases in energy requirements for cooling or heating respectively. Further, general efficiencies of thermal power plants reduce with increasing temperature, requiring more fuel per unit than at colder regimes.

Precipitation: changes in precipitation can affect the suitability and performance of energy production. Heavy hail may damage solar photovoltaic farms or biofuel crop production.

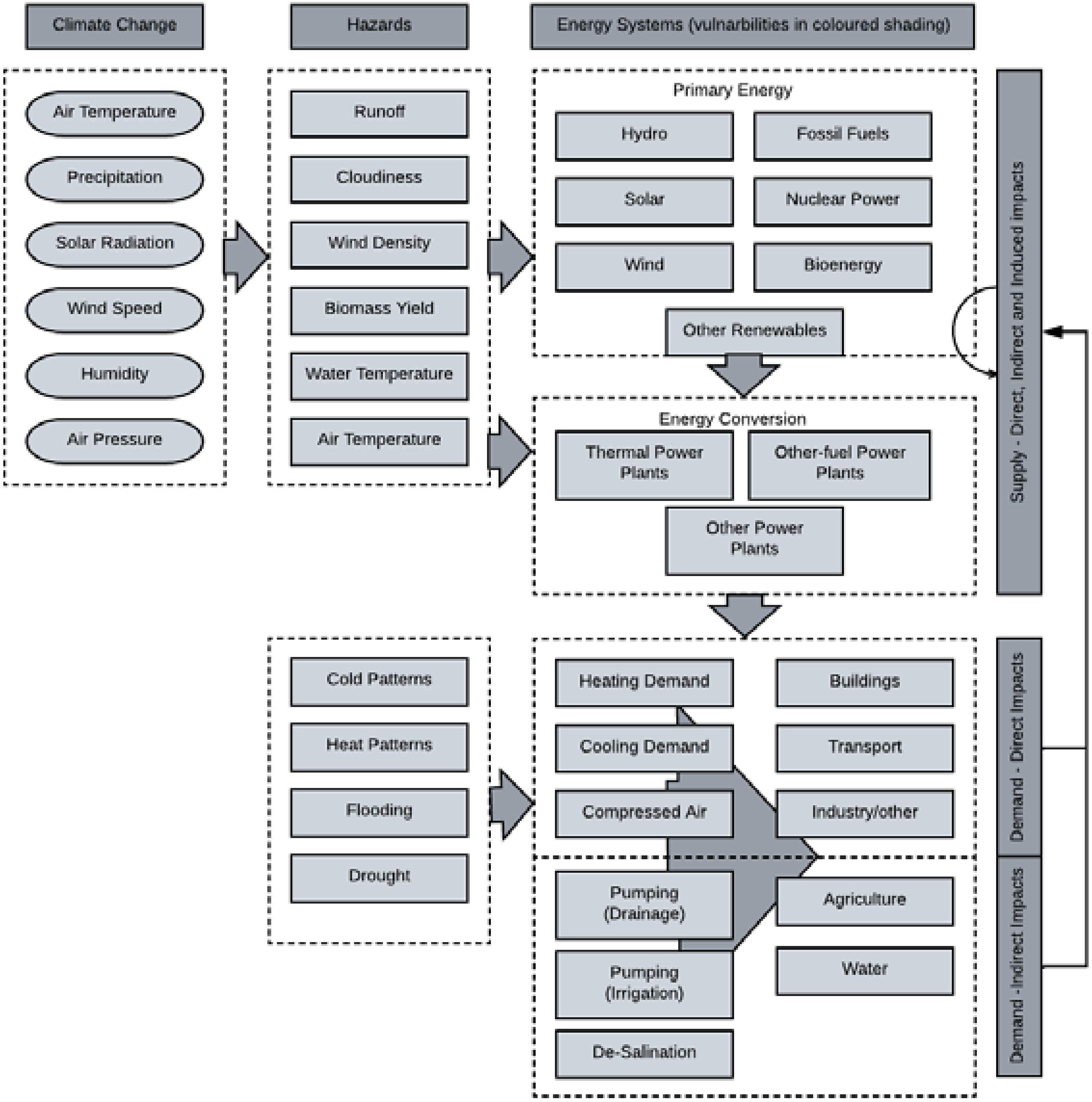
Runoff: changes in precipitation patterns and surface water discharge can impact hydropower generation and water availability for cooling at power plants.

Drought: dry days impact water levels and can decrease generation by hydropower plants. Yields of wood and other biofuels may also decrease from drought events. Drought can also impact the demand for water resources, such as agricultural irrigation, resulting in increased demand for electricity.

Flooding and storms: can result in blackouts in homes and essential buildings, requiring emergency generation. Storms and flooding can damage generation, transmission and other grid infrastructure in the energy system.

Figure 4.5 illustrates the potential impacts of climate hazards on the energy sector overall. Impacts are split between effects to energy supply and demand. Supply effects are further divided between effects on primary energy supply and energy conversion. **Direct** drivers are those that affect the supply and demand of energy. For instance, a dry and warm period of drought may cause less hydropower generation (which may or may not ultimately result in more unserved energy) as there is less runoff to the dam (direct supply effect), while at the same time, the increased heat may increase the demand for cooling in buildings, which then drives up the electricity demand (direct demand effect). **Indirect** effects are those that result from non-energy sectors interacting with energy services due to climate hazards. Following the same example introduced above, in the agriculture sector, water pumping for irrigation will increase as there is less rainfall, which drives up the demand for electricity. Further, an **induced** effect results from the system's reaction to the reduction in energy generation, increase in demand, or both. Systems have often not been designed to cope with direct, indirect, and systems interaction effects. Finally, a combination of indirect and induced effects result in **compound impacts**. As a result, concurrent shocks can cause damage. This is true in developed regions of the globe, where the power system is relatively robust (see for instance "More Demand, Less Supply: Drought and Heat Test U.S. Power Grid" n.d.) and even more so where power systems are frail or underdeveloped, as is the case in much of Africa. In the same example, increased water pumping from reservoirs for irrigation may reduce dam levels, further reducing the hydropower potential, right at a time when more power is needed for that pumping – **compounding** the impact.

Figure 4.5. Impacts of Climate Hazards on the Energy Sector



Source: Adapted from Yalew et al. (2020)

To screen the various climate hazards for a given location, the frequency and severity of historic events are first analyzed. However, it is important to consider the future exposure over the course of the project's useful lifespan. Generally, projects with a short useful lifespan may only need to focus on the impact of extreme weather events consistent with those experienced historically. In contrast, projects with longer lifespans should carefully inspect whether the project is exposed to new hazards and the increased frequency and severity of existing ones. Given the significant degree of uncertainty about future climate conditions, it is recommended to consider the broadest possible range of climate hazards, including those considered less likely, rating the severity of each threat to identify those most relevant for the project.

Various tools exist that can be used to screen a project's exposure to climate hazards; **Textbox 4.2** shows a selection of tools that could be used. Note that the individual outputs from these different tools may not be directly comparable to each other due to differences in the design of the tool and the assumptions it makes. In addition, these tools are not designed for detailed asset-level risk analysis but rather offer broad insights about the hazards present at the location of a proposed project. Subject-matter experts and local stakeholders should further supplement the climate risk screening results from these tools, as a mechanism to both validate the identified threats and reduce the risk of omitting relevant hazards.

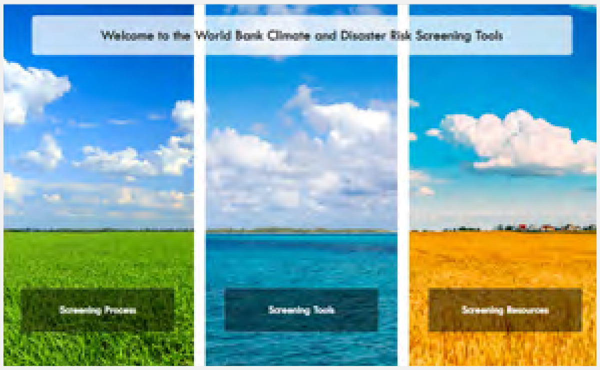
Activity 1b: Determine the project criticality to establish the appropriate level of effort required to assess project resilience. In the energy sector, a project could encompass a particular component of the sector (e.g., a hydropower plant), a sub-system (e.g., the HVAC systems in commercial buildings), or a tightly connected energy-chain (e.g., a connected power-grid with a combination of power-plants, the grid itself and electricity-using devices). In many developing countries the conceptualization of the connected power-grid as 'the project' is relevant as their utilities are vertically integrated from distribution to generation. Further, efficient resilience measures are often better deployed at grid, rather than asset level. System-wide projects could include changes to the socio-economy and its organization. **While the focus of this guidance note is on the project design level (component, sub-system, or energy chain), it is crucial to understand the development setting in which the project is situated.** All project design decisions should be mindful of local conditions, including the policy landscape, as well as technical and institutional capacity (see Compendium Volume Chapter 2 for a discussion of these kinds of cross-cutting factors that can enable or hinder a project).

Evaluating the impacts of the climate hazards identified to be relevant to the project can be complex, data-intensive, and expensive. However, not every project requires the same level of analytical complexity, and to ensure the framework is practical and accessible, projects are classified into two tiers. A low tier method is less data-intensive and simpler than a high tier method, which is generally treated as being able to more accurately model the project's response to climate hazards. Distinct components within a large project that require separate analysis or modeling could be analyzed separately and may be classified into different tiers.

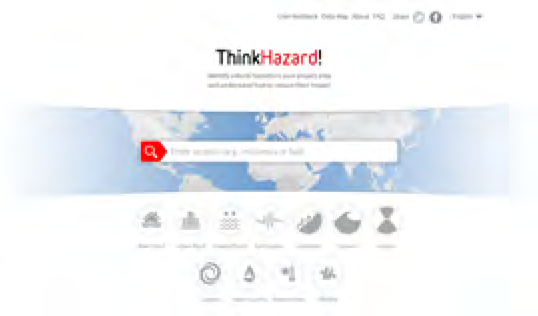
The tier of a project can be determined using the sample process shown in **Figure 4.6**, which assesses criticality based on whether the project considers a single component or sub-system, or a broader integrated supply chain (such as a connected grid), as well as how extensively damages accrue due to climate hazards (e.g., damages accrue only to those directly in an area affected by a storm versus damages transmitted through the chain to others beyond where the storm physically took place). Following the framework shown in **Figure 4.6**, a low tier analysis would typically be suitable when considering a component (e.g. micro hydropower) or sub-system (e.g., industrial heating, HVAC in commercial buildings) within the energy system as a whole, with that component or sub-system being vulnerable to climate hazards. In contrast, a high tier analysis would require consideration of a whole energy supply-chain as the risks faced are induced (rather than direct), such that the hazard acts in a manner that affects the whole chain, generally resulting in higher total damages. For example, if a hydropower plant under-produces due to drought in a low tier analysis, the losses incurred would be of revenue to the power plant. But considering the whole chain in a high tier analysis, losses to energy users would be far higher since the cost of energy not served is also considered.

Textbox 4.2: Climate Hazard Exposure Screening Tools

Climate and Disaster Risk Screening Tool (**World Bank)**. This tool provides a guided method to identify climate hazards and levels of risk to project evaluators at an early stage in the project design process. It focuses on physical and non-physical components of the project, and ranks the threat between low to high, including a no risk and insufficient understanding category. It has a "rapid" (about 30 min) and "in-depth" (about 2 hours) version for multiple sectors, the latter being highly recommended unless the evaluator is familiar with climate science and the project context. The tool relies on the World Bank's Climate Change Knowledge Portal, which is a web tool that provides processed and synthetized historical and projected climate information from the Intergovernmental Panel on Climate Change. The tool considers extreme temperatures, extreme precipitation, flooding, drought, winds, sea level rise, and storm surge. Users would ideally be in possession of a project concept or design, as well as subject matter expertise for the country and project context. In terms of strengths, the tool guides the user on how to perform the screening and how to use data from other tools. It provides an assessment that includes the hazards at the project location as well as the potential impacts on the project's infrastructure and service delivery, as well as how institutional and contextual factors interact with hazards and the project's physical components.

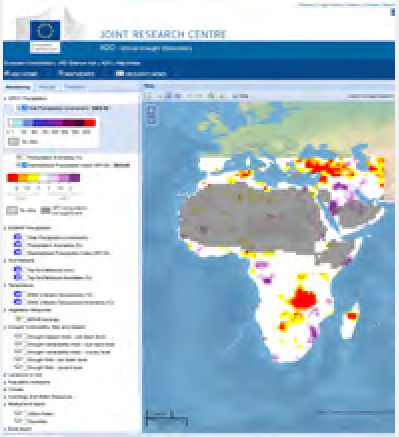

Welcome to the World Bank Climate and Disaster Risk Screening Tools

ThinkHazard! (**Global Facility for Disaster Reduction and Recovery)**. A web tool that provides a general assessment of climate hazards at a sub-national scale. The tool covers 12 different hazards including flooding (river, urban, and coastal), extreme heat, water scarcity, and cyclones. The tool presents a qualitative assessment of the level of a particular threat (i.e., low to high) both now and in the future given potential impacts of climate change, describing general impacts of the hazard along with generic recommendations for planning and evaluation. The tool also includes additional local and/or regional online resources when available. All that is required to run the tool is a general project location. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining a list of the relevant hazards to consider in a particular area, without requiring project specific information. It can help place climate hazards in context with other non-climate threats.



Textbox 4.2 (continued): Climate Hazard Exposure Screening Tools

African Drought Observatory (**European Commission Joint Research Centre)**. A web map service to identify potential drought hazard and risk levels in Africa. It offers access to recent drought monitoring data, as well as probabilistic forecasts for near term precipitation. A general project location is required to run the tool. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining an overview of historic climate hazards to consider in a particular area, without requiring project specific information.



Aqueduct Water Risk Atlas (**World Resources Institute)**. A global web map service that provides an assessment of coastal and riverine flood risks. The tool allows the customization of water hazards by time horizon, climate scenario and projection model, and return period. A general project location is required to run the tool. In terms of strengths, it easily allows users to explore how water risks change under different future climate scenarios.

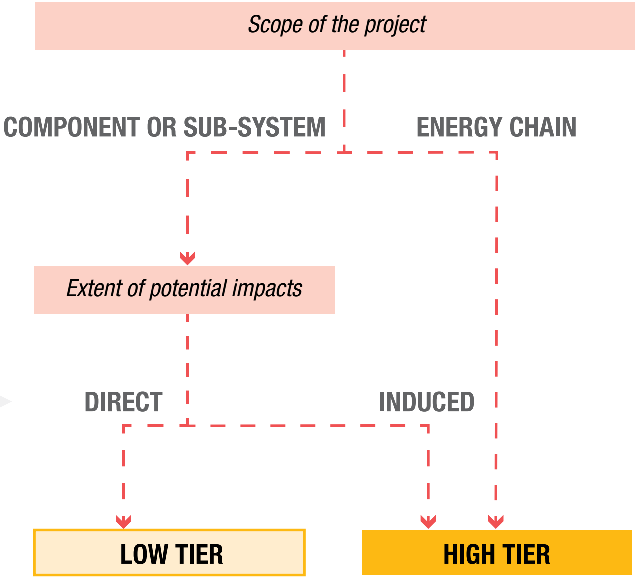
ClimateLinks Screening and Management Tools (**United States Agency for International Development)**. The screening and management tool provides a sectoral toolkit for self-screening and rating of climate risks in the early stages of project design. The risk profiles consist of short briefs for countries and regions that assess the potential impacts of climate change on key economic sectors, including an overview of historical and future climate trends, the policy context, and existing adaptation projects.

Textbox 4.2 (continued): Climate Hazard Exposure Screening Tools

Additional non-web-based tools that could be consulted include:

The CRiSTAL (**International Institute for Sustainable Development**). A project planning tool for identifying climate risks and design components to enhance resilience. It incorporates stakeholder consultation and expert interviews, as well as guidance notes for internal evaluation developed by the African and Asian Development Banks. The tool includes an initial screening step that can be used to understand the potential impacts of climate hazards on the project and local livelihoods in the area. It expands beyond a cursory screening tool, offering guidance for project design and evaluation through a participatory process. A project concept or design is necessary in order to run the tool. In terms of strengths, it guides the user to perform a screening following a questionnaire and provides a community-based perspective of the project, as opposed to the perspective of funders only. It additionally puts climate hazards in context with social, political, and cultural conditions and provides a framework for incorporating local and expert knowledge through consultation.

FIGURE 4.6. Sample Tier Determination Process



Direct: Damages accrue only to those directly served by the component or sub-system. I.e., owner or users.

Induced: Damages are transmitted through the system to others beyond.

Note that this framework is qualitative and flexible in nature, with Figure 4.6 providing guiding principles and a suggested rubric to assess the appropriate tier for the project under evaluation. However, **project teams and stakeholders should consider a more flexible set of criteria, carefully assessing which guiding principles and cutoff values are appropriate for their particular project and inspecting whether using the selected criteria results in an appropriate level of criticality.** For example, when looking at energy investments, high tier projects could also include those that address access to critical services or offer significant enhancements in gender equity. These examples highlight that context is required to appropriately determine the criticality of a project.

Activity 1c. Establish a biophysical modeling approach for components, sub-systems, and chains, based on the project tier. The results of the tier determination process serve as the basis for establishing a biophysical modeling approach that simulates the physical behavior of the project under different climatic conditions (e.g., translating changes in future temperature to altered power plant generation). These models (i.e., simplified, conceptual, mathematical representations of a chain) require climate variables as inputs and produce outputs of interest that are later used for the socio-economic evaluation. The kind of climate and other input variables required will vary based on the biophysical modeling approach selected.

Selecting a model for a particular analysis always depends on the specifics of the project, sub-sectors and/or the associated supply chain. Project-level insights necessary to select appropriate models include a hazards' direct effect on the vulnerable component(s) or sub-sector(s), including impacts to the component or sub-sectors' physical and economic operation. This would typically be undertaken in a low tier analysis (as previously defined in **Figure 4.6** above). High tier projects will typically also need to account for the complexity of energy supply chain analysis, whereby any induced impacts on linked energy supply chains are also assessed. Thus, to conduct a high tier analysis, a model of the energy systems' supply chain(s) is required.

Energy-supply chain models can be broken down into **top-down models** which are typically in the form of an economic model with some technology representation; **bottom-up models** which are typically biophysical models with thermodynamic and mass-balance relations; and **hybrid models**, which are a mix of bottom-up and top-down models. **Typically, bottom-up systems models are useful for resilience analysis** because they can be programmed to simulate project level climate impacts and assess their compounded induced effects. Interestingly these models are typically calibrated to the supply chains at hand, which means that very few models are the same, as national and regional situations are not the same. Appropriately structured systems modeling allows the project team to undertake cost-benefit analysis and translate its results into policy, which is needed to unpack where vulnerabilities exist in the chain. These models allow for an assessment of the energy chain's current risk profile, and how that risk profile might change under different climate futures or with different technology, system, or system-interaction profiles.

For the purpose of assessing climate vulnerability and resilience, models should be selected (or built) based on their capacity to inform and improve the design of the component, sub-sector or supply chains based on changes in climate inputs. For this selection process, it is important not just that the model relates climate variables to outcomes of interest, but also to consider which individual climate variables the model is sensitive to, as well as possible interaction effects among multiple variables. For example, the lifetime extension of a thermal powerplant would normally consider its role in the electricity grid and the water intensity of cooling technologies it should adopt. The case of a hydropower plant would require modeling of the electricity grid, as well as operation of the plant with different levels of water availability for generation. The hydropower case might include a high-resolution model to understand in detail how sub-annual operations would change in response to short-term precipitation shocks. Alternatively, an analysis could (as will be shown in the case study presented later in this section) only consider average dispatch but focus on changes with respect to overall generation and how that affects the expansion of the grid and its assets in an integrated chain — see Sridharan *et al.* (2019) for an example of this kind of analysis where the focus is on average changes to monthly precipitation over a multi-decade investment period. Were acute shocks, rapid detailed dispatch strategies or specific asset vulnerabilities to extreme weather conditions to be of concern, other modeling tools would be employed. **Ultimately, model selection should be conducted considering the scope, functionality, availability, and processing capacity of a particular model, experience utilizing it, knowledge of its caveats and limitations, and data availability.** That said, where existing models and analytical tools already exist for a project that are more analytically rigorous and detailed than the identified tier, these existing tools should be preferentially used.

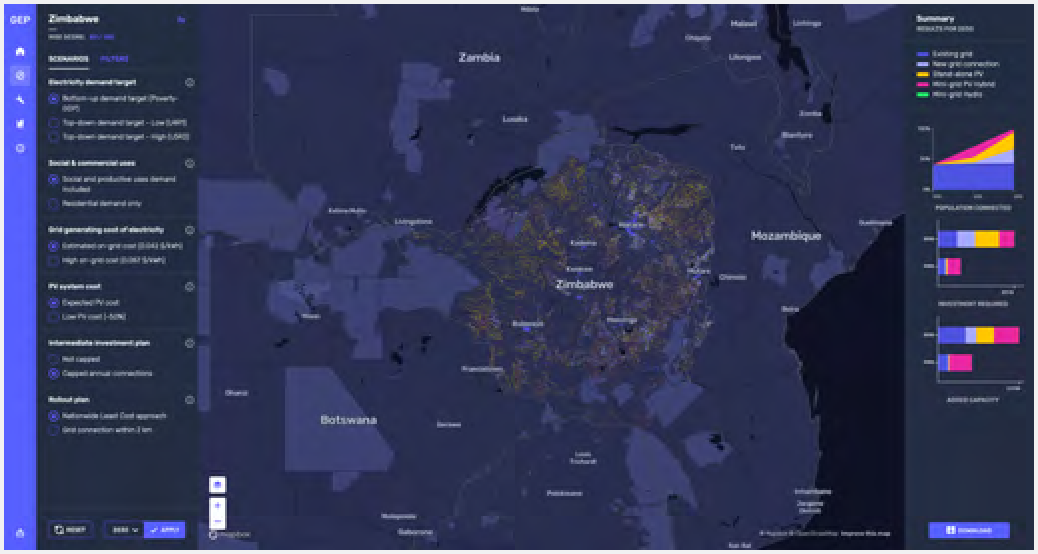
There is a myriad of models that are used in the energy sector. **Table 4.1** below provides guidance for the selection of a modeling approach to be utilized for the biophysical evaluation, including the key climate variables that should be considered in the analysis. A set of open energy-chain modeling resources with training material can be found at OpenLearnCreate: Climate Compatible Growth (2022). Typically, these models also include the ability to estimate cost and benefit, which are referenced later in this guidance. The ability of a model to integrate components, sub-systems, multiple energy chains or even other sectors is critical for high tier projects when energy chain or energy system-wide modeling is required. As an example, an analysis focusing on the shorter-term operation of power systems could use the International Renewable Energy Agency's FlexTool (no date)– here the analyst might consider how to quickly react to an operational shock when one or several vulnerable components are exposed to a climate hazard. With this tool they would be able to understand if the electricity chain has enough flexibility to respond and evaluate if reserves or adaptive capacity are sufficient. Medium to long term energy system investment could use OSeMOSYS (Howells, Boehlert, and Benitez 2021). This might focus on a longer-term analysis of average operation and investment. While indirect impacts are often not included in energy models, extended tools, such as the Climate, Land, Energy & Water systems approach could be used to do so (Ramos et al. 2020).

Table 4.1. Modeling Approaches in the Energy Sector

System	Climate Variables	Low Tier (Project Level Impacts)	High Tier (Energy-Chain Impacts)
Supply			
Thermal Power Plants	• Temperature	A database of potential cooling options for all thermal plants with costs and performance estimates.	(1) A power-systems operational model to understand associated short-term vulnerability mitigation. (2) A power-systems expansion model to understand longer term vulnerability mitigation and potential cost increases.
Solar / Wind Power	• Temperature • Solar radiation • Wind speed	Engineering design models for component resilience.	
Hydropower	• Precipitation • Runoff • Peak flows	A water systems model that routes runoff through a network of reservoirs and water demands with associated -plant configurations and costs estimates.	(1) A power-systems operational model to understand associated short-term vulnerability mitigation. (2) A power-systems expansion model to understand longer term vulnerability mitigation and potential cost increases. (3) Hydropower (integrated basin model).
Biomass / Biofuel Production	• Temperature • Precipitation • Evapotranspiration	• Monthly model that considers precipitation and potential evapotranspiration effects only. • Daily biophysical/ process crop model that also considers direct temperature effects. • Biomass/biofuel supply modelling of scenarios as a function of climate scenarios.	(1&2) A power-systems operational model and a power-system expansion model, if Biomass / Biofuel is being used as feed for power plants And/or (4) an energy systems model with all energy chains that include biomass represented (e.g. household cooking, ethanol blending in liquid fuels etc.)
Demand			
Buildings / Industry (Direct Demands)	• Heat/cold patterns • Flooding • Drought	• Statistical relationship between annual temperature (degree days) and HVAC demand. • Engineering energy management models for industrial demand. • Development of energy sector demand modelling scenarios as a function of climate scenarios.	(1,2 and 4) A power-systems operational model, a power-system expansion model and an energy systems model to represent induced impact. And associated costs of resilience (i.e. trading off more efficient HVAC costs, with increased low-vulnerability power supplies).
Agriculture (Indirect Demands)	• Drought	• Irrigation demand and water allocation modeling with associated energy requirements. • Development of energy sector demand modeling scenarios as a function of climate scenarios.	(1,2 and 4) A power-systems operational model, a power-system expansion model and an energy systems model to represent induced impact. And associated costs of resilience (i.e. trading off more efficient HVAC costs, with increased low-vulnerability power supplies)

System	Climate Variables	Low Tier (Project Level Impacts)	High Tier (Energy-Chain Impacts)
Water (Indirect Demands)	• Drought & Flooding	As above but with comprehensive water supply modeling and associated energy demands. (For example, in drought periods aquifer depletion may increase groundwater depths, which requires increased pumping, and increased power demand).	An extension of (1,2 and 4) a power-systems operational model, a power-system expansion model and an energy systems model, but to include indirect water demands.
Systemic (Including Simultaneous Hazard-Vulnerability Impacts)			
System-wide (Direct And InduCed Impacts)	Based on the propagation of the impacts on relevant vulnerable components and sub-systems through their associated energy chains. This is to be done simultaneously as the same hazard will affect all vulnerable infrastructure (in the vicinity) at the same time.	• Comprehensive mapping of all vulnerable projects to climate change hazards. • Scenario development of 'hazard-strikes' by hazard type and infrastructure. • Modeling of climate scenarios in terms of vulnerable energy: • -Supply projects • -Direct energy demand projects.	Energy systems models (that can evaluate one or more energy chain(s)) that represent a dynamic balance between the supply and demand of energy, representing all vulnerable components or sub-systems. Considers detailed techno-economic representation in order to understand the induced impacts on the system as a whole. This is done such that a climate hazard is simultaneously propagated through the system.
System-wide (direct, indirect and induced impacts)	As above, but with simultaneous direct and indirect impacts. (Note that anything less than this approach risks oversight, and only considers the impact of partial exposure to said hazard.)	As above, but including indirect energy demand projects.	As above, but including indirect demands.
System interaction (nexus)	Can include multiple simultaneous feedbacks (e.g. agriculture might require more water, resulting in lower hydropower flows, reducing generation needed for irrigation. There are systematically compounded vulnerabilities)	• Mapping of project impacts as a function of vulnerabilities and climate hazards across all projects in all sectors. • Developing climate-hazard scenarios (mapped to vulnerable projects). • Developing project-level impact scenarios (for propagation in an integrated model).	Nexus and systems-of-systems models.

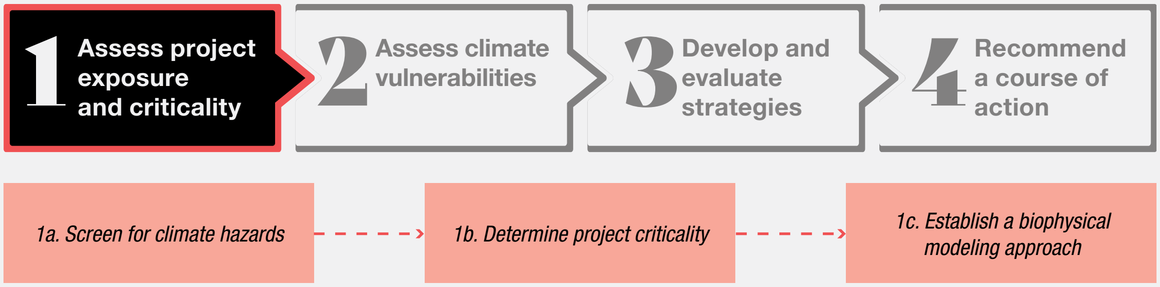
Case Study Demonstration of Step 1: Potential Climate Change Risks to Hydropower Expansion in Zimbabwe



(Source: Global Electrification Platform, Energy Sector Management Assistance Program and World Bank Group).

Background: Zimbabwe has ambitious and laudable power system growth and greenhouse gas mitigation targets. Specifically in the connected grid, these are being underpinned by the (further) planned development of hydropower in the Zambezi River. In fact, these proposed hydropower facilities are the foundation of Zimbabwe's Nationally Determined Contributions (NDCs) to reduce its greenhouse gas emissions. If these facilities are implemented, Zimbabwe's emissions are projected to be reduced by close to 33 percent (together with a relatively small number of other NDC measures) by 2030, as compared to a coal-based future. However, hydropower generation and its expansion are vulnerable to climate change, and as the bulk of Zimbabwe's NDC targets are to be realized via this project – so too its NDC is vulnerable to climate change. Should the climate change in accordance with recent projections, these investments will be at risk directly and will induce severe constraints on electricity supply, causing high degrees of economic damage.

This case study is forward looking and explores the development of the Batoka and Devil's Gorge hydropower plants on the Zambezi. It applies the framework presented in this guidance to demonstrate the vulnerability of these proposed investments. All data and information are derived from the peer-reviewed analysis of Howells, Boehlert, and Benitez (2021).



1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

1a. Screen for climate hazards

1b. Determine project criticality

1c. Establish a biophysical modeling approach

Case Study Demonstration of Step 1 (continued): Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

Climate hazards: While there are other elements of Zimbabwe's connected power grid that are vulnerable to climate hazards, hydropower is highly dependent upon climate conditions. Were those conditions to become systematically drier under climate change, the achievement of power grid supplies and emissions savings would be at risk. The devastating droughts Zimbabwe has experienced in recent times —and the resulting electricity shortages due to production shortfalls at Kariba and elsewhere—appear to be occurring more frequently, and this trend of larger extremes is likely to continue based on climate change projections.

Project criticality: The criticality of these proposed investments was assessed based on the scope of the project (i.e., a single component, sub-system, or a broader system of integrated supply chains), as well as the extent of possible damages that may accrue from long-term climate hazards (i.e., direct damages only versus induced damages throughout the supply chain). Given the importance of these proposed muti-decadal investments to Zimbabwe's broader energy system and their ability to create dramatic knock-on effects that extend significantly beyond lost revenue to just the power plant itself, it is classed as a high tier project. (Note that we are interested in macro-level changes rather than specific sub-annual power-dispatch decisions or responses to individual acute weather events).

Biophysical modelling approach: The overall modelling approach comprised of several steps, from precipitation projections to run-off modelling, to plant-specific annual load factor reductions, to system-wide power supply and demand, and finally to unserved energy. Three models were used:

- A first model was used to develop possible futures scenarios. This was done by utilizing climate projections from the World Bank's Enhancing the Climate Resilience of Africa's Infrastructure study (Cervigni et al. 2015). Future scenarios were developed using downscaled rainfall projections to calculate projected runoff, which was then allocated to different uses across the Zambezi basin. Hydropower production estimates from a water systems model were fed into an energy systems model of Zimbabwe (described in the next bullet). As a high tier project, the analysis calculated hydropower production potential as a function of a water system that took into account simultaneous increases in water withdrawals to satisfy upstream demand.

Case Study Demonstration of Step 1 (continued): Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

- The next model simulated the macro power grid. It was developed using the OSeMOSYS model generator, focusing on the electricity supply to demand chains of the country. (OSeMOSYS was chosen as it has a modular structure and has been extensively applied. Online teaching material and 70 national starter datasets, plus calibrated models are available here). The objective function of OSeMOSYS is to develop a least cost energy system expansion configuration, subject to various constraints. It calculates the total discounted cost for all assets that could be invested in (in the connected power-grid chain). In this case, climate hazards were represented as changes in annual limits (derived from the run-off model) in Zimbabwe's hydropower plants. Induced impacts were based on the amount of energy not served (power shortages) to the economy.

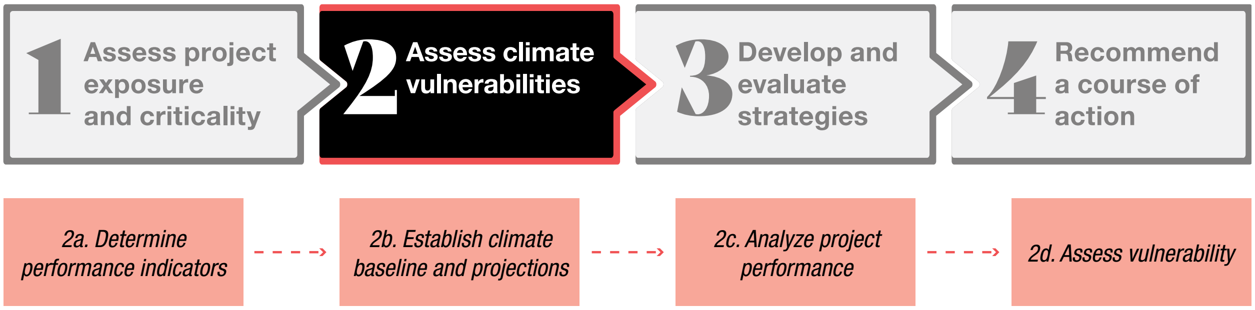
  The generation profile for power plants (apart from solar and wind) is determined endogenously in the model. Hydropower plants are allowed annual storage flexibility and store water to use in times where the marginal price of power is particularly high. (This allows the model to effectively fill its reservoirs when power generation is not needed, and 'fill the gaps' in generation caused by intermittent renewables if that is cost optimal).

  Additionally, this model was then 'forced' to simulate sub-optimal futures (e.g., investment in coal power plants) for exploratory purposes. While Zimbabwe is familiar with the process of investing in and generating electricity using coal power plants and coal mining is a familiar form of employment in the country, such an investment may be undesirable for a variety of reasons including the associated emissions. In the OSeMOSYS-generated model the 'endogenous' expansion of coal can be simulated by limiting investment in alternatives such as solar, wind and large-scale electrical energy efficiency.

- Finally, accounting estimates to project funders (debt and equity holders) at project level were calculated. As the actual project finance details are still being determined, this analysis chose deliberately conservative parameters and simplifying assumptions. Thus, the actual amounts will likely be higher than those calculated. The analysis assumed that the primary vehicle for the development of the hydropower system would be a power purchase agreement. Therein a fixed payment for each unit of power generated would be paid to repay the capital and operating costs.

Outcome: At the end of this step, the project team should have acquired a high-level understanding of the climate hazards the project is exposed to as well as the analytical requirements to adequately conduct a climate impact assessment of the project. Depending on the identified tier, an appropriate modeling approach should be established in consultation with modeling experts. Where a project is composed of separate investment components that are exposed to a different set of hazards, all the activities in Step 1 should be completed for each individual project component in turn.

4.2.2. Step 2: Assess the Vulnerability of the Project to the Identified Climate Hazards



Textbox 4.3: Suggested Performance Indicators for Energy Investments

- Power supply reliability (lack of disruptions and outages)
- Thermal building performance
- Pollutant emissions
- Proportion of household income spent on energy bills
- Energy bill stability
- Greenhouse gas emissions
- Local pollution
- Fuel import levels
- Energy demand not served
- Operating, capital, fuel, and electricity production costs
- Direct and indirect job creation

Objective: After the project screening and assessment of the necessary analytical complexity, the next step is to **assess the project's vulnerability to climate hazards**. This process seeks to identify how a project performs under extreme climate conditions and, incrementally, under a future with climate change (which can further impact the frequency and intensity of extreme events), as compared to current conditions. This same framework will also be used later to assess the performance of possible adaptation options to build climate resilience. The process involves four different activities, each described below.

Activity 2a. Determine performance indicators and targets to assess the climate vulnerability of the project. On the one hand, these metrics would include the economic return of the project measured as net present value, benefit-cost ratio, or internal rate of return, and minimum acceptable returns or hurdle rates as targets (e.g., a net present value above zero, an economic rate of return above a minimum return). On the other hand, indicators that characterize and assess the success (or failure) of the project and its contribution to energy security should be considered. **Textbox 4.3** provides a sample list of possible indicators for energy-focused investments. Depending on their nature, some may be quantitative outputs from the biophysical or socio-economic models, while others may require additional calculation assumptions. For instance, estimating electricity generation requires an assumption on average electricity demand. When feasible, performance indicators should incorporate metrics established by the broader policy environment and development strategy, particularly when those address climate resilience already.

Whereas typical project evaluation methods consider means and weighted averages as performance metrics, given the large degree of uncertainty associated with future climate conditions, an evaluation of climate resilience should look at a range of expected values across different potential future climate scenarios (for instance, as defined in reports from the Intergovernmental Panel on Climate Change (IPCC)), as well as thresholds that cause a project to fail, in order to identify project designs that perform well across a range of different future conditions.

Activity 2b. Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions. The climate baseline describes the default conditions applicable to the initial design of the project, representing the reference point for the analysis. During later stages in this step, a subset of baseline conditions will be perturbed, and performance between baseline and future conditions will be compared for assessing vulnerability.

> When feasible, performance indicators should incorporate metrics established by the broader policy environment and development strategy, particularly when those address climate resilience already.

Resilience Spotlight: The Salima Solar Photovoltaic Plant in Malawi

Malawi's has an electrification rate of only 18.2% and the Government of Malawi has recognized expanding energy access as a critical driver of economic growth. Furthermore, 98 percent of total installed generation capacity is dependent on hydropower, which is increasingly vulnerable to the impacts of climate change with low water levels already impacting power supplies during times of drought. A 60-megawatt solar photovoltaic plant in Salima will become one of the first independent power producers in Malawi and will add a new source of energy supply in the country, offering greater resilience to the country's hydropower sector.

In terms of enhancing the climate resilience of the solar plant infrastructure itself, emerging research from the United States suggests that the **planting of crops under solar arrays may improve the performance of the solar system during hot summer months**: water evaporating from the crops cooled the panels, resulting in 3% more electricity generated during summer months. In addition, the panels also helped moderate ground temperatures, reduce water use and improve the carbon uptake among the plants, with food production doubling under this kind of novel agrivoltaic system. While further research is needed, particularly in a Sub-Saharan African context, these remarkable findings suggest that **combining food and solar production results not just in increased resilience to possible future hotter conditions, but overall better performance of both systems.**

In order to generate a baseline, the project team must first evaluate the availability and quality of historical data (possibly using statistical tools to fill in any data gaps), keeping in mind the expected lifetime of the project. An appropriate time frame for establishing a climate baseline from observed data in the energy sector varies. However, potentially vulnerable components of the energy system (e.g., hydropower plants or biofuel) would benefit from at least 30 years of historic records. In cases with limited data, a baseline of the last 10-20 years could be acceptable, however, the shorter the period used the greater the possibility that the period used is not representative of the long-term climate. Depending on the project, baseline climate data would include historical hydro-meteorological records such as temperature, rainfall, low flows, high flows, and wind speed. The World Bank's Climate Change Knowledge Portal is a good place to start to obtain existing historical data for a particular area. In addition, water temperatures should be considered for thermal power plants where discharges will be into sensitive ecosystems. Non-vulnerable components of the energy sector do not need to develop 'special' baselines.[4]

When considering investments in the energy sector, of special note is the role of natural climate variability particularly as it relates to water availability for hydropower. Precipitation and thus river discharge are strongly seasonal in Sub-Saharan Africa, with the impacts of variability made more pronounced by the relatively limited water storage available. Furthermore, within some parts

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[4] Technologies such as nuclear will be tested against extreme hazards by design. Additionally, many energy-use appliances or technologies (such as cars or information and communications technology-equipment) are relatively robust and/or not exposed to most climate hazards.

of Sub-Saharan Africa, the climate manifests low frequency variability due to El Nino Southern Oscillation phenomena and other factors that cause significant periods of anomalous climate as compared to long term means. As such, there is no clear consensus as to whether river flows in a particular region will increase or decrease under climate change, meaning that potential impacts on hydropower are particularly uncertain.

For projects with lifespans of approximately 30 years or less, natural climate variability is the dominant concern, over and above the long-term impacts of changes to mean conditions as caused by climate change. Projects with longer time horizons, however, are subject to greater uncertainty and should consider a wide range of future climate conditions. The question of which climate futures to consider is a non-trivial decision point in the evaluation process. Future climate is uncertain not just because of natural stochastic variability in the climate (i.e., one rainy season can be wetter than another), but also because of uncertainty about how future greenhouse gas emissions will grow, and uncertainty about how the climate system will respond to future emissions levels. One way of exploring these various sources of uncertainty is through the use of different future scenarios or pathways. While tempting to focus in on just one or a few individual climate futures, there are compelling reasons to consider a broader range of possible conditions: a single climate future describes only one possible version of the future, with many other possibilities going unexamined, making it difficult to draw well-substantiated conclusions.

> Future climate is uncertain not just because of natural stochastic variability in the climate (i.e., one rainy season can be wetter than another), but also because of uncertainty about how future greenhouse gas emissions will grow, and uncertainty about how the climate system will respond to future emissions levels.

For a low tier analysis, evaluation of the impacts of a set of weather extremes is all that is needed in the first instance. Where those extremes reveal concerning vulnerabilities, or where repeated exposure causes failure, more detailed analysis is then needed. For example, simulated stress testing of a public hospital's air conditioners during a heat wave is likely sufficient, while local biofuel production may be more complex and require more detailed analysis, especially where multiple changes associated with rain and temperature may affect yields. (For more on biomass-related climate vulnerability and resilience see the guidance note on agriculture included in the Compendium Volume).

High tier analyses require consideration of the whole energy system and impacts scenarios and hazards simultaneously. This is important as many risks are induced, where the hazard acts in a manner that affects the whole system, generally resulting in higher total damages. A high tier analysis typically considers a full ensemble of future climate simulations modeled through GCMs. Recent World Bank guidance (2022) focuses specifically on the selection of future climate projections and recommends considering **an optimistic and a pessimistic scenario of greenhouse gas concentrations** as driven by global greenhouse gas emissions trajectories and climate mitigation policies, as well as s**everal scenarios that represent a "dry and hot" and a "wet and warm" future**. The first set of scenarios allows one to assess the impact of uncertain global climate mitigation efforts on project outcomes, whereas the second set helps assess local climate risks and overall uncertainty in climate model outputs on project outcomes. The latter is important because different models simulate different climate outcomes for the same emissions scenario due to their reliance on different modeling approaches. In addition, as a general rule, an analysis should consider different GCMs in order to capture the range of possibilities predicted by climate scientists. Attention should be paid to the range of future conditions described by these model ensembles (by considering confidence intervals, for example) rather than just their averages. **Textbox 4.4** provides guidance on where to obtain climate projections, with further details presented in the technical note on working with climate projections included in the Compendium Volume.

An example of a large ensemble of climate scenarios that use a biophysical model to calibrate an energy model for the East African power pool and then determine its vulnerability can be found in Sridharan *et al.* (2019). As there are complexities associated with energy systems that require models, it is advised that care is taken to ensure scenarios are calibrated (a single hazard is propagated across supply, direct and indirect demands) and that multiple scenarios are run to understand where induced vulnerabilities may be. That said, this can be an intensive exercise.

An even more rigorous analysis suitable for high tier projects would include considering the full range of future climate uncertainty (as compared to selecting a number of individual climate scenarios) through stochastic estimations of climate variables from a weather generator. The Decision Tree Framework (Ray and Brown 2015) provides additional guidance on how to use a weather generator in project evaluation.

Finally, through stakeholder consultation and expert advice, the project team should assess the degree of uncertainty suggested by the range of climate scenarios considered, as well as to what extent these uncertainties are tolerable and/or should be mitigated.

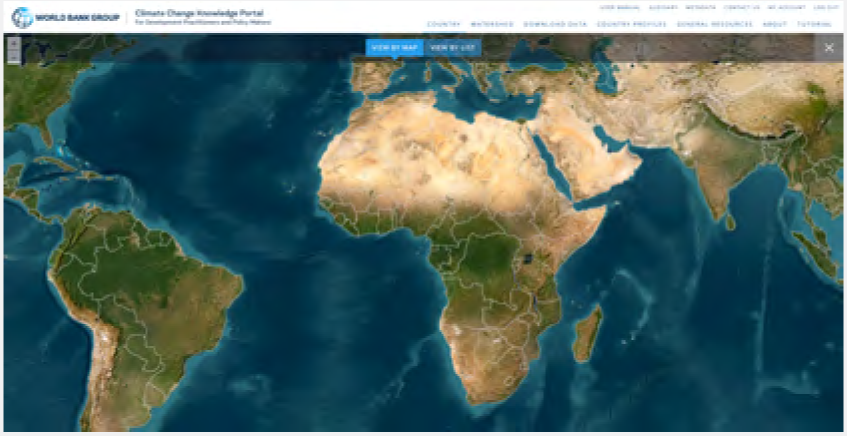
Activity 2c. Analyze project's performance under the selected climate scenarios. The output of Activity 2b is then directed into socio-economic models that convert biophysical outputs into costs and benefits, identifying the performance of the project for both baseline and future scenarios. Occasionally, biophysical and economic modeling are combined into a single model, as some performance models include costs. However, generally in a system analysis, the biophysical performance data of individual components or sub-systems will be included in a system-wide energy model. An example of this is presented in the case study included in this section, where performance metrics for hydropower plants were calculated from a run-off model that assessed its generation profile. That profile was then run in an energy model to determine system-wide effects. These results, along with the performance metrics established in Activity 2a, serve as the basis for the evaluation.

In cases when the socio-economic evaluation is self-contained (typically within an energy system and excluding the larger economy), standard investment evaluation practice follows either a Cost-Benefit or Cost-Effectiveness analysis. Physical investments may cause externalities in the surrounding environment, particularly those within the energy sector (e.g., damages from air or water pollution caused by a coal-fired power station). Economic analysis takes the view of a social (e.g., government) planner, and ideally considers all changes in welfare in the assessment. The technical note on economic modeling included in the Compendium Volume provides a primer on these models and the quantification of externalities, as well as on approaches that may be useful for cases in which it is determined that the project's performance results in significant changes in macroeconomic variables further down the value chain (e.g., changes in commodity prices).

Textbox 4.4: Where to Obtain Climate Projections

The output of future climate simulations can be obtained from various sources:

The World Bank's Climate Change Knowledge Portal has both historical data and future climate simulations available for every country/sub-national unit/drainage basin in the world. All information contained within the Knowledge Portal is consistently produced and thus directly comparable. As well as being free of charge, it is well-suited to project teams who are not used to working with raw, unprocessed output from climate models and it saves time on data searches and data processing.

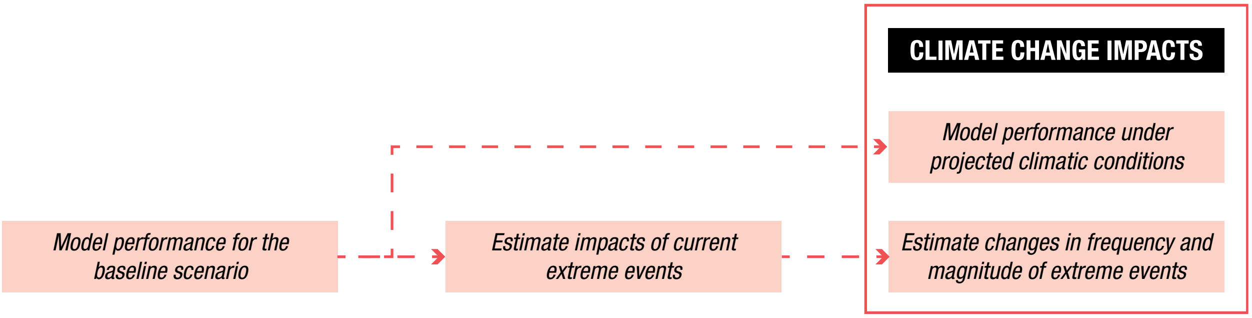


National meteorological agencies often also provide localized climate information, which can be accessed through the World Meteorological Organization's website.

Global observations and computer simulations from the Intergovernmental Panel on Climate Change's various assessment reports, can be obtained from their Data Distribution Centre. Similar information can also be collected from the KNMI/World Meteorological Organization Climate Explorer. These latter two sources provide raw, unprocessed model outputs, which require significant time and expertise to process and bias correct, before they can be utilized in project analyses.

Following the analytical approach determined in Step 1, the analysis should model the impacts of climate hazards following the process in **Figure 4.7**. Climate change impacts should be modeled for all the future scenarios considered in the previous activity and compared against the baseline. Hallegatte *et al.* (2021) and Asian Development Bank (2015) provide further guidance on how to incorporate the effects of climate change and extreme weather events in cost-benefit analysis. A specific example of assessing energy infrastructure in Africa can be found in Cervigni *et al.* (2015), a comprehensive summary of regional and global assessments can be found in Yalew *et al.* (2020), and notes on how climate change affects demand specifically can be found in Viguié *et al.* (2021) and supply systems in Ebinger and Vergara (n.d.) For projects with long time horizons, it is recommended to look at the results at multiple timestamps (e.g., midcentury and end of century).

Figure 4.7. Evaluation Process for Climate Hazards



When conducting the assessment of a new development, a counterfactual representing a no-investment scenario, would be appropriate to assess whether the investment is better than a no-action scenario, as well as to measure the overall contribution (i.e., benefits minus costs) of the investment.

Activity 2d. Assess the vulnerability of the project in the form of a stress test. The analysis should then explore the performance of the project under the range of possible climate futures selected in Activity 2b to assess whether the project fails under those conditions based on the results from Activity 2c. This stress test will help the project team identify thresholds for failure, as well as failure scenarios (e.g., when the project does not meet the minimum economic returns) and the extent of the failure (i.e., difference between the results and a target measure).

As introduced in Step 1, vulnerability in the energy sector, in the context of climate hazards, can be classified into three types: **direct, indirect,** and **induced vulnerabilities. Direct vulnerabilities** are those related to a component or sub-system of the energy system. In terms of energy demand, direct vulnerabilities consider those related to energy services such as HVAC. In terms of supply, direct vulnerabilities often include facilities (or groups of similar facilities) that are exposed to (or rely on) climate-related variables such as precipitation or temperature. For example, rainfall levels will affect the runoff of water to hydropower stations or cooling water intakes to thermal power plants. **Indirect vulnerabilities** occur as vulnerable non-energy sectors interact with climate hazards, causing clear consequences that impact energy services. Increased electricity demands for emergency pumping after a flood, groundwater pumping for irrigation, or water desalination during a drought constitute examples of indirect vulnerabilities. **Induced vulnerabilities** result as additional parts of the energy system (from the components or sub-systems under analysis) react to direct or indirect vulnerabilities. The energy system, especially the power system, is often tightly interconnected and impacts on distinct elements of the system from climate hazards can have disproportionate effects elsewhere in the system, which often result from reduction in production, increase in demand, or both. For example, a recent report for the United States indicated that "A widespread blackout during an intense heat wave may be the deadliest climate-related event we can imagine" (Flavelle 2021) – this situation occurs where there is a concurrent increase in (direct) demand and decrease in (direct) supply, the combination of which can strain the whole power system and induce blackouts. Those blackouts create induced impacts which have much higher costs than either of the 'direct' effects.

The vulnerability of the project is assessed by looking at all the results generated in the previous activity for each future scenario. As with vulnerabilities, impacts can be direct, indirect, or induced. The following questions guide the vulnerability assessment:

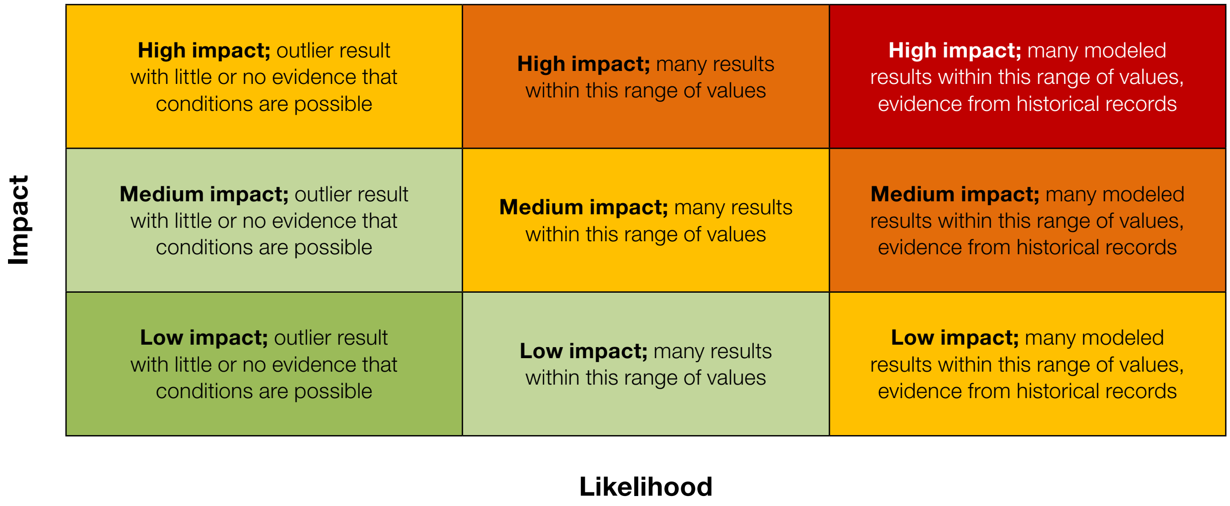
- Does the project meet the **minimum direct performance targets?** When looking at economic return metrics, these generally require the project to have a positive Net Present Value and/or meet an Internal Rate of Return hurdle rate (see the technical note on economic modeling included in the Compendium Volume for a primer on economic evaluation) after considering direct impacts. For example, reduced runoff may result in reduced generation in a hydropower plant, which will, in turn, result in reduced revenues from electricity and adversely affect its profitability. A project can also be vulnerable to a climate hazard when minimum performance in other metrics is not met under at least one scenario. For example, a project may fail if does not deliver a minimum amount of electricity to supply critical services such as hospitals.
- Does the project's performance cause **additional indirect or induced impacts?** Sometimes, these effects may already be considered in both economic and non-economic performance targets. Indirect and induced impacts follow the same logic presented above. For example, a farmer without enough electricity to pump water for irrigation of crops during a drought will experience economic losses. For planning purposes, this can be added to the Net Present Value of the project, as well as food security consequences that may affect separate goals. Induced impacts are generally by far the most significant, and the impact of a vulnerable (or set of vulnerable) project(s) is typically in the form of power shortages with far-reaching economic consequences. Consider for example a dry period in a system with much hydropower. If the decrease in supply is large enough, it will result in shortages throughout the power system. The direct damage to the project may be (direct) reduced sales, but the induced impact (shortages to other parts of the economy) will bear a damage cost that is usually multiple times the former.
- To what degree **does the project meet the minimum performance targets, considering additional indirect and induced impacts?** The extent of the failure can be measured through the range of results across different climate futures. This analysis may indicate the presence of scenarios with results below an acceptable threshold, which may render the project vulnerable if consequences can be catastrophic. This can occur for both a project or for the energy chain in which the project operates (- if the latter, the vulnerability is induced). For example, storm events that interrupt, if even for a limited time, major electricity operations through impacting power plants or other energy infrastructure such as utility lines may have severe consequences on value chains, aside from the direct damages caused by the storms themselves.

On the basis of these questions, a project can be considered vulnerable to climate change impacts if in the future (i) the results for individual climate scenarios are worse than the baseline, (ii) there is a greater number of failure scenarios than in the baseline, (iii) the potential range of results worsens, or (iv) a combination of these situations. For example, the development of a new biofuel project should be evaluated in terms of whether temperature or precipitation will result in the inability to achieve desired fuel yields in order to meet project targets. The analysis may find that for a single GCM scenario, the performance of the investment is sufficient to meet project targets. However, other scenarios show greater changes in future temperatures and precipitation patterns, resulting in the investment no longer meeting its targets. Those scenarios that show a problematic outcome indicate that the project is vulnerable should those futures occur. By using a large number of scenarios, the project team can have more confidence in the level of concern associated with the vulnerability (i.e., large number of problematic scenarios versus few).

A practical framework to summarize the results of the vulnerability analysis, particularly for high tier projects with a large number of results, is to generate a risk matrix that considers impact and likelihood. Impacts refer to the effects of the climate hazard on the project's performance. Likelihood can be thought of as a "weight of evidence" that provides insights as to the level of concern associated with the vulnerabilities. Likelihoods can be assessed in relative terms, based on whether the results of each GCM run fall within the general range of all results or is an outlier, and whether the climatic conditions have been observed in the historical baseline.

Figure 4.8 presents an illustrative example of a risk matrix adapted from Ray and Brown (2015), where higher impacts and higher likelihoods lead to higher levels of risk. All projects found to be vulnerable, particularly those at higher levels of risk, should advance to the next step of the framework to examine whether the project's resilience can be improved.

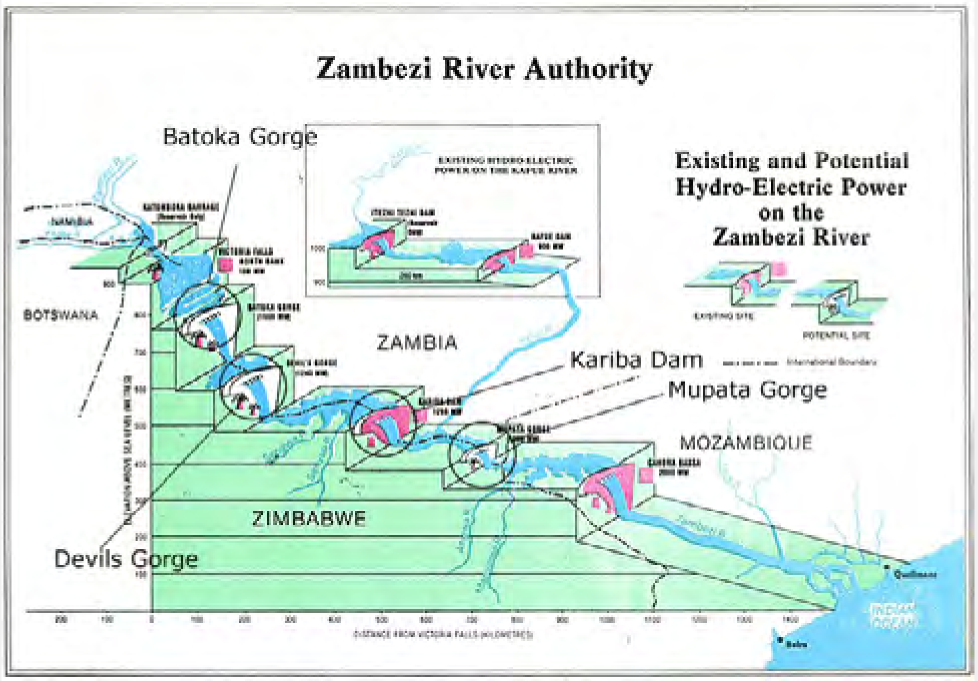
Figure 4.8. Sample Risk Matrix



High impact; outlier result with little or no evidence that conditions are possible	**High impact;** many results within this range of values	**High impact;** many modeled results within this range of values, evidence from historical records
Medium impact; outlier result with little or no evidence that conditions are possible	**Medium impact;** many results within this range of values	**Medium impact;** many modeled results within this range of values, evidence from historical records
Low impact; outlier result with little or no evidence that conditions are possible	**Low impact;** many results within this range of values	**Low impact;** many modeled results within this range of values, evidence from historical records

Outcome: The result of this step is an understanding of the climate vulnerability of the project as currently designed. Comparison between the performance of the project under a historical baseline and under various climate futures provides an estimate of the degree of vulnerability of the project to climate change. It is possible that some project designs may be found to already be climate resilient in their performance given climate uncertainty and these projects can exit the framework here.

Case Study Demonstration of Step 2: Potential Climate Change Risks to Hydropower Expansion in Zimbabwe



1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

2a. Determine performance indicators → *2b. Establish climate baseline and projections* → *2c. Analyze project performance* → *2d. Assess vulnerability*

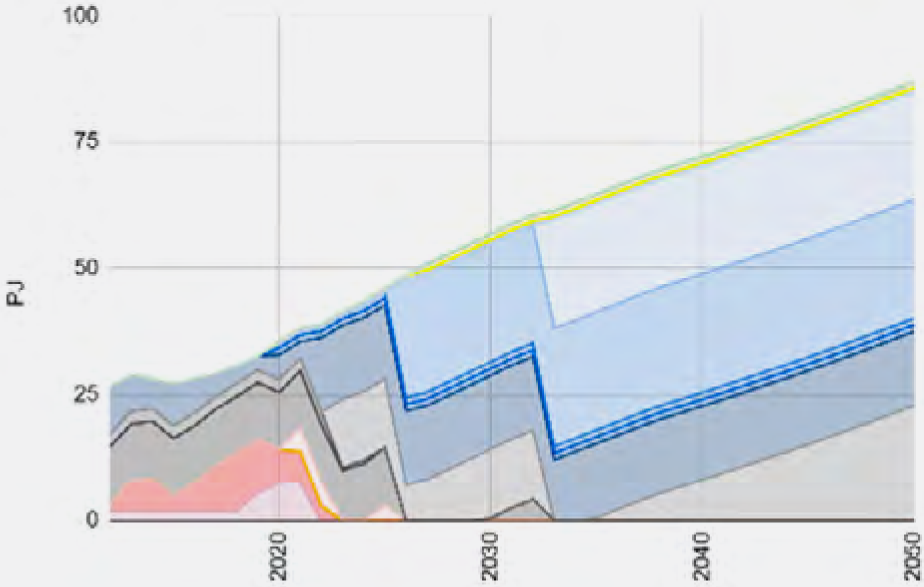
Performance indicators: Four performance indicators were considered for the analysis, namely

- losses to the project funders
- total cost of the system
- power shortages (energy unserved)
- greenhouse gas emissions.

Other attributes were calculated as well, including generation by a large suite of potential power projects and the capacity that would need to be invested in.

Case Study Demonstration of Step 2 (continued): Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

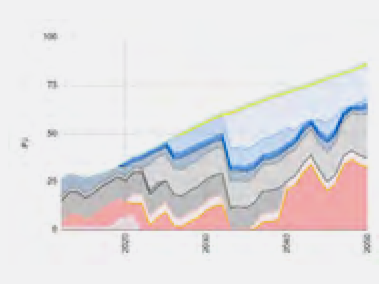
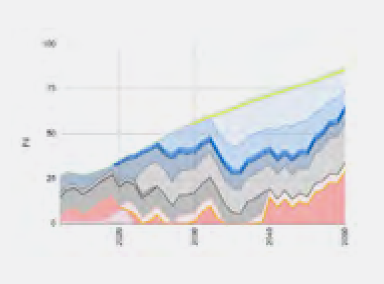
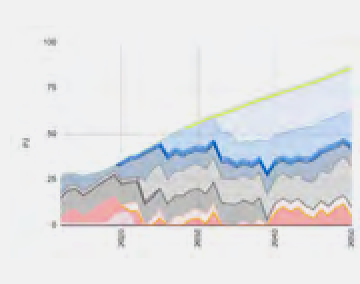
Climate baseline and projections: The climate 'baseline' was determined based on a national analysis embedded in the country's System Development Plan. That was then used to estimate the expected generation of the two proposed hydropower projects, as well as the overall power system costs and emissions. This baseline performance was then compared to three different future scenarios that were developed using climate projections from the Enhancing the Climate Resilience of Africa's Infrastructure study (Cervigni *et al.* 2015). Geo-location specific downscaled rainfall projections were used, which were subsequently translated into run-off estimates for the hydropower plants in question.



Power generation from different power plant options for the climate baseline, with red indicating power shortages. Blue of different shades indicates major hydropower projects. (Source: Howells, Boehlert, and Benitez 2021)

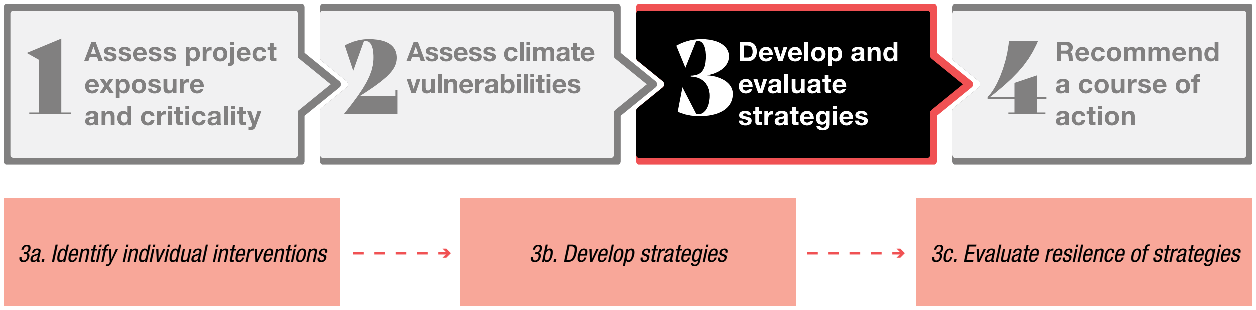
Analyze system performance and vulnerability: When examining the performance of the proposed hydropower projects under baseline climate conditions as compared to different future scenarios that include climate change, there are sales losses of anywhere between 27 and 50 percent. Depending on the specific scenario, this equates to unpaid debts of at least 1.4 to 2.7 billion USD. The system performance under the three different climate change scenarios is very poor, as shown in the figure below. Most critical are the high levels of power outages or 'unserved' energy, shown in red in the figure below.

Case Study Demonstration of Step 2 (continued): Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

GCM: GISS-E2-H, run 1 RCP 4.5 Downscaling: Princeton-BCSD	GCM: MIROC-ESM_CHEM, run 1 RCP 8.5 Downscaling: Princeton-BCSD	GCM: bcc-csm1-1 RCP 8.5 Downscaling: UCT
		

Generation from different power plant options under three different future climate scenarios, with red indicating power shortages. Blue of different shades indicates major hydropower projects. (Source: Howells, Boehlert, and Benitez 2021)

4.2.3. Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience



Objective: This next step in the framework develops a set of possible strategies by which to adapt the project to climate hazards so to improve its resilience. The analysis seeks to provide insights about the performance of the project given climate change as compared to the adapted project given climate change, and considers three activities.

Activity 3a: Identify individual interventions to enhance the climate resilience of the project. Building resilience involves strengthening the capacity of the energy system to cope with climate hazards. As such, the assessment should start from the results of the analysis in Step 2, and search for interventions that can mitigate the project's vulnerabilities by decreasing the magnitude and recurrence of failure scenarios. In general, these practices to enhance resilience fall into four different categories (Asian Development Bank 2013):

- **Structural**: structural modifications to a project or subsector in terms of its capacity, dimensions, materials used, etc. and the inclusion of protective infrastructure. For example, a hydropower plant may be built with a larger reservoir.
- **Technology**: use of emerging technologies to improve the resilience of a project. For instance, using liquid petroleum gas stoves for cooking, rather than agricultural residues in low-income homes.
- **Management and planning**: appropriate energy system planning. For example, including power system designs that incorporate a strategic climate resilience reserve in their reserve margins.
- **Knowledge**: capacity building and training. For example, the establishment of planning communities of practice, such as the Energy Modeling Platform for Africa.

An overarching framework for approaching climate resilient energy practices is the "climate proofing" of infrastructure. Climate proofing can provide a broad risk-based approach that can be applied to the development of energy projects (Asian Development Bank 2005). The Asian Development Bank's Guidelines for Climate Proofing Investment in the Energy Sector (2013) provide a climate proofing framework focused on projects in the energy sector. In addition to providing a process for implementing climate proofing for individual energy projects, these guidelines also discuss strategies for building adaptation and resilience into policy and planning.

Table 4.2 lists some measures that can reduce direct, indirect, induced, and system-interaction vulnerabilities, which include climate proofing as well as additional interventions. These practices can be used to enhance resilience in Sub-Saharan Africa's energy sector. Finally, it is important to highlight the role of **nature-based solutions**, which harness biodiversity and ecosystems services to reduce vulnerability and build resilience to climate change. For instance, the restoration of a forest upstream, which improves river flow during the dry season, can serve as an adaptation measure for a hydropower plant. The ecosystems note included in this Compendium Volume provides additional guidance on incorporating such measures into a project.

Table 4.2. Energy Practices to Enhance Climate Resilience

System	Practices to Reduce Vulnerability
Supply	
Thermal Power Plants	• **Direct:** Implement dry-cooling alternatives (to reduce water needs). • **Indirect:** Develop multifunctional cooling water storage. • **Induced:** Repurpose mothballed power plants (to increase reserves). • **System Interaction:** Implement market rules to ensure “readiness” of climate resilience reserves.
Hydropower	• **Direct:** Implement market structures to support multifunctional operation, rewarding capacity, increased reservoir storage and improved reservoir management to limit sedimentation, flexibility, and baseload operation. • **Induced:** Implement operations and market mechanisms that allow for hydropower to move from water-intensive baseload to variable “balancing” operations (the primary function of which is to allow more intermittent renewable energy into the system). • **Induced:** Ensure releases are consistent with downstream agricultural and other critical water needs. • **System interaction:** Schedule production to allow for reservoir emptying before flooding.
Extensive Renewable Resources	• **Direct:** Engineer and manage infrastructure to endure hail, wind, and flood damage. • **Induced:** Increase the use of distributed renewable energy technology generation (e.g. rooftop solar) where it is close to demand (as this reduces vulnerabilities associated with induced power system stability).
Biomass Production	• **Direct:** Reduce dependency for cooking and heating, move to low-carbon fossil fuels or alternatives that are less vulnerable to climate hazards. • **Direct:** Engineer and manage plantations for increased extreme weather resistance. • **Induced:** Implement markets for and development of biomass stockpiles for resilience reserves. • **System interaction:** Increase forest plantations to increase flood resilience.
Demand	

System	Practices to Reduce Vulnerability
Buildings / Industry	• **Direct:** Improve HVAC efficiency, compressed air management, refrigeration, and passive cooling. • **Direct:** Put in place building standards to ensure low energy footprint and limit climate dependence of demand. • **Induced:** Implement distributed auto-generation to cope with power outages. • **Induced:** Implement cold and compressed air storage to cope with intermittent generation. • **System interaction:** Rainwater harvesting and gray-water recycling.
Agriculture	• **Direct:** Implement distributed auto-generation to cope with power outages. Invest in water storage that can be drawn down. • **Indirect:** Low water use irrigation systems and crop selection, requiring lower pumping volumes. • **System interaction:** Ensure agricultural water withdrawals are consistent with power system use requirements.
System-wide	
Power System	• **Direct:** Shift to non-vulnerable (often lower-water use) alternatives. (This is typically a function of the hazard to which the system is most at risk. Examples of low-water use technologies include dry-cooled thermal plants, photovoltaic, etc.) • **Direct:** Identify options for "rapid roll out" of alternatives during times of climate impacts (such as portable generators). • **Direct:** Create robust design specifications that will allow structures (including transmission lines) to withstand more extreme weather conditions and temperatures. • **Indirect:** Ensure that projections for energy demand are a function of services across sectors that account for climate vulnerability. • **Induced:** Implement market structures that allow for climate resilience reserves, strategic stockpiles, climate options for flexible operation, flexible interconnectors, and trade. • **System interaction:** Create redundancy in the transmission and distribution system to avoid blackouts (when surges in demand are experienced due to climate hazards).

Activity 3b: Develop adaptation strategies to enhance resilience. Once a set of promising and feasible adaptation measures has been identified for the project, more comprehensive and integrated strategies to build resilience should be developed by combining individual measures. Strategies should consider different sets of interventions, as well as different degrees of implementation, timing, or locations as appropriate, and should be part of a participatory consultation with stakeholders to identify and validate solutions. For example, one strategy could consider both upgrading existing coal infrastructure to higher standards, as well as developing new clean energy sources to enhance the redundancy of the system. Moreover, project evaluators should also pay attention to possible interactions between measures.

Ultimately, which interventions become part of a strategy will depend on what attributes of resilience need to be enhanced to reduce climate vulnerability, as well as how stakeholders and users define resilience for the particular project in question. **Textbox 4.5** presents a list of key attributes for an energy system, which can guide the development of adaptation strategies to enhance resilience, with these attributes ideally to be tailored to local circumstances. While these attributes are introduced here as guidelines to consider when developing possible adaptation strategies, they are a powerful tool to strengthen project design, especially when integrated as key resilience concepts into the project narrative from the outset and then used to track progress towards achieving greater resilience. Additional guidance can be found in the note for practitioners titled Integrating Resilience Attributes into Operations (Ospina and Rigaud 2021).

In the face of climate uncertainty, it is appropriate that strategies consider a portfolio of measures to mitigate the impacts from multiple climate hazards, along with insurance and contingency plans for when conditions exceed the capacity of the adapted system to cope. Some of the measures to improve vulnerability may need to be incorporated in the immediate planning term due to long lead times and the long-lived nature of much energy system hardware.

Textbox 4.5: Resilience Attributes for Energy

Key capacities to build climate resilience in infrastructure investments in Sub-Saharan Africa's energy sector include (adapted from Ospina and Rigaud 2021):

- **Robustness:** the ability to withstand the impacts of climate extremes and variability, maintaining the energy system's reliability and the functioning of the supporting processes and infrastructure, while minimizing variability in performance.
- **Redundancy:** the availability of additional or spare resources that can be accessed in case of an extreme, for instance multiple electricity sources for a single location.
- **Rapidity:** the speed at which critical resources such as energy infrastructure (e.g., power plants) and supporting systems (e.g., electricity grids), or supply chain assets (e.g., fuel resources) can be assessed.
- **Connectedness:** the breadth of resources and structures at different levels that a system can access to respond or adopt to shocks or stressors, which is an important consideration for an electricity grid that needs to be accessed by several different populations.
- **Inclusion:** building on diversity and inclusion, ensuring that women and vulnerable groups have the necessary tools and resources, both in normal conditions and during crisis.

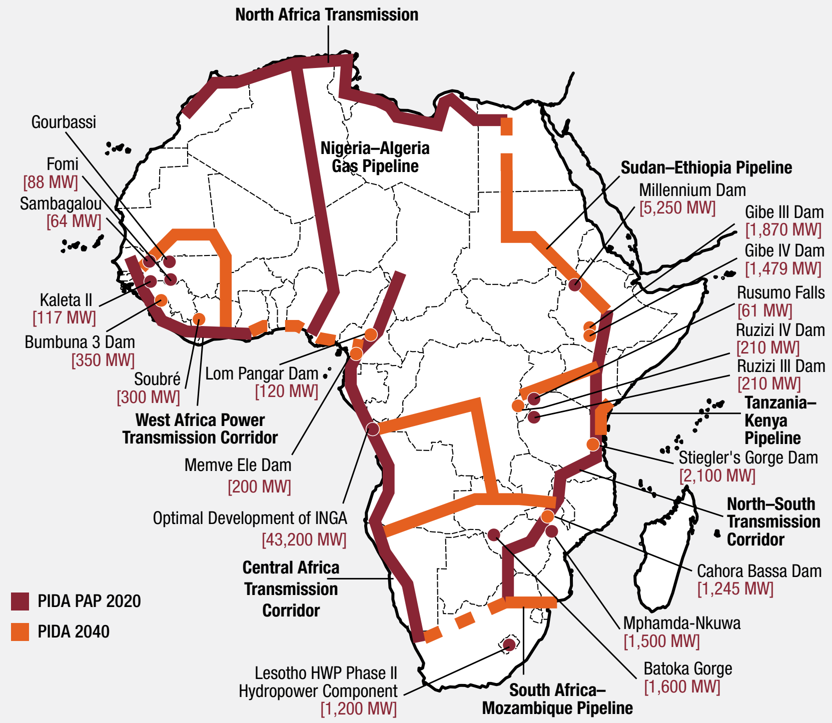
Though this guidance note focuses predominantly on climate adaptation (with adaptation considered the priority at present for Sub-Saharan Africa), it is important that adaptation and climate mitigation goals and activities are not treated in isolation, as the resilience of a project can also be impacted by climate mitigation-related considerations. The focus of this note on adaptation should not detract from the identification and quantification of any co-benefits that may accrue from climate mitigation. For instance, there may be opportunities for reducing emissions through investment in hydropower, but the direction and magnitude of those effects are dependent on local factors.

Activity 3c: Evaluate the selected strategies' contribution to the resilience of the project. Having identified a feasible portfolio of individual adaptation measures, the next step involves using the same modeling framework established in the vulnerability assessment described in Step 2 to evaluate the performance of the different adaptation strategies being considered.

Depending on the specific interventions, it is possible that new model parameters or assumptions may need to be defined (looping back to Step 2) before being able to estimate the costs and benefits of different interventions, which may require the gathering of additional data. Comparing the performance of the strategies to the project as originally designed (in Step 2) in terms of how much they reduce the magnitude and recurrence of project failure provides a sense of the degree of climate resilience that different strategies offer. In other words, an adaptation strategy that increases climate resilience is one that results in fewer cases of failure, a reduced impact in the failure scenarios, or both (e.g., adding redundancy to power transmission to cope with high demand and low hydropower generation capacity during dry spells). The extent of these improvements can be tracked using the Risk Matrix previously shown in **Figure 4.8**.

Resilience Spotlight: Resilience Though the African Single Electricity Market

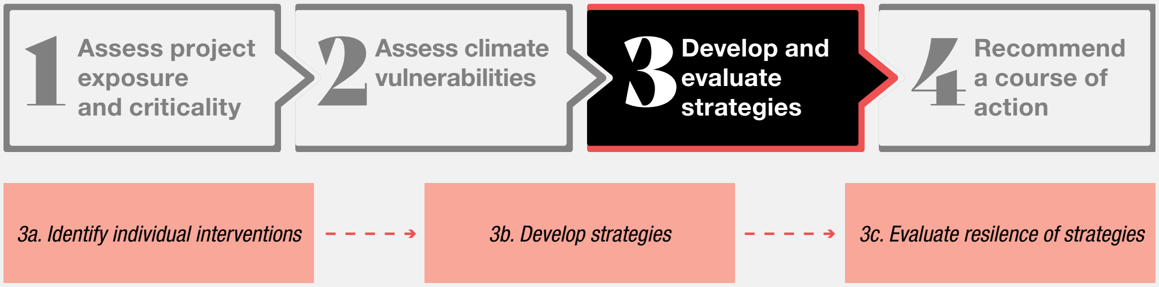
On 3 June 2021, the African Union officially launched the African Single Electricity Market. When complete, this multi-decade endeavor will provide improved electricity security to more than 1.3 billion people across 55 African Union member states. The task ahead is immense, including the harmonizing of regulatory frameworks and integrating generation, as well as linking existing and developing new transmission and distribution infrastructure. **By linking diverse geographical regions and different sources of electricity generation, such a unified market has the potential to improve the climate resilience of the market as a whole.**



Source: African Union Development Agency.

Outcome: At the end of Step 3, the project team will have identified promising portfolios of interventions that enhance the climate resilience of the original project design evaluated in Step 2. The output of this step is an updated set of results showing the project's performance for each adaptation strategy and climate scenario. This output will be the input for the following decision-making step.

Case Study Demonstration of Step 3: Potential Climate Change Risks to Hydropower Expansion in Zimbabwe



Identify individual interventions and adaptation strategies: Two different adaptation strategies were developed for this project, with each looking at both project and system-level considerations. The strategies seek to reduce the impact of hydropower shortages by considering alternative sources of power that are less climate vulnerable:

- **Strategy #1:** We used a cost-optimization model to explore the expansion of power generation using alternative traditional energy sources instead of hydropower, renewable energy technologies and deep energy efficiency investments. As there is no natural gas supply in Zimbabwe, no regional pipeline to import liquid natural gas from a neighboring country and oil prices are relatively high, the model chooses coal as the remaining cost-effective, albeit emissions-intensive, alternative to hydropower. Coal-fired power plants could be constructed and operated to ensure that the power system avoids expensive (induced) power cuts associated with lower hydropower production. This strategy of building a coal resilience reserve was labeled '**coal reinforcement**'. It is a conventional option, that would result in Zimbabwe not meeting its NDC targets.

  At the **asset level,** the power purchasing agreement for electricity sold from the hydropower plant would need to be renegotiated. This might require developing fixed annual remuneration and an obligation to generate and dispatch power when optimal. Little change would be required in the re-design of the two hydropower plants. At the **grid level**, a resilience reserve of coal fired power plants would be run relatively flexibly as the dispatch of these plants would be coordinated with the hydropower plant's releases. Those releases – enabled by reservoir storage - would be predictable, allowing start-up, downtime and minimum-stable-operation constraints to be met. There would be no need for these coal assets to be run as a 'peaking plant'- while new coal plants can be built at a premium for relatively flexible operation, the need for this would be limited. It is difficult to mine 'coal-on-demand' and in this case, continuous mining operations could be maintained in order to have a coal stockpile, which would be drawn down at a relatively variable rate i.e., after an initial stockpiling, the coal mined per year would be equal to the average used by the power plants in that year. This would allow for an appropriate coal purchase agreement. To operationalize this form of resilience reserve, changes will be needed in the power system market. The coal mining, stockpiling, coal-power-plant capacity reserve and coal-fired production at peak times would need to be remunerated, likely resulting in a surcharge to power prices.

Case Study Demonstration of Step 3 (continued): Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

- **Strategy #2:** This strategy (the **clean adaptation strategy**) assumes a system transformation. While the two hydropower projects in question are kept, larger quantities of solar and wind power are allowed into the system generating a combined maximum of 50 percent of the alternative supplies for any one year. Deep energy efficiency measures cut demand by up to 20 percent. As a last resort, any additional power sources needed to meet demand will originate from new coal investment. This 20 percent efficiency improvement is well within the range of international studies and might even be exceeded as modernization allows for a significant overhaul of current intensive energy-using infrastructure. The market will however need deeper restructuring. Solar, wind and energy efficiency measures are not normally used as capacity reserves, and capacity reserves will be required at peak times. The co-incidence of solar and wind generation with peak demand when needed is limited (and this trend is represented in the OSeMOSYS-generated model). That said, the climate resilience reserve (especially where the hydropower facility can store water and dispatch it at peak times) is very much about adding appropriate levels of energy to the system – which the clean adaptation strategy – and associated resilience (not capacity) reserves do.

  At the **asset level**, the power plants would require design and payment agreements to ensure that flexible operation (including storage) was both feasible and rewarded. At the **grid level**, the market would need re-designing in order for it to reward the hydropower plants for so-called ‘balancing services and capacity reserves’. The hydropower plants would need to be remunerated for releasing power when solar and wind are not generating and for maintaining reservoir storage levels just prior to peak demand times (such that they are available to contribute to the peak capacity reserve margin). Again, these resilience reserves would likely be remunerated from a surcharge to the power price.

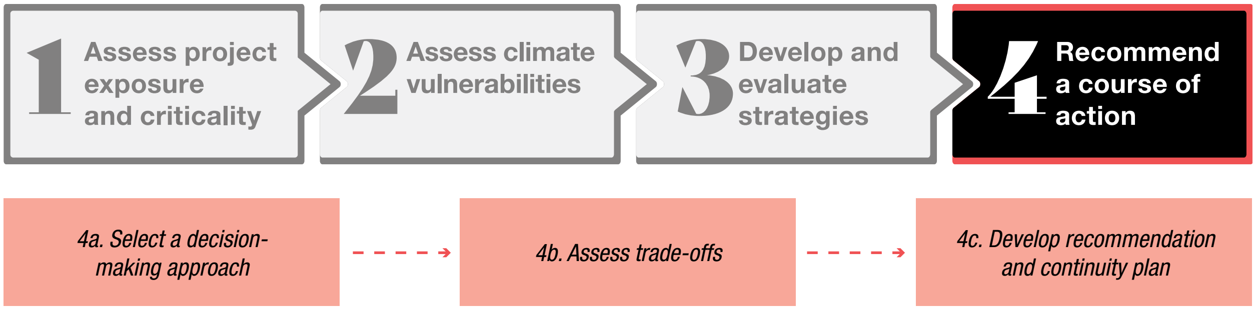
Evaluate the resilience of the different strategies: In the following figure, the two different adaptive strategies are compared. In both the coal reinforcement and clean adaptation options, there is a reduction in energy-not-served as compared to the baseline “no adaptation” hydropower plant design as new power plants are built and operated in the future. This reduces economic damages and results in the supply of reliable electricity. Note, however, that in the short term there are still power shortages, indicted by the red areas of the graphs, occurring in the early 2020s. This occurs, in part, due to an over-dependence on hydropower generation at present: when low rainfall occurs over the coming decade, there is little corrective action that can be taken as the new plants simply cannot be built in time. In the medium term, this is overcome by investment in new hydropower capacity.

Looking more closely at the second column of the figure below which shows the results for the **coal reinforcement adaptation strategy**, of importance is the fact that emissions (shown in the middle bottom graph), skyrocket. The dashed line indicates the NDC target (heavily reliant on hydropower investment), where the climate is anticipated to be favorable. The solid line indicates a more than quadrupling of emissions by the end of the analysis period. This is almost as high as a business-as-usual future that continues to rely predominantly on coal and almost all environmental gains are lost when pursuing this strategy. However, as shown in the graph on the bottom left, the economic damage avoided, and the total cost to the economy is less than half of that when no climate adaptation strategy is pursued.

Case Study Demonstration of Step 3 (continued): Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

The **clean adaptation case** is critically different. It takes advantage of renewables, high energy efficiency updates and balances the system with hydropower and if needed as a last resort, coal. (By first pursuing renewables and energy efficiency measures, it requires less hydropower and coal). Its emissions are lower than the coal reinforcement strategy and lower than the original NDC targets. Furthermore, the extra renewable energy capacity costs are offset by lower fuel costs and reductions in demand due to energy efficiency. However, while the benefits are strong, so too are the institutional

4.2.4. Step 4: Recommend a Course of Action



Objective: Finally, this step will lay out a decision-making approach to identify a course of action from the adaptation strategies considered in Step 3 that considers trade-offs and looks at the full economic lifetime of the project. Three activities are involved.

Activity 4a: Select a decision-making approach that is able to help identify a strategy (from the set developed in Step 3) that is well-suited for a broad range of uncertain conditions. This requires assessing and trading off project performance across a variety of uncertain future conditions, rather than simply maximizing the expected results from averaged future conditions. While the focus in this note is on uncertainty about future climate conditions, resilience analyses in Sub-Saharan Africa are faced with a variety of different uncertainties, including from inadequate historical climate data, the divergence of existing climate projections, as well as changing political and policy environments, external market conditions, or levels of technology adoption. In this context, traditional decision-making methods often fall short because they typically strive to identify an optimal design for an average or most likely set of future conditions. (This group of methods is often described as being founded on **predicting and then acting** – see the technical note on decision making under climate uncertainty included in the Compendium Volume for an overview of these traditional decision analysis methods.)

Given the significant degree of uncertainty associated with future climate conditions, a new group of decision-making methods has been developed that focus on **preparing and adapting**, rather than predicting and acting. This class of methods emphasizes **the identification of flexible decisions that enable ongoing adaptation, or robust decisions that will prove wise across a wide range of future climate conditions.** In general, these methods involve framing the analysis and conducting an exploratory assessment, choosing initial and contingent actions to iterate and perform re-examination, and allowing participation of stakeholders. **Table 4.3** provides a summary of some of these decision-making approaches, grouped based on whether they emphasize the robustness or flexibility of the decision. (See the technical note on decision making under climate uncertainty included in the Compendium Volume for further details.)

Table 4.3. Summary of Approaches for Decision-Making Under Climate Uncertainty

Emphasis of Framework	Description	Examples
Robustness	These approaches focus on achieving acceptable project performance across a wide range of possible future conditions. The emphasis is on the investment decision to be made now and generally follows a conservative approach when incorporating future conditions that are significantly different from the baseline.	• Decision Scaling • Robust Decision Making
Flexibility	These approaches prioritize identifying a design that can adapt in the future given different climate conditions. In general, these value the agility of a design more than its robustness and include consideration of "tipping points" for climate variables that will indicate a change from one set of actions to another.	• Engineering Options Analysis • Adaptation Pathways

The selection of a decision-making framework should be informed by the preference either to account for future uncertainty now through measures that enhance the robustness of the decision or leave options open for future adaptation. This choice should be informed by

- the available resources today and in the future,
- the capacity of the project team to control or influence changes in the future, and
- the optimism that future information will help to clarify the adaptation decision and will arrive in a timely way.

For instance, while a critical power plant providing electricity to a city may benefit more from a robust approach that ensures the infrastructure is designed to withstand low-probability but high-impact flooding events, it may be considered acceptable for a small-scale run-of-river hydropower operation to experience increasingly frequent flooding outages as sea level rises before decisions are made as to whether to pursue other more expensive adaptation strategies.

As mentioned before and shown in **Figure 4.3**. presented at the start of this chapter, the framework for enhancing the climate resilience of projects that is presented in this note is circular: it is possible that after selecting a decision-making approach, the activities completed during earlier steps in the framework may need to be revisited and adjusted. For instance, having prioritized the flexibility to make incremental adaptation decisions and delay large investments till later (as compared to prioritizing system robustness now), this decision may necessitate returning to Step 3 and identifying additional adaptation interventions that enable flexibility, as well as returning to Step 2 and selecting a few additional uncertainty scenarios to explore if particular climate futures are concerning to decision makers.

Activity 4b: Assess the trade-offs of each strategy. Generally, there is no perfect adaptation strategy, and more beneficial strategies tend to be more expensive. Strategies that are good for mitigating the impacts of one climate hazard, for instance drought, may also fail at properly addressing others such as flooding. Furthermore, strategies that benefit one sector may cause negative downstream impacts to other stakeholders. In this context, the decision-making process must also look at minimizing trade-offs. The starting point of this activity requires identifying, and if possible, quantifying, the trade-offs of each strategy. Typical trade-offs between investment decisions in the sector include the cost of adding resilience reserves while keeping electricity price increases for reliable electricity supplies to a minimum. A specific example might be where best to 'intervene': demand-side measures are often cheaper (e.g., better energy efficiency) but require more active intervention than supply-side measures (e.g., building reserve capacity). When it comes to determining the size of any additional climate resilience reserve that is implemented, various solutions would need to be examined on a case-by-case basis. These could include diversification of supply sources, implementation of demand-side interventions including energy efficiency, and deployment of transmission, among other options. It is often unclear whether significant capital expenditures made today may not be needed in the future due to climate change, or due to anticipating climate changes that ultimately do not occur. Thus, there are difficult questions as to whether to act or not to address climate vulnerabilities.

> Typical trade-offs between investment decisions in the sector include the cost of adding resilience reserves while keeping electricity price increases for reliable electricity supplies to a minimum.

Resilience Spotlight: Enhancing the Climate Resilience of the Nachtigal Hydropower Project in Cameroon

The Nachtigal Hydropower Project in Cameroon is a 420MW greenfield hydroelectric power project. The project consists of a hydroelectric plant with a reservoir on the Sanaga River, a concrete-lined canal, a high-voltage transmission line and construction of an owner's village. The project is expected to support 30% of Cameroon's electricity production, or nearly 10 million people. The project will offer resilience against variable precipitation, by enabling all-season flow and thus reliable electricity generation on the Sanaga River via a new regulating dam and main reservoir upstream. In addition, reservoirs offer more than just resilience for the energy sector: they provide flood control, water for irrigation and urban users, and downstream flow management enabling navigation, among others. **A variety of asset-level, landscape-level and management interventions can help enhance the climate resilience of the hydropower facility itself, including increasing the reservoir design volume, reforestation of upstream catchment areas and better managing of reservoir dredging activities (both of which help maintain long-term reservoir storage).**

The quantitative analysis performed during Steps 2 and 3 can produce two kinds of results: a point estimate of an economic performance indicator (e.g., internal rate of return or net present value) and information related to the variability (i.e., distribution of uncertainty) around the point estimate. Under uncertain future conditions, the point estimate may be no more likely to occur than the wide range of other possible outcomes around it. For this reason, when assessing trade-offs, the project team should consider the distribution of uncertainty around point estimates to promote better decision-making.

In order to weigh the importance of different strategies, the project team should develop a hierarchy of all consequences that result from project failure. These causes of failure correspond to all the reasons why the project does not meet the performance metrics in the face of extreme weather events and climate change, as identified from the vulnerability assessment and addressed through adaptation strategies. For instance, if precipitation events of average magnitude (and therefore of frequent occurrence) are found to cause greater disruption in total than occasional high-magnitude floods, standard infrastructure reinforcement for many power plants may be a more worthwhile strategy than reinforcing a small subset of already up-to-standard power plants. This list will indicate the order of priority and urgency and should be produced in consultation with and validated by stakeholders of the project.

The project team should then carry out the decision-making process, with the benefits of the strategy (i.e., the performance metrics defined in Step 2 and evaluated in Step 3, considering the distribution of uncertainty of estimates), its direct costs and associated trade-offs, and the hierarchy of priorities as inputs. As mentioned, this process may require revising the analysis done in previous steps as new information is obtained and inputs are gathered from stakeholders. Decisions then could fall into three categories, namely:

1) **Investing in climate-proofing the component, sub-system, or system transformation at the time of design**, which can result in low-regret, no-regret and/or win-win options depending on the projected costs and benefits;

2) **Deferring from investing in climate-proofing but designing the component, sub-system, or system in such a way it can be more easily climate-proofed in the future**, if deemed necessary. For instance, this could include the modular design of power-plant deployment, which may allow for fast build out as changes to the climate become less uncertain; or

3) **Deciding that the project design and monitoring should not take account of climate variables and their impacts at the present time**, and that investment in climate-proofing will be undertaken at a later point, if needed.

The first option sees more substantial investments in climate resilience at the project outset than the latter two options. The second option is commonly referred to as **adaptive management**, where proactive and incremental adaptation investments are introduced over the project's lifetime. The third decision making approach embodies **a wait-and-see mindset** – while this latter approach maximizes flexibility and adaptability, minimizes the hardening of infrastructure today, and may be preferred when funds are limited, and uncertainty is high, it is only suitable for situations where baseline risk is considered acceptably low. For example, the life of a coal, gas, or oil power plant might be extended at a low cost. This could provide immediate power supplies and push the need for new investment further into the future. If that new investment is climate vulnerable, it is hoped that climate uncertainty lessens the further that decision is pushed into the future.

The recommendation of a preferred course of action should cover all components of the project cycle, starting with project identification, focusing on risk screening and identifying critical stakeholders and their roles and responsibilities. The recommendation should focus on those adaptation solutions that are technically feasible to address projected climate vulnerabilities, taking into account the related costs and benefits. In this context, the trade-offs analysis should also inspect the feasibility of a strategy in terms of technical capacities, policy environment, and financial constraints, with particular attention to the extent to which the environment supports or limits their implementation. Potentially, the analysis may require returning to Step 3 and revising the strategies proposed. Project implementation should identify stakeholders with the capacity to implement the preferred adaptation option(s) and include necessary capacity building at the individual and institutional levels. Lastly, the recommendation works best if it draws and builds upon existing country-level plans that identify priority areas for action.

Activity 4c: The development of a recommendation and continuity plan should provide a narrative that justifies the selection of a course of action from the process in the previous activity. Moreover, the continuity plan should describe how project evaluation will be conducted, along with a clear schedule of activities and stakeholder responsibilities into the future, both during and after the implementation phase, including how resources for maintenance and/or continued adaptation will be mobilized, to ensure the investment continues to perform over the course of its life.

Both the narrative and continuity plan should discuss residual climate risks not addressed in the proposed project design that are still material to the project. Since it is not always economical or preferred to address all risks under all potential future conditions, there will generally be a residual risk. However, since the future is uncertain, it is possible for residual risk to grow over time in unanticipated ways to a point where it would be appropriate to address, and should be the basis for a monitoring and evaluation plan. For example, precipitation-related risks may not be considered relevant today if most climate scenarios point to a drier future but may become significant if the climate evolves differently than predicted. Monitoring and evaluation should focus on assessing how progress toward vulnerability reduction and changes in residual risk will be measured in terms of indicators, tipping points, and thresholds, and how lessons learned can be used to improve current and future projects underpinned by a fit-for-purpose monitoring, evaluation and reporting framework.

This plan should include which actors will be responsible for each action and when, and should cover the full economic life of the project. Developing such a plan is fundamental when selecting a wait-and-see type of strategy that requires future actions. Even when interventions are prioritized in the near-term, as (climate and non-climate) uncertainties resolve over time, the continuity plan provides critical milestones for revising the resilience of the project.

Both the narrative and continuity plan should discuss residual climate risks not addressed in the proposed project design that are still material to the project. Since it is not always economical or preferred to address all risks under all potential future conditions, there will generally be a residual risk.

Outcome: After completing these four steps, the project team should be capable of providing an assessment of the vulnerability of the project as initially proposed, and developing a narrative on how much a particular strategy (or set of alternative strategies) can enhance its resilience and, therefore, reduce its vulnerability. The assessment, moreover, should enable the team to understand whether the improvements (and corresponding trade-offs) are acceptable, as well as the costs of following each course of action.

Case Study Demonstration of Step 4: Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

Batoka Gorge (Source: Zambezi River Authority).

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

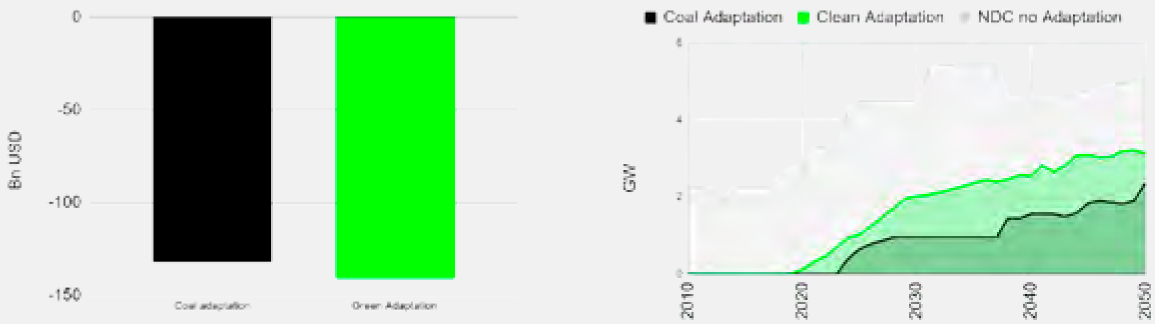
4 Recommend a course of action

4a. Select a decision-making approach → *4b. Assess trade-offs* → *4c. Develop recommendation and continuity plan*

Select a decision-making approach: In this case study, a choice was made to ultimately recommend the so-called ‘clean adaptation’ strategy to enhance the resilience of the proposed hydropower projects. This included allowing hydropower to operate flexibly when there was a shortage of water: rather than being run ‘flat out’ during periods of drought, the hydropower facilities would be turned on only when solar power was in short supply – namely at night. Meanwhile alternative technologies such as solar, wind and increased energy-efficiency are complements to hydropower that are both clean and inexpensive. Ultimately, flexibility was prioritized in the decision-making process.

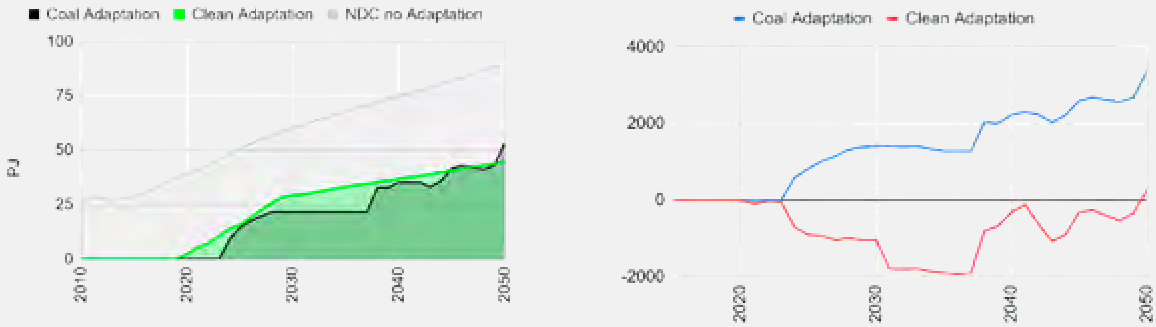
Case Study Demonstration of Step 4 (continued): Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

Assess trade-offs: Comparing the two adaptation strategies – the costs associated with both cases are lower than those associated with the no adaptation alternative, with the clean adaptation case costs being marginally lower than the strategy that relies on a coal reserve. The costs included are direct costs, including capital, operating and maintenance, fuel and unserved energy costs. There are other costs associated with clean adaptation that are not accounted for, including the market and institutional restructuring required to expand and manage a structurally different power system - these should be further investigated. In the figure on the next page, costs, capacity, generation and emissions are compared to a no adaptation alternative, where the black line indicates relative changes for coal-reinforcement and the green, clean adaptation.



a. Costs

b. Capacity



c. Generation

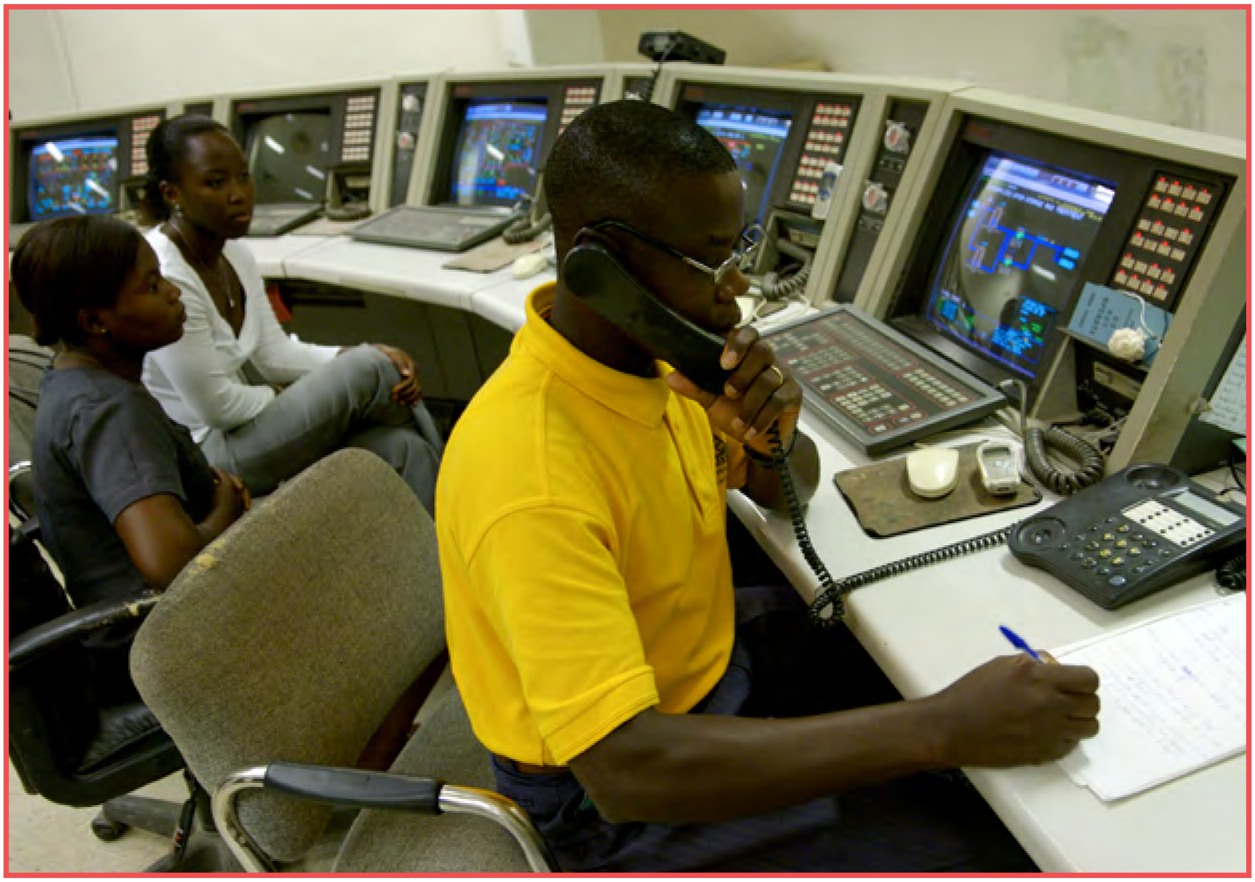
d. Emissions

(Source: Howells, Boehlert, and Benitez 2021)

Case Study Demonstration of Step 4 (continued): Potential Climate Change Risks to Hydropower Expansion in Zimbabwe

Develop recommendation: Figure a above shows the costs of coal adaptation versus clean adaptation, assuming the same hydrology for each case, as compared to a baseline of no extra investment to adapt to the changed climate. The study ultimately recommended the ‘Clean Adaptation’ strategy to improve project resilience. We see (noted in green above in b) that this strategy involves significant additional investments in renewable energy technologies. This apparent ‘over investment’ is required to overcome relatively low capacity factors of the renewables considered. On the other hand, in c, we see that comparable quantities of energy are generated from coal in the ‘Coal Adaptation’ and renewables (and displaced by efficiency measures) in the ‘Clean Adaptation’ future. Noted in d, emissions are lower than the ‘No Adaptation’ future and significantly lower than the ‘Coal Adaptation’. Thus, there are compelling reasons to recommend the ‘Clean Adaptation' route.

The recommendation comes with important caveats. Firstly, the energy sector is vast in its coverage and interlinked with itself, as well as other physical resource systems and other parts of the economy. In this case we focus on power for illustrative purposes. We also use models that do not predict, but help us look at projections of, the future. At the same time any action or inaction is a decision, so decisions are being made every day with no knowledge. This approach helps provide insightful gains - to the best of our presently available imperfect knowledge.



Concluding Remarks

This guidance note presents a practical framework for enhancing the climate resilience of infrastructure development projects in Sub-Saharan Africa's energy sector. The framework includes four steps: (1) assessing the exposure to climate hazards and determining the criticality of the project; (2) assessing the vulnerability of the project to the identified climate hazards; (3) developing and evaluating strategies to enhance the project's resilience; and (4) recommending a course of action. For each step, the note provides illustrative examples, along with references to additional technical notes for issues that expand beyond the scope of the guidance note and are common to the other sectors covered in the Compendium Volume.

There is no single approach for assessing climate hazards in project evaluation, and this guidance note is based on the authors' understanding of the most appropriate methods available for the energy sector in Sub-Saharan Africa. Future climate conditions are uncertain in nature, and the proposed framework was designed for incorporating the vast and evolving field of study in climate science by way of a practical and flexible approach that can adapt to new emerging knowledge.

In the case of the energy sector, it is important to look not only at direct vulnerabilities, but indirect and induced (system-wide) impacts associated with exposure to climate hazards. Doing so allows for the evaluation of climate resilience reserves, to be added to other reserves that are standard inclusions in what planners refer to as a system reserve margin. Associated with maintaining and paying for that, the market structures overseeing the power system will need to be adjusted accordingly. However, as noted in the case study presented above, the cost of the climate resilience reserve is far lower than the cost of inaction.

This note is of an incremental nature: it seeks to inform how to incorporate climate-related uncertainties and the assessment of resilience over existing project evaluation methodologies. Only the fundamentals of economic, climate, and biophysical modeling, as well as of decision-making under uncertainty are covered in this note, and extensive references to external resources are provided to those seeking further detail. The note does not address other uncertainties in project performance such as demographic changes, political and policy environment, or macroeconomic factors. However, although the principles presented in this note can be extended to other uncertainties, specific guidance on these is preferable.

The framework presented in this note will always benefit from further refinement through widespread application in Sub-Saharan Africa, for a wide range of geographies, socio-economic, and climatic conditions. As conditions in the region change, and climate knowledge advances become more accessible, periodic updating of this note will ensure that users continue to be provided with the best guidance possible for enhancing the climate resilience of much-needed infrastructure investments in the region.

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GUIDANCE NOTE:

Enhancing the Climate Resilience of Water Infrastructure Projects in Sub-Saharan Africa

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Acronyms

AFRI-RES	Africa Climate Resilient Investment Facility
GCM	General Circulation Model (or Global Climate Model)
IPCC	Intergovernmental Panel on Climate Change
SWAT	Soil Water Assessment Tool
WEAP	Water Environment Assessment Planning model

5.1. Introduction and Background

5.1.1. Problem Statement

Sub-Saharan Africa's hydroclimatology is marked by strong seasonality in precipitation and consequently strong seasonality in river discharge. This means that water dependent sectors, most notably agriculture but also domestic and industrial water supply, face periods of excess water and periods of water scarcity as a normal course of the calendar year, which in turn influences the quality of available water supplies. While mankind and ecosystems have long adapted to these ebbs and flows, modern industrialized society expects reliability in water supplies throughout the year. This has been largely achieved through infrastructure and water management institutions, both of which are deficient in Sub-Saharan Africa. **These deficiencies leave water-dependent sectors vulnerable to not just seasonal variability in water resources, but also the occurrence of anomalous drought and flood conditions.**

> Climate change is likely to exacerbate existing challenges as well as potentially introduce new ones.

Although there is much focus on the state of water infrastructure in Sub-Saharan Africa, **water management institutions are arguably of equal or greater importance** despite the difficulty of quantifying the current degree of institutional deficit. Water institutions in Sub-Saharan Africa must grapple with intra-national challenges, especially urban versus rural water uses, low rates of water treatment and sanitation, and tribal conflict. In addition, in many cases, international water challenges are also prominent due to the large number of transboundary rivers in Sub-Saharan Africa (see **Figure 5.1** below). Water institutions set the policies for water sharing and water allocation and conduct the strategic planning that underpins wise infrastructure investment. However, in many cases water infrastructure is prioritized based on political goals rather than rigorous economic and environmental analysis. Indeed, **a distinct asset of Sub-Saharan Africa relative to many industrialized countries is the well-preserved state of natural infrastructure**

(including wetlands) that can mitigate the variability in precipitation characteristic of the region and contribute to improved water quality. Without strong institutions and political will, the current bounty of natural infrastructure may deteriorate and leave Sub-Saharan Africa further behind in its ability to manage both existing and emerging water challenges.

The anticipated effects of climate change must be viewed through the lens of the current state of water management in Sub-Saharan Africa as described above. **Climate change is likely to exacerbate existing challenges as well as potentially introduce new ones. On the other hand, it cannot be ruled out that in some cases climate change may ameliorate water scarcity.** The scientific consensus, as encapsulated in the most recent generation of General Circulation Model (GCM) projections of the Intergovernmental Panel on Climate Change (IPCC), shows increases in global temperatures of 1 to 2 degrees Celsius over the next 50 years. Precipitation projections exhibit greater variability, with the projections for most parts of the continent largely overlapping with the historical range of precipitation. **Predicting how climate variability might change in the future is the critical question from a water management perspective but is also the most challenging aspect of climate change to predict.** In short, it remains true that we know the least about the elements of climate that we need the most for water planning (Hirsch 2011).

Figure 5.1. **Transboundary River Basins of Africa**

Source: Babel et al. 2012.

As such, the future state of water resources in Sub-Saharan Africa is much more dependent on the state of infrastructure, both natural and built, and institutions than the effects of climate change. **Climate change is real and cannot be overlooked but it should not serve as an impediment to water investment in Sub-Saharan Africa but rather as motivation to invest in smart, resilient systems,** where resilience is *the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner* (Intergovernmental Panel on Climate Change 2012). Priorities include strategic investment in preserving natural infrastructure, selected investment in built infrastructure, building capacity in water management agencies, strengthening institutions (including those in sectors that utilize or influence water, such as agriculture, environment, energy and industry), and developing appropriate systems for managing the variability and surprise that the climate inevitably delivers. In particular, improvements in short term forecasting and early warning systems, and equally important, in the systems that can take action based on forecasts, are low regrets opportunities. Against this backdrop, this document presents a guidance note that offers practical suggestions for developing climate-resilient water infrastructure projects in the Sub-Saharan African context.

5.1.2. Objectives and Scope of This Guidance Note

Funded through the Africa Climate Resilient Investment Facility (AFRI-RES), this document provides guidance on enhancing the climate resilience of water infrastructure investment projects in Sub-Saharan Africa5. It is pedagogically oriented and draws on extensive experience and robust research and analytical methods. This guidance note provides **a framework for evaluating infrastructure project assets to ensure they meet project objectives in spite of possible future climate impacts.** As a result, this note is primarily relevant for climate adaptation, with climate mitigation benefits only considered if they are an explicit objective of the project being considered. The focus of this note is on guidance, serving neither as a comprehensive technical text nor an exhaustive policy handbook, but as brief direction on the most important principles to take into account when seeking to enhance the climate resilience of infrastructure projects in the face of future climate uncertainty. (While the note focuses on uncertainty as it relates to future climate conditions, the principles presented here could be extended to include other sources of uncertainty such as demographic changes, the political and policy environment, and macroeconomic factors.) In addition, this note focuses on enhancing the resilience of projects that have been at least roughly scoped in terms of their location and the type of investment to be made, being less relevant for very early-stage projects where the location and type of project are as of yet unknown.

These notes build on a range of existing resources produced by the World Bank and others, notably including the Resilience Rating System (World Bank Group 2021) and the disaster and climate risk stress test methodology (Hallegatte et al. 2021). In addition, this note internalizes many of the sector-specific methods developed by the Water Global Practice at the World Bank over the course of the last decade, including: The Decision Tree Framework (Ray and Brown 2015), which serves as a decision support tool to assist project planning under climate uncertainty; A Road Map for Building the Resilience of Water Supply and Sanitation Utilities to Climate Change and Other Threats (Bonzanigo et al. 2018), which provides guidance on incorporating climate risks in the design, planning and operations of water supply and sanitation utilities; the Resilient Water Infrastructure Design Brief (World Bank 2020), which describes a process to enhance the resilience of water and sanitation infrastructure against floods, droughts, and high winds. Finally, the framework presented in these notes also complements new guidance developed by the World Bank to ensure that future Bank investment projects are in alignment with both the climate mitigation targets set out in the Paris Agreement (United Nations 2015) as well as the country's adaptation goals.

The Resilience Rating System mentioned above distinguishes between two dimensions of resilience, namely **resilience of** the project and **through** the project (World Bank 2021):

- **Resilience of** the project is the extent to which a project's assets have considered climate and disaster risk in their design e.g., a hydropower plant with turbines that operate over a wider range of water levels to account for increasing inflow variability in the future.

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5 A partnership with the African Union, United Nations Economic Commission of Africa, Nordic Development Fund, African Development Bank, and the World Bank. This note is part of a series of guidance and technical notes funded by AFRI-RES that focus on climate resilient investment in Sub-Saharan Africa.

- **Resilience through** project outcomes reflects whether a project's objective is to enhance the target sector and beneficiaries' climate resilience through its interventions (e.g., a water harvesting project aimed at improving water security for a village).

The scope of this note is focused on the **resilience of** projects, including the resilience of direct project outputs. While many investments in water systems can enhance both the resilience of and through projects, **the framework presented in this note focuses on the resilience of particular investment projects** and not on how those investments enhance the resilience of a community or sector that benefits from it.

While **the focus of this note is on the project design level,** it remains **crucial to understand the particular policy, regulatory, and institutional context in which the project is situated.** Hence, all project design decisions should be taken with both the policy landscape and local capacity in mind, acting as either enablers or barriers for implementation. This note is part of a larger Compendium Volume, with these cross-cutting issues discussed in Chapter 2 of the Compendium Volume. Chapter 1 of the Compendium provides a general introduction, with the remainder of the Compendium broken down into two parts: Part 1 houses sector-specific guidance notes (including this one), while Part 2 provides a series of more detailed technical notes.

The scope of this note covers development in the water sector at large, with the sector categorized into the following sub-systems, all of which interact with and influence each other:

- **Agricultural water management:** This includes systems for irrigation and drainage, new water supply sources (surface or groundwater), improvements to irrigation systems (e.g., lining of canals, field leveling), advanced irrigation technology (e.g., drip, center pivot), watershed management measures, water conservation measures, monitoring systems to track irrigation flows and water quality, monitoring of groundwater levels and well water quality, and development of water infrastructure for livestock.

> The focus of this note is on guidance, serving neither as a comprehensive technical text nor an exhaustive policy handbook, but as brief direction on the most important principles to take into account when seeking to enhance the climate resilience of infrastructure projects in the face of future climate uncertainty.

- **Hydropower:** Investments in hydroelectricity production include single use run-of-the-river facilities and multi-use storage reservoirs with electricity generating facilities as well as water deliveries for other sectors. Key design considerations include the capacity of the generating facilities and capacity of the hydraulic facilities (e.g., penstock). Of particular climate concern is the flood spillways that dams use to safely pass flood flows given that flood volumes may grow in the future.
- **Municipal water supply:** Municipal water supply includes water provided to the inhabitants of towns and cities. Water sources include groundwater and surface water and considerations may include storage and conveyance facilities. Climate change is particularly relevant to questions of capacity and storage requirements, water quality, as well as the future demand for water.
- **Wastewater treatment:** Facilities that treat wastewater from municipal water supply are sensitive to the volume and composition of wastewater expected, which is in turn influenced by precipitation. In addition, wastewater treatment facilities typically include biological treatment processes where microorganisms consume waste constituents and these processes are sensitive to temperature.
- **Stormwater and flood protection:** Excess water is typically categorized into stormwater flooding (due to localized extreme precipitation), flash flooding in urban settings, and riverine flooding based on excess flows in rivers. Design of stormwater management facilities is typically based on assumptions of precipitation events (design storms) while flood protection is design on river discharge assumptions (design floods).

The impacts of a changing climate on water for the environment, green infrastructure, and nature-based solutions are discussed in a separate guidance note focused on enhancing the resilience of ecosystem projects in Sub-Saharan Africa, also included within this Compendium Volume.

The note is not specific nor prescriptive regarding particular uses or sources of water, but rather presents principles that can be applied to the evaluation of infrastructure investment projects of any kind. Improved adaption to climate change will depend on comprehensive and inclusive policies and strategies that are inter-sectoral, underpinned by a unified framework such as the one presented in this note that allows meaningful coordination and provides adequate climate information services.

5.1.3. Target Audience

There are three primary audiences for this guidance note:

- **Practitioners.** The note will help practitioners develop their staff and internal expertise to perform the necessary climate vulnerability and adaptation analyses.
- **Government Staff and Basin Office Staff.** The note will give staff from all levels of government (national, provincial and local) as well as staff at river and lake basin offices understanding of the steps involved in evaluating and enhancing the resilience of a proposed project, how to be prepared for creative and alternative investment packages, and how to draft Terms of Reference for practitioners to develop climate resilient projects.
- **Donors and Development Banks.** The note will help donors and development banks provide clear direction and guidance to consultants for how to make project designs more resilient to climate change.

Each of these three target audiences differ considerably in their technical focus, operational roles, and objectives. Typical investment projects will see this note used both as high-level guidance by donors and banks, as well as more detailed technical guidance for use within client countries. This note was developed to be accessible to these different audiences, with the general framework presented here supplemented by further detail in the technical notes included in Part 2 of the Compendium Volume.

> Typical investment projects will see this note used both as high-level guidance by donors and banks, as well as more detailed technical guidance for use within client countries.

5.1.4. When to Use This Note

While each of these target audiences will use the note in slightly different ways, within the overall project development process, this guidance note is intended to be used anywhere from the project's **conception** and **planning** stages, as well as during post-project completion **monitoring** (see the orange components of **Figure 5.2**). It is anticipated that in most cases, project teams will utilize this guidance note during the scoping, early design, and final design stages of the project planning process. That said, the earlier in the project lifecycle that climate resilience considerations (as described in this guidance note) are incorporated, the greater the scope and opportunity to improve the performance of the project given climate uncertainty. Furthermore, while not the focus of this note, attention should be paid throughout the project planning process to the policy and institutional landscape, as well as the role of policy shifts and improved local capacity in building resilience.

Figure 5.2. **Applicability of This Guidance Note During a Typical Project Life Cycle**

5.1.5. Structure of and Roadmap to Using This Note

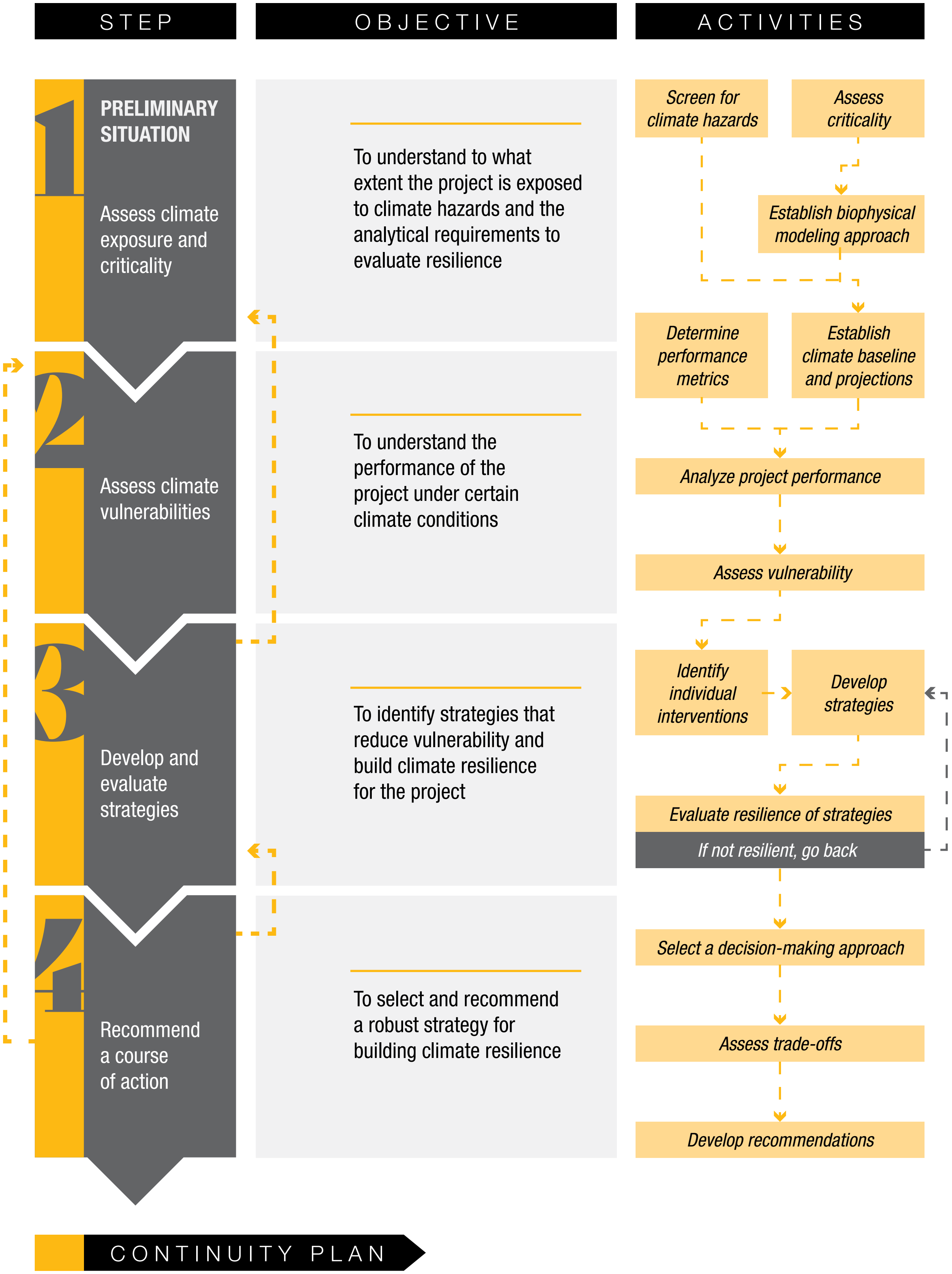
The remainder of this document is structured as follows: Section 5.2 describes a step-by-step framework used to enhance the resilience of projects in the water sector to climate hazards. This section is subdivided into four steps, each containing different activities to carry out the analysis. Rigorously completing each activity requires a non-trivial amount of resources in terms of time, data, and analytical know-how. Where these resources are not available, completion of a more rapid qualitative assessment is still useful to undertake in order to provide a high-level understanding of the situation, but such high-level insights alone should not form the basis for recommendations. A case study is provided to illustrate the framework and is intended to be consulted by all users of the note. Lastly, Section 5.3 offers brief concluding remarks.

Finally, while the focus of this note is specifically on water-focused infrastructure investments, many projects include cross-sectoral components and depending on the different investment components included in a project, several of the individual guidance notes beyond this one may need to be consulted. When using this note, **project leads should look beyond their particular project to consider both the broader system as well as any possible inter-system effects in their evaluation process.** For instance, those involved in a proposed hydropower plant that supplies energy to irrigation operations would benefit from also consulting the energy and agricultural notes; a team working on an urban water supply project should consider also consulting the cities note; and efforts to reduce flooding impacts should additionally review the ecosystems note, with all these notes included in the Compendium Volume.

5.2. A Framework For Enhancing the Climate Resilience of Water Infrastructure Projects in Sub-Saharan Africa

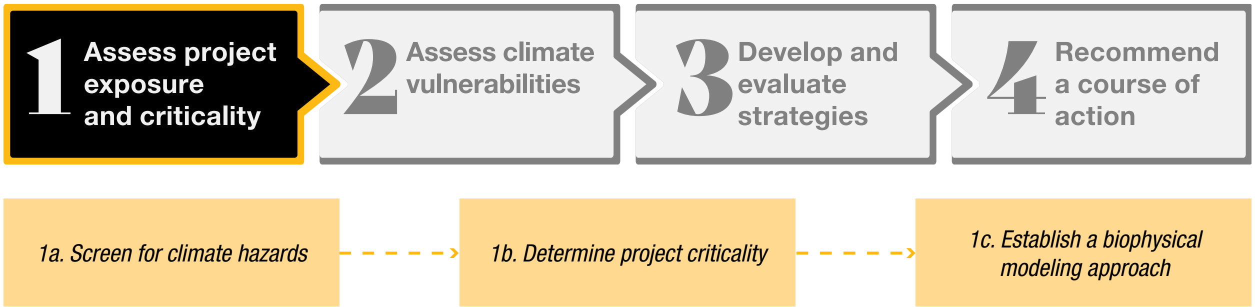
The guidance for developing climate-resilient investments presented in this note builds on a broadly applicable, multi-step framework, summarized in **Figure 5.3.** The framework consists of a series of four steps, each explained in further detail below, with many of the steps linked through important feedback loops. As noted in Chapter 2 of the Compendium Volume, the framework is founded on an initial assessment of the preliminary situation, which examines the **institutional and project context** (including the existence of country-level development plans, support from relevant ministries, and the state of weather and climate change monitoring capabilities) as well as identifies **relevant stakeholders** (including community groups, beneficiaries, technical experts, policymakers, and non-governmental organizations).

Figure 5.3. Framework for Enhancing the Climate Resilience of Investment Projects



STEP	OBJECTIVE	ACTIVITIES
1 **PRELIMINARY SITUATION** Assess climate exposure and criticality	To understand to what extent the project is exposed to climate hazards and the analytical requirements to evaluate resilience	*Screen for climate hazards* *Assess criticality* *Establish biophysical modeling approach* *Determine performance metrics* *Establish climate baseline and projections*
2 Assess climate vulnerabilities	To understand the performance of the project under certain climate conditions	*Analyze project performance* *Assess vulnerability*
3 Develop and evaluate strategies	To identify strategies that reduce vulnerability and build climate resilience for the project	*Identify individual interventions* *Develop strategies* *Evaluate resilience of strategies* *If not resilient, go back*
4 Recommend a course of action	To select and recommend a robust strategy for building climate resilience	*Select a decision-making approach* *Assess trade-offs* *Develop recommendations*

5.2.1. Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality



Objective: The purpose of the first step is twofold. One, the process evaluates whether the project is exposed to any climate hazards, both now and over the course of the project's expected lifespan. And two, the process seeks to determine the level of complexity required for the analysis based on the project criticality.

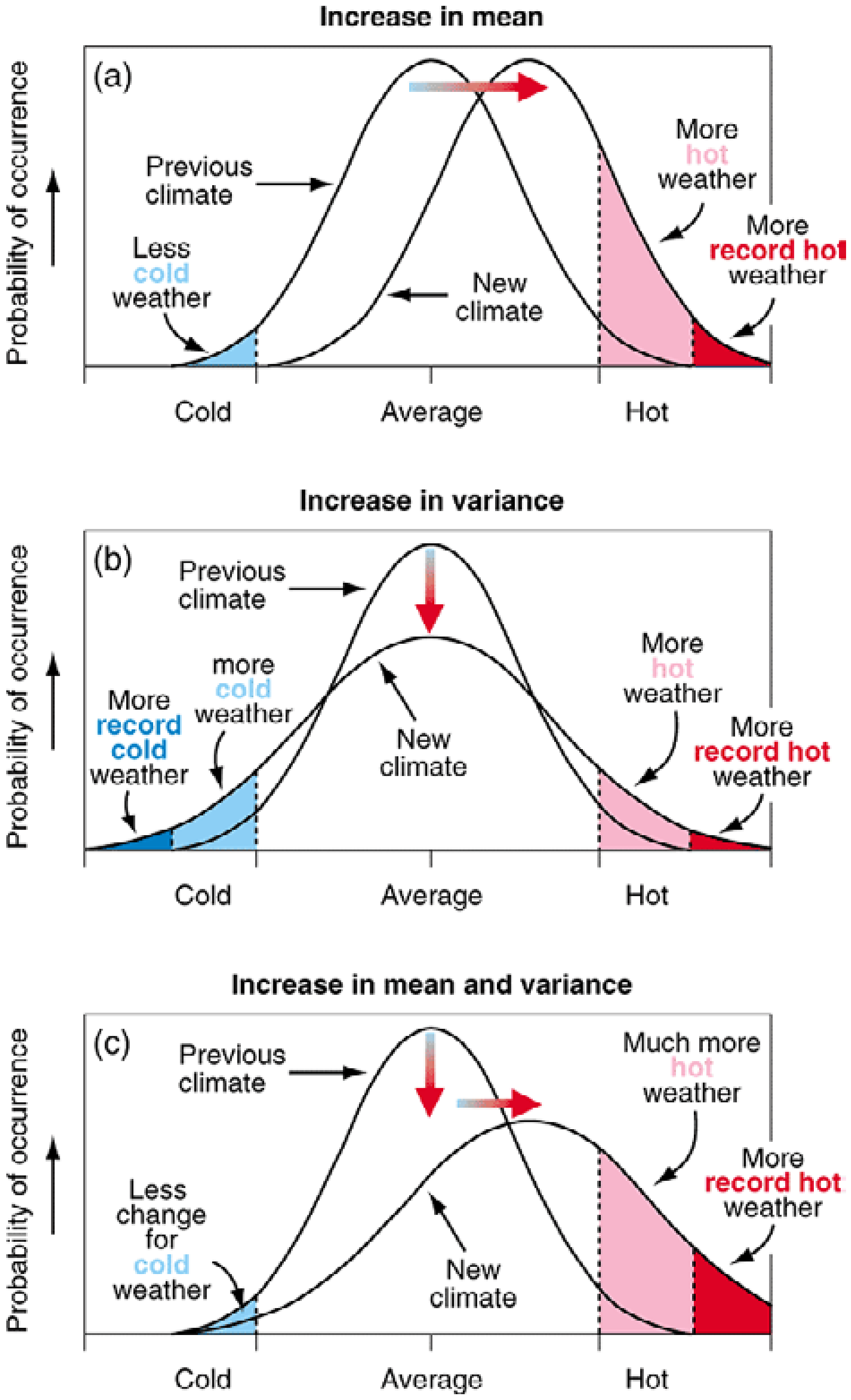
Activity 1a. Screening for climate hazards. A climate hazard is any climate-driven event that may result in damage and loss to the project. These can be a product of:

- **Extreme weather events:** low-probability but high-impact climatic phenomena (such as floods, droughts, or heat waves), as well as more frequent, lower-intensity events which can also cause significant impacts
- **Long-term changes to normal climate conditions:** changes relative to the historic baseline

As **Figure 5.4** shows, taken together, climate change can impact both the mean conditions to which a project will be exposed (e.g., higher temperature on average in the future), as well as the frequency and intensity of extreme weather events (e.g., more record hot weather). Exposure to climate hazards refers to whether the hazard is present at the project's location, either because of natural conditions or the absence of protective systems. When considering future exposure over the course of the project's useful lifespan, understanding the uncertain nature of future climate hazards is essential for evaluating the climate resilience of a project.

Screening for climate hazards will help the project team identify the types of hazards that threaten the performance of the project, given the project's location and expected useful lifespan. Typical climate variables to consider for water resource projects are temperature, precipitation, and evapotranspiration. These variables can constitute a hazard when their magnitude and/or duration affect the performance of the project. **Textbox 5.1** summarizes key climate hazards for the water sector in Sub-Saharan Africa.

Figure 5.4. Illustration of Climate Change Impacts



Source: Intergovernmental Panel on Climate Change (2001).

Textbox 5.1: Key Climate Hazards That Impact Water Resources in Sub-Saharan Africa

Temperature: higher temperatures of intake water affect the performance of water and wastewater treatment processes. Higher water temperatures can also increase the solubility and thus toxicity of certain compounds as well as promote algal blooms, both of which require additional water treatment. Further, temperature increases or decreases can result in increases in energy requirements for cooling or heating respectively, which influences hydropower production and may have implications for other downstream water users.

Precipitation: warmer air can hold more water vapor, resulting in an increased frequency of heavy rainfall events. This can lead to flooding of communities and infrastructure, as well as increased soil erosion. While projections differ on whether regions will become wetter or dryer, the seasonality of precipitation is, however, likely to change.

Drought: extended dry spells make the soil dry out and when rainfall does occur, much of the water runs off the hard ground into rivers and streams, exacerbating flood peaks. Droughts will influence water availability for all users, including municipal water use, agriculture, hydropower, industry and the environment.

Flooding and storms: can cause loss of life, harm to property, increase soil erosion, and damage existing water resources infrastructure. Strong winds can increase evapotranspiration and exacerbate drought conditions.

Sea level rise: can flood existing water supply and treatment infrastructure and overwhelm flood protection systems such as levees and sea walls.

> Typically, short-lived investments primarily consist of water-related equipment, such as groundwater pumps or hydrometeorological instruments.

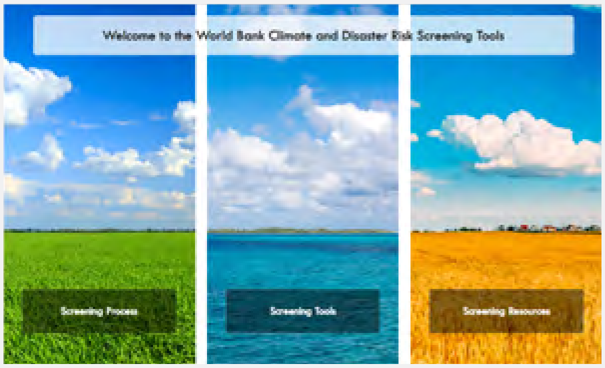
To screen the various climate hazards for a given location, the frequency and severity of historic events are first analyzed. However, it is important to consider the future exposure over the course of the project's useful lifespan. Generally, projects with a short useful lifespan may only need to focus on the impact of extreme weather events consistent with those experienced historically. In contrast, projects with longer lifespans should carefully inspect whether the project is exposed to new hazards and the increased frequency and severity of existing ones. Typically, short-lived investments primarily consist of water-related equipment, such as groundwater pumps or hydrometeorological instruments. In contrast, most water-related infrastructure (e.g., reservoirs, hydropower facilities, water supply and sanitation systems, etc.) have long lifespans and would therefore warrant a careful inspection of climate change effects. Given the significant degree of

uncertainty about future climate conditions, it is recommended to consider the broadest possible range of climate hazards, including those considered less likely, rating the severity of each threat to identify those most relevant for the project.

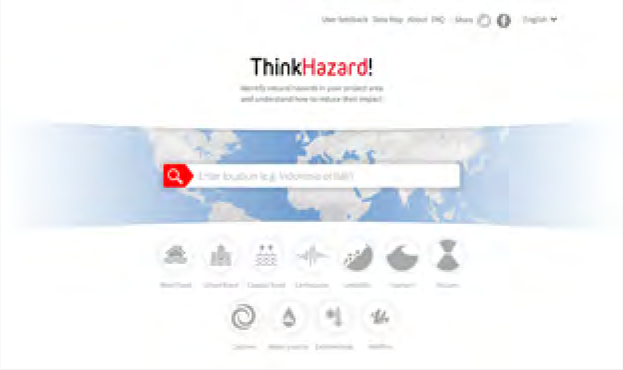
Various tools exist that can be used to screen a project's exposure to climate hazards; **Textbox 5.2** shows a selection of tools that could be used. Note that the individual outputs from these different tools may not be directly comparable to each other due to differences in the design of the tool and the assumptions it makes. In addition, these tools are not designed for detailed asset-level risk analysis but rather offer broad insights about the hazards present at the location of a proposed project. Subject-matter experts and local stakeholders should further supplement the climate risk screening results from these tools, as a mechanism to both validate the identified threats and reduce the risk of omitting relevant hazards.

Textbox 5.2: Climate Hazard Exposure Screening Tools

Climate and Disaster Risk Screening Tool **(World Bank).** This tool provides a guided method to identify climate hazards and levels of risk to project evaluators at an early stage in the project design process. It focuses on physical and non-physical components of the project, and ranks the threat between low to high, including a no risk and insufficient understanding category. It has a “rapid” (about 30 min) and “in-depth” (about 2 hours) version for multiple sectors, the latter being highly recommended unless the evaluator is familiar with climate science and the project context. The tool relies on the World Bank’s Climate Change Knowledge Portal, which is a web tool that provides processed and synthetized historical and projected climate information from the Intergovernmental Panel on Climate Change. The tool considers extreme temperatures, extreme precipitation, flooding, drought, winds, sea level rise, and storm surge. Users would ideally be in possession of a project concept or design, as well as subject matter expertise for the country and project context. In terms of strengths, the tool guides the user on how to perform the screening and how to use data from other tools. It provides an assessment that includes the hazards at the project location as well as the potential impacts on the project’s infrastructure and service delivery, as well as how institutional and contextual factors interact with hazards and the project’s physical components.

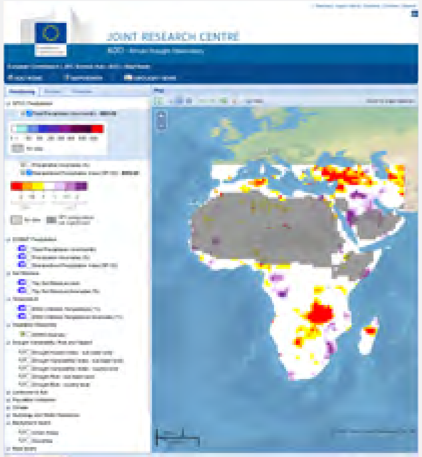


ThinkHazard! **(Global Facility for Disaster Reduction and Recovery).** A web tool that provides a general assessment of climate hazards at a sub-national scale. The tool covers 12 different hazards including flooding (river, urban, and coastal), extreme heat, water scarcity, and cyclones. The tool presents a qualitative assessment of the level of a particular threat (i.e., low to high) both now and in the future given potential impacts of climate change, describing general impacts of the hazard along with generic recommendations for planning and evaluation. The tool also includes additional local and/or regional online resources when available. All that is required to run the tool is a general project location. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining a list of the relevant hazards to consider in a particular area, without requiring project specific information. It can help place climate hazards in context with other non-climate threats.



Textbox 5.2 (continued): Climate Hazard Exposure Screening Tools

African Drought Observatory **(European Commission Joint Research Centre).** A web map service to identify potential drought hazard and risk levels in Africa. It offers access to recent drought monitoring data, as well as probabilistic forecasts for near term precipitation. A general project location is required to run the tool. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining an overview of historic climate hazards to consider in a particular area, without requiring project specific information.



Aqueduct Water Risk Atlas **(World Resources Institute).** A global web map service that provides an assessment of coastal and riverine flood risks. The tool allows the customization of water hazards by time horizon, climate scenario and projection model, and return period. A general project location is required to run the tool. In terms of strengths, it easily allows users to explore how water risks change under different future climate scenarios.

Textbox 5.2 (continued): Climate Hazard Exposure Screening Tools

Additional non-web-based tools that could be consulted include:

The CRiSTAL **(International Institute for Sustainable Development).** A project planning tool for identifying climate risks and design components to enhance resilience. It incorporates stakeholder consultation and expert interviews, as well as guidance notes for internal evaluation developed by the African and Asian Development Banks. The tool includes an initial screening step that can be used to understand the potential impacts of climate hazards on the project and local livelihoods in the area. It expands beyond a cursory screening tool, offering guidance for project design and evaluation through a participatory process. A project concept or design is necessary in order to run the tool. In terms of strengths, it guides the user to perform a screening following a questionnaire and provides a community-based perspective of the project, as opposed to the perspective of funders only. It additionally puts climate hazards in context with social, political, and cultural conditions and provides a framework for incorporating local and expert knowledge through consultation.

Finally, when it comes to water-focused investments, a **Hydro-Climatic Stress Testing tool** is currently being developed by the World Bank and will be forthcoming in 2023. When complete, this tool will contribute to more resilience-informed project design. It will go beyond simply screening for climate hazards, combining a global hydrological model with a weather generator that together will allow users to stress test key project variables to better understand vulnerabilities and performance thresholds.

Activity 1b: Determine the project criticality to establish the appropriate level of effort required to assess project resilience. Evaluating the impacts of the climate hazards identified to be relevant to the project can be complex, data-intensive, and expensive. However, not every project requires the same level of analytical complexity, and to ensure the framework is practical and accessible, projects are classified into two tiers. A low tier method is less data-intensive and simpler than a high tier method, which is generally treated as being able to more accurately model the project's response to climate hazards. For example, an integrated watershed management program will likely be considered a low tier investment, whereas a new scheme to supply and deliver water for irrigation is a high tier investment. Distinct components within a large project that require separate analysis or modeling could be analyzed separately and may be classified into different tiers.

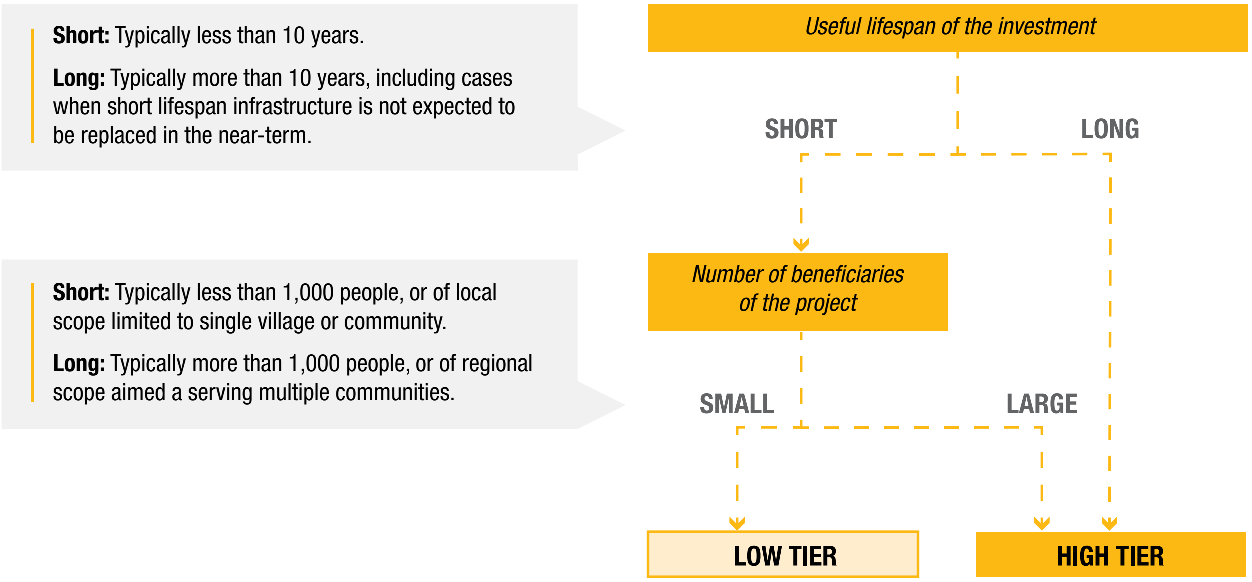
Resilience Spotlight: Bringing Green and Grey Together in the City of Beira, Mozambique

Mozambique is the third-most climate-hazard exposed country in Africa. It is at high risk of impacts from not just floods and droughts, but also cyclones. The coastal city of Beira is plagued by recurrent flooding due to coastal storms, made worse by poorly planned settlements and inadequate housing. Over the course of the last decade, the city has implemented a number of different measures to improve the flood resilience of the area, as documented by the city's resilience master plan. Through the Cities and Climate Change Project, the World Bank and its development partners have financed a number of these investments including **improvements to grey infrastructure such as drainage systems, as well as green nature-based solutions focused on restoring the Chiveve River's capacity to mitigate floods.** Restoration of the Chiveve has seen the formerly polluted river and riverbanks transformed into a green urban park that provides recreational spaces in addition to retaining and absorbing floodwaters. **The climate resilience of these investments in the Chiveve were safeguarded by conducting ongoing community rehabilitation of its degraded mangroves and native flora.** By investing in green and grey interventions together, the objective was to enhance climate resilience while simultaneously improving the quality of life for the inhabitants of Beira.

While the focus of this guidance note is on the project design level, it is crucial to understand the development setting in which the project is situated. All project design decisions should be mindful of local conditions, including the policy landscape, as well as technical and institutional capacity (see Compendium Volume Chapter 2 for a discussion of these kinds of cross-cutting factors that can enable or hinder a project). Additionally, even though the note is focused on resilience of the project, it is possible that a project may be climate-resilient within the bounds of the study area but may still lower the overall climate-resilience of the basin (i.e., resilience through the project), for instance by lowering downstream environmental flows. As such, some awareness of resilience through the project should help inform critical decisions such as the area to include in the modeling analysis.

The tier of a project can be determined using the sample process shown in **Figure 5.5**, which assesses criticality based on the useful lifespan and number of beneficiaries of the project. **Note that this framework is qualitative and flexible in nature, with Figure 5.5 providing guiding principles** (i.e., project lifespan and number of beneficiaries) and suggested cutoffs to determine short/long lifespan and small/large number of beneficiaries to judge the project under evaluation. However, **project teams and stakeholders should consider a more flexible set of criteria, carefully assessing which guiding principles and cutoff values are appropriate for their particular project and inspecting whether using the selected criteria result in an appropriate level of criticality.** For example, an integrated watershed management program could be considered a high tier project if it significantly impacts priority development outcomes like food security. These examples highlight that context is required to appropriately determine the criticality of a project.

Figure 5.5. **Sample Tier Determination Process**



Short: Typically less than 10 years.

Long: Typically more than 10 years, including cases when short lifespan infrastructure is not expected to be replaced in the near-term.

Short: Typically less than 1,000 people, or of local scope limited to single village or community.

Long: Typically more than 1,000 people, or of regional scope aimed a serving multiple communities.

Activity 1c. Establish a biophysical modeling approach based on the project tier. The results of the tier determination process serve as the basis for establishing a biophysical modeling approach that simulates the physical behavior of the project under different climatic conditions (e.g., translating changes in future precipitation to altered water supply reliability). These models (i.e., simplified, conceptual, mathematical representations of a system) require climate variables as inputs and produce outputs of interest that are later used for the socio-economic evaluation. The kind of climate and other input variables required will vary based on the biophysical modeling approach selected.

There is a myriad of models that could be used for the water sector and a summary of some typical water resources models is provided in this report by the United Nations Framework Convention on Climate Change (2008). Selecting a model for a particular analysis always depends on the specifics of the project. For example, the Soil Water Assessment Tool (SWAT) developed by the United States Department of Agriculture has been widely used for hydrologic analysis and soil erosion studies. The Water Environment Assessment Planning (WEAP) model is an integrated model that incorporates hydrology, urban water demand, agricultural growth and infrastructure. Models should be determined based on their capacity to inform and improve the design of the project, particularly from changes in climate inputs. Figure 5.6 below provides guidance for the selection of a tier-specific modeling approach to be utilized for biophysical evaluation of the project, with Table 5.1 presenting further detail on these models. Many of these models are interconnected, with some outputs becoming inputs for another model, and different assessments can require the linking of different individual tools. For instance, a system's hydrology could be modeled using SWAT, and then those outputs would be used in WEAP to simulate infrastructure performance and storage yields. Moreover, additional non-water specific models may be needed to complete the evaluation. For example, a hydropower analysis may require additional tools to model energy generation and demand, while flooding would require an approach to translate flood peaks into economic damages.

Figure 5.6. Possible Modeling Approaches by tier

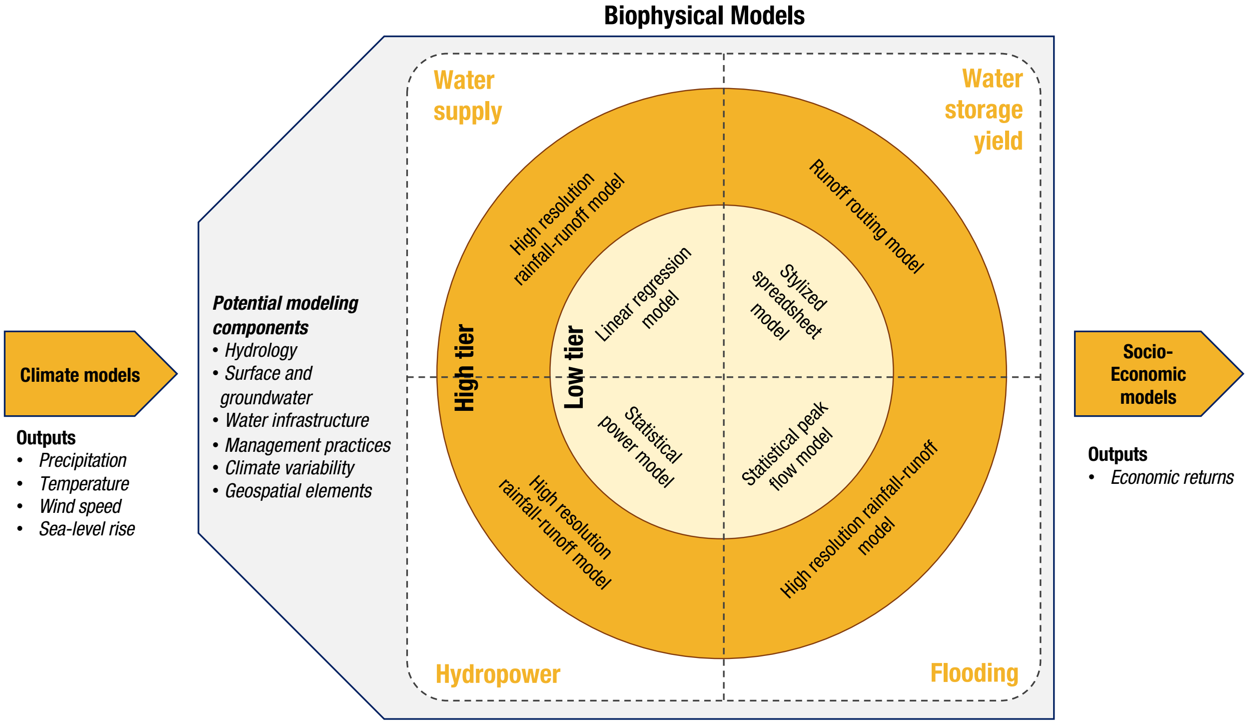


Table 5.1. Examples of different types of models suitable for EACH TIER

Models	Low tier	High tier
Water supply	Log linear regression model of annual water availability as a function of basin area, temperature and precipitation	Calibrated daily or monthly rainfall-runoff model; spatially explicit land use model evaluating erosion and water quality effects; explicit representation of climate variability
Hydropower	Statistical relationship between annual temperature and precipitation, and firm power yield	
Flooding	Statistical modeling based on peak annual flow	
Water storage yield	Stylized excel-based approach such as the sequent peak algorithm	A water systems model that routes runoff through a network of reservoirs and water demands; explicit representation of climate variability

When selecting a modeling approach, it is not just important that the model relates climate variables to outcomes of interest, but also to consider which individual climate variables the model is sensitive, as well as possible interaction effects among multiple variables. External inputs, such as river basin characteristics or water demand information, may have increasing levels of detail for higher tiers. Furthermore, it is important to consider whether system-wide modeling is necessary to understand the risks to or benefits from a project, and in these cases, system-wide modeling would need to be undertaken. **Ultimately, model selection should be conducted considering the scope, functionality, availability and processing capacity of a particular model, experience utilizing it,**

knowledge of its caveats and limitations, and data availability. That said, where existing models and analytical tools already exist for a project that are more analytically rigorous and detailed than the identified tier level, these existing tools should be preferentially used.

Finally, a particular challenge when conducting modeling for projects located in Sub-Saharan Africa is the limited data available for the region, with many existing data time series either covering a limited period of time or incomplete. The World Bank's Water Data website and Spatial Agent Data Portal offer convenient access to a multitude of existing datasets that may be required when modeling water resources projects. In addition, there has been significant emphasis in recent years on the use of earth observation methods such as remote sensing to provide the information needed to address key water challenges, with these methods particularly useful for poorly gauged river basins (see for instance Garcia et al. (2016) for further details on the use of remote sensing data for water management).

Resilience Spotlight: Enhancing the Climate Resilience of the Mwache Multi-purpose Dam Project in Kenya

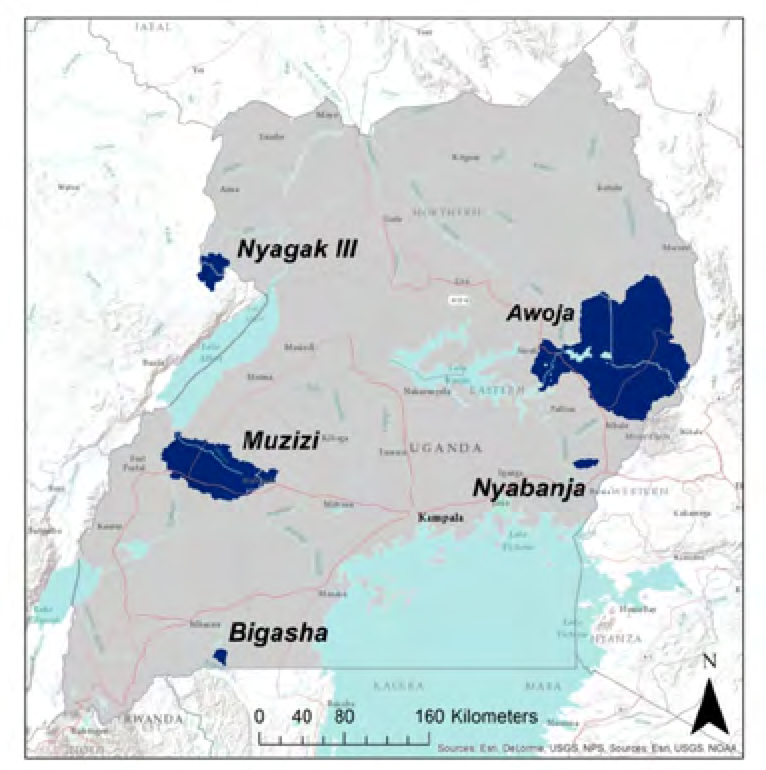
The Mwache Dam water resources development project, located in the Coastal Province of Kenya, is designed to provide 220,000 cubic meters per day for domestic water use in the greater Mombasa area as well as for irrigation of around 2,000 hectares of agricultural land in Kwale County. This project is expected to significantly reduce existing water deficits in the region, with current deficits as high as 60 percent of the total demand.

Several studies have been conducted to assess the risks to the current Mwache Dam design due to climatic change (see for instance, Taner, et al. 2019). In terms of enhancing the climate resilience of the project, possible adaptation options could include **increasing the design volume of the reservoir, or implementing a comprehensive sediment management plan to help maintain long-term reservoir storage.**

Outcome: At the end of this step, the project team should have acquired a high-level understanding of the climate hazards the project is exposed to as well as the analytical requirements to adequately conduct a climate impact assessment of the project. Depending on the identified tier, an appropriate modeling approach should be established in consultation with modeling experts. Where a project is composed of separate investment components that are exposed to a different set of hazards, all the activities in Step 1 should be completed for each individual project component in turn.

> Depending on the identified tier, an appropriate modeling approach should be established in consultation with modeling experts.

Case Study Demonstration of Step 1: Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda



Map showing the location of the Awoja Catchment (Source: Industrial Economics, Incorporated 2014)

Background: Over the course of the last decade, Uganda's Ministry of Water and Environment has taken steps to de-centralize water resource management in the country. One component of this has seen the development of catchment management plans at the individual catchment level, with the Awoja catchment of the Kyoga water management zone one of the earliest plans completed. As part of a number of studies completed for the Awoja catchment, different water infrastructure investments, including irrigation and run-of-river hydropower, were evaluated for inclusion in the catchment management plan. The likely effects of climate change on these investments were assessed prior to possible investment.

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

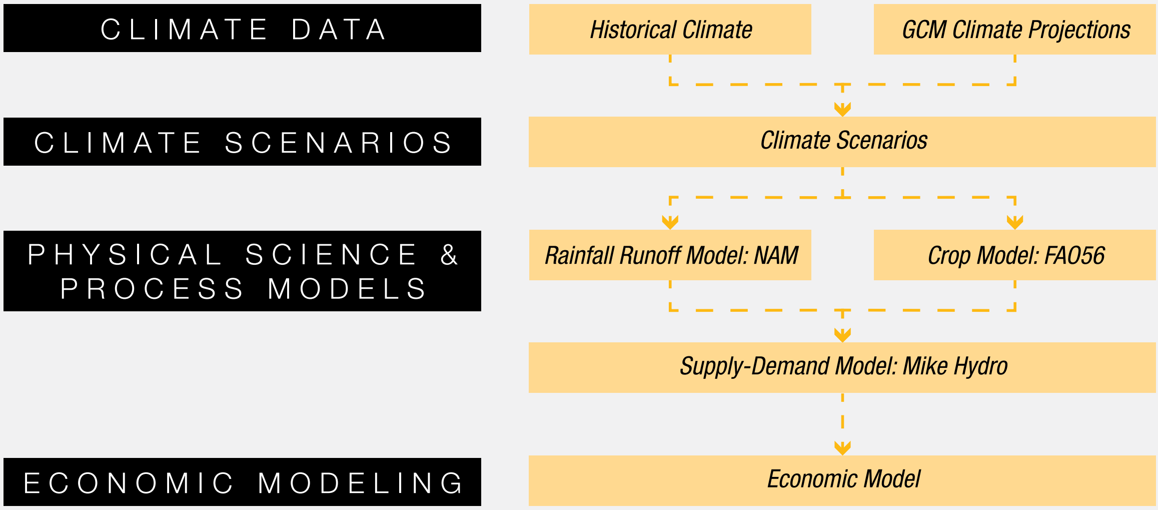
1a. Screen for climate hazards → *1b. Determine project criticality* → *1c. Establish a biophysical modeling approach*

Case Study Demonstration of Step 1 (continued): Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda

Climate hazards: The primary climate hazard for the proposed run-of-river hydropower and irrigation investments in the Awoja catchment is possible changes to the streamflow of the river due to precipitation variability and change. Additionally, temperature increases due to climate change can increase the evapotranspiration of water throughout the river basin and decrease river discharge.

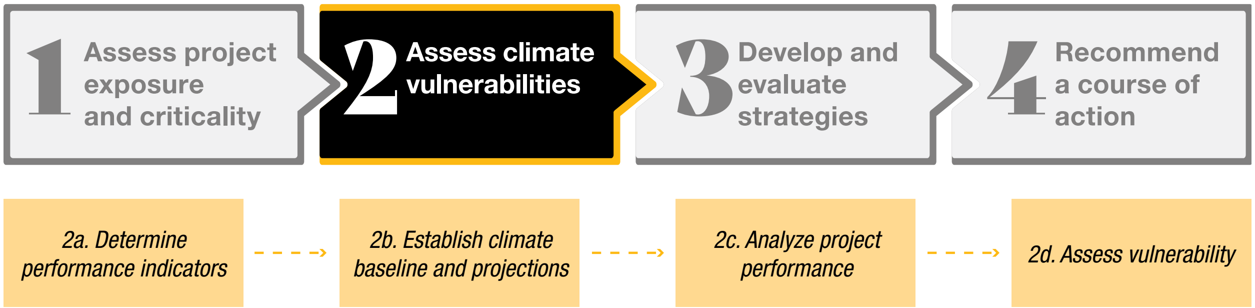
Project criticality: The investment in water infrastructure in the Awoja catchment is classified as a high tier project due to the long lifespans of typical hydropower and irrigation projects. Furthermore, of the more than 700,000 people living in the Awoja catchment, almost all are rural, with more than 80 percent depending on agriculture for their livelihoods. Most of this agriculture is rain-fed subsistence cropping, so these proposed investments play a crucial role in regional development and food security.

Biophysical modelling approach: The impacts of climate change on investments in the Awoja catchment were modeled using the modeling chain shown in the figure below. First, historical climate information and output from Global Circulation Models were fed into a physically-based rainfall-runoff simulation model to produce streamflow runoff estimates, as well as into a crop model to produce irrigation demand estimates. Along with other hydrologic system inputs and non-irrigation sector water demand estimates, the runoff and irrigation water demand estimates were then incorporated into the Mike Hydro model, where water storage, hydropower potential, and water availability were modeled based on their interaction with the temporal and spatial climate and demand characteristics of the river basin. Finally, the Mike Hydro hydropower generation and crop yield results were analyzed for their economic implications for the region.



Flowchart showing modeling sequence (Source: Industrial Economics, Incorporated 2014)

5.2.2. Step 2: Assess the Vulnerability of the Project to the Identified Climate Hazards



Objective: After the project screening and assessment of the necessary analytical complexity, the next step is to **assess the project's vulnerability to climate hazards.** This process seeks to identify how a project performs under extreme climate conditions and, incrementally, under a future with climate change (which can further impact the frequency and intensity of extreme events), as compared to current conditions. This same framework will also be used later to assess the performance of possible adaptation options to build climate resilience. The process involves four different activities, each described below.

Activity 2a. Determine performance indicators and targets to assess the climate vulnerability of the project. On the one hand, these metrics would include the economic return of the project measured as net present value, benefit-cost ratio, or internal rate of return, and minimum acceptable returns or hurdle rates as targets (e.g., a net present value above zero, an economic rate of return above a minimum return). On the other hand, indicators that characterize and assess the success (or failure) of the project and its contribution to key development priorities should be considered. **Textbox 5.3** provides a sample list of possible indicators for water-focused investments – it is important to emphasize that both water quantity and quality can be influenced by climate change, and depending on the project (e.g., a municipal water supply project), performance indicators should include both water quantity- and quality-focused metrics. Depending on their nature, some indicators may be quantitative outputs from the biophysical or socio-economic models, while others may require additional calculation assumptions. For instance, estimating future municipal and industrial water demand requires an assumption on average per capita water use as well as the kinds of industries that may develop in an area. When feasible, performance indicators should incorporate metrics established by the broader policy environment and development strategy, particularly when those address climate resilience already.

Textbox 5.3: Performance Indicators in Water Resources Management

- Water supply reliability
- Proportion of the population served by water and wastewater treatment facilities
- Participation rates by local population
- Water pollution levels
- Human health indicators
- Area flooded
- Flood damages
- Water demand not met
- Price per unit of water supplied
- Increased water availability per capita
- Number of irrigation systems in operation

Whereas typical project evaluation methods consider means and weighted averages as performance metrics, given the large degree of uncertainty associated with future climate conditions, an evaluation of climate resilience should look at a range of expected values across different potential future climate scenarios (for instance, as defined in reports from the IPCC), as well as thresholds that cause a project to fail, in order to identify project designs that perform well across a range of different future conditions.

Activity 2b. Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions. The climate baseline describes the default conditions applicable to the initial design of the project, representing the reference point for the analysis. During later stages in this step, a subset of baseline conditions will be perturbed, and performance between baseline and future conditions will be compared for assessing vulnerability.

Resilience Spotlight: Climate resilience of the sanitation sector in Ilha Josina Machel, Mozambique

Efforts are underway to increase the coverage of drinking water and sanitation in a rural area of the District of Manhiça in Mozambique. The area has seen an increase in intense rainfall events in recent years, resulting in widespread flooding, with the resulting higher water tables leading to an increased risk of contaminated water points, as latrines and other sources of pollution are more likely to infiltrate the ground and mix with the water. In addition, pit latrines become non-functional when filled with water and they may collapse or experience damage during flood events. **A water, sanitation and hygiene project in Ilha Josina Machel has developed specially adapted sanitation solutions to flooding. This includes the design of boreholes and latrines adapted to climate change. A team of technical experts designed a network of elevated latrines which are more resilient than traditional pit latrines to the anticipated impacts of climate change, including an exceptionally high-water table.** Other resilience measures that could have been considered include using special coatings, or building pit latrines with smaller or shallower size of pits to improve their ability to withstand flood events and reduce contamination in the case of collapse (Morshed and Sobhan 2010).

In order to generate a baseline, the project team must first evaluate the availability and quality of historical data (possibly using statistical tools to fill in any data gaps), keeping in mind the expected lifetime of the project. An appropriate time frame for establishing a climate baseline from observed data in the water sector would be 30 years of historic records. In cases with limited data, a baseline of the last 10-20 years could be acceptable, however, the shorter the period used the greater the possibility that the period used is not representative of the long-term climate. Depending on the project, baseline climate data would include historical hydro-meteorological records such as temperature, rainfall, low flows, high flows, and wind speed. The World Bank's Climate Change Knowledge Portal is a good place to start to obtain existing historical data for a particular area or watershed.

When considering investments in the water sector, of special note is the role of natural climate variability. As introduced in Section 5.1.1, precipitation and thus river discharge are strongly seasonal in Sub-Saharan Africa, with the impacts of variability made more pronounced by the relatively limited water storage available. Furthermore, within some parts of Sub-Saharan Africa, the climate manifests low frequency variability due to El Nino Southern Oscillation phenomena and other factors that cause significant periods of anomalous climate as compared to long term means.

As such, for projects with lifespans of approximately 30 years or less, the range of natural climate variability is the dominant concern, over and above the long-term impacts of changes to mean conditions as caused by climate change. For example, an integrated watershed management project may take climate variability as well as any observed trends attributed to climate change into account at the outset, while managing further impacts from climate change adaptively in the medium term. Projects with longer time horizons, however, are subject to greater uncertainty and should consider a wide range of future climate conditions. For instance, a new hydropower project is likely to experience a wide range of climate conditions over its lifespan due to both climate variability and climate change.

There is a great deal of uncertainty about future climate conditions, particularly for long time horizons, which makes the question of which climate futures to consider a non-trivial decision point in the evaluation process. Future climate is uncertain not just because of natural stochastic variability in the climate (i.e., one rainy season can be wetter than another), but also because of uncertainty about how future greenhouse gas emissions will grow, and uncertainty about how the climate system will respond to future emissions levels. One way of exploring these various sources of uncertainty is through the use of different future scenarios or pathways (see the technical note on decision-making under climate uncertainty included in the Compendium Volume for more information on so-called **adaptation pathways**). While tempting to focus in on just one or a few individual climate futures, there are compelling reasons to consider a broader range of possible conditions: a single climate future describes only one possible version of the future, with many other possibilities going unexamined, making it difficult to draw well-substantiated conclusions.

Detailed, quantitative simulations of future climate can be obtained from projections modeled through GCMs. Recent World Bank guidance (2022) focuses specifically on the selection of future climate projections and recommends considering **an optimistic and a pessimistic scenario of greenhouse gas concentrations** as driven by global greenhouse gas emissions trajectories and climate mitigation policies, as well as **several scenarios that represent a "dry and hot" and a "wet and warm" future.** The first set of scenarios allows one to assess the impact of uncertain global climate mitigation efforts on project outcomes, whereas the second set helps assess local climate risks and overall uncertainty in climate model outputs on project outcomes. The latter is important because different models simulate different climate outcomes for the same emissions scenario due to their reliance on different modeling approaches. In addition, as a general rule, an analysis should consider different GCMs in order to capture the range of possibilities predicted by climate scientists. Attention should be paid to the range of future conditions described by these model ensembles (by considering confidence intervals, for example) rather than just their averages. **Textbox 5.4** provides guidance on where to obtain climate projections, with further details presented in the technical note on working with climate projections included in the Compendium Volume.

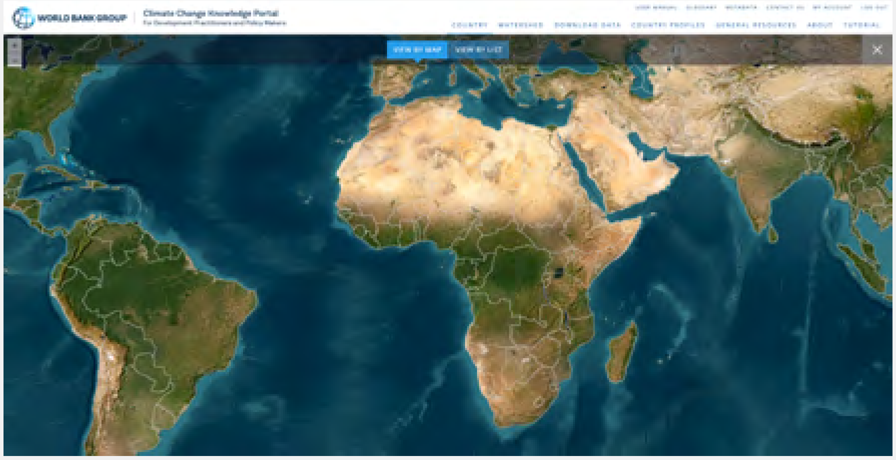
An even more rigorous analysis suitable for high tier projects would include considering the full range of future climate uncertainty (as compared to selecting a number of individual climate scenarios) through stochastic estimations of climate variables from a weather generator. The Decision Tree Framework (Ray and Brown 2015) provides additional guidance on how to use a weather generator in project evaluation. The World Bank's forthcoming **Hydro-Climatic Stress Testing tool** will operationalize such a weather generator, enabling users to stress test key project variables to gain insights about a project's vulnerability to different climate factors.

Finally, through stakeholder consultation and expert advice, the project team should assess the degree of uncertainty suggested by the range of climate scenarios considered, as well as to what extent these uncertainties are tolerable and/or should be mitigated.

Textbox 5.4: Where to Obtain Climate Projections

The output of future climate simulations can be obtained from various sources:

The World Bank's Climate Change Knowledge Portal has both historical data and future climate simulations available for every country/sub-national unit/drainage basin in the world. All information contained within the Knowledge Portal is consistently produced and thus directly comparable. As well as being free of charge, it is well-suited to project teams who are not used to working with raw, unprocessed output from climate models and it saves time on data searches and data processing.



National meteorological agencies often also provide localized climate information, which can be accessed through the World Meteorological Organization's website.

Global observations and computer simulations from the Intergovernmental Panel on Climate Change's various assessment reports, can be obtained from their Data Distribution Centre. Similar information can also be collected from the KNMI/World Meteorological Organization Climate Explorer. The latter two sources provide raw, unprocessed model outputs, which require significant time and expertise to process and bias correct, before they can be utilized in project analyses.

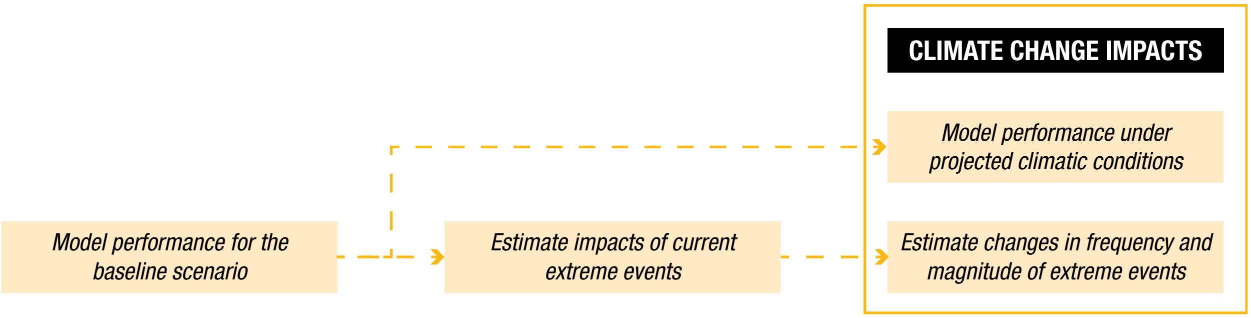
Activity 2c. Analyze the project's performance under the selected climate scenarios. The output of Activity 2b is then directed into socio-economic models that convert biophysical outputs into costs and benefits, identifying the performance of the project for both baseline and future scenarios. For example, a hydrology model provides estimates of streamflow which is then used to estimate the future power production of a hydroelectricity facility. These results, along with the performance in the metrics established in Activity 2a, serve as the basis for the evaluation.

Standard investment evaluations practice follows either a Cost-Benefit or Cost-Effectiveness analysis. Economic analysis takes the view of a social (e.g., government) planner, and ideally considers all changes in welfare in the assessment. The technical note on economic modeling included in the

Compendium Volume provides a primer on these models and the quantification of externalities, as well as on approaches required for cases in which the project's performance results in changes in macroeconomic variables further down the value chain (e.g., changes in commodity prices).

Following the analytical approach determined in Step 1, the analysis should model the impacts of climate hazards following the process in **Figure 5.7.** Climate change impacts should be modeled for all the future scenarios considered in the previous activity and compared against the baseline. Hallegatte et al. (2021) and Asian Development Bank (2015) provide further guidance on how to incorporate the effects of climate change and extreme weather events in cost-benefit analysis. For projects with long time horizons, it is recommended to look at the result at multiple timestamps (e.g., midcentury and end of century).

Figure 5.7. Evaluation Process for Climate Hazards



When conducting the assessment of a new development, a counterfactual representing a no-investment scenario, would be appropriate to assess whether the investment is better than a no-action scenario, as well as to measure the overall contribution (i.e., benefits minus costs) of the investment.

Activity 2d. Assess the vulnerability of the project in the form of a stress test. The analysis should then explore the performance of the project under the range of possible climate futures selected in Activity 2b to assess whether the project fails under those conditions based on the results from Activity 2c. This stress test will help the project team identify thresholds for failure, as well as failure scenarios (e.g., when the project does not meet the minimum economic returns) and the extent of the failure (i.e., difference between the results and a target measure). The vulnerability of the project is then assessed by looking at all the results generated in the previous activity for each future scenario. The following questions guide the vulnerability assessment:

- **Does the project meet the minimum performance targets?** When looking at economic return metrics, these generally require the project to have a positive Net Present Value and/or meet an Internal Rate of Return hurdle rate (see the technical note on economic modeling included in the Compendium Volume for a primer on economic evaluation). A project can also be vulnerable to a climate hazard when minimum performance in other metrics is not met under at least one scenario. For example, reduced runoff may result in reduced generation in a hydropower plant, which will, in turn, result in reduced revenues from electricity and adversely affect its profitability.

- **To what degree does the project meet the minimum performance targets?** The extent of the failure can be measured through the range of results across different climate futures. This analysis may indicate the presence of scenarios with results below an acceptable threshold, which may render the project vulnerable if consequences can be catastrophic. For example, increased precipitation variability may push a municipal water utility's ability to supply water below the required reliability level.

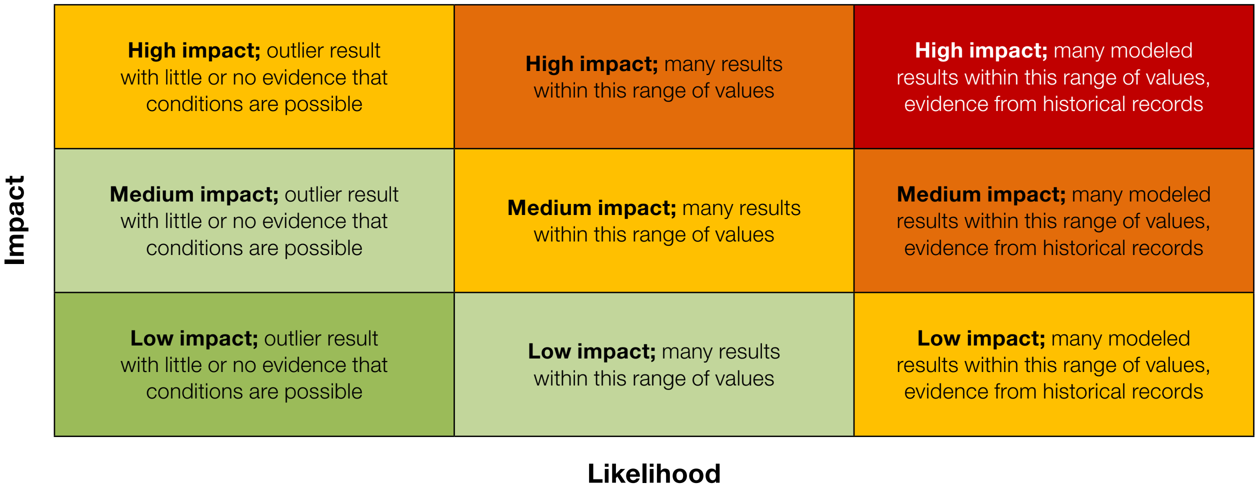
On the basis of these questions, a project can be considered vulnerable to climate change impacts if in the future (i) the results for individual climate scenarios are worse than the baseline, (ii) there is a greater number of failure scenarios than in the baseline, (iii) the potential range of results worsens, or (iv) a combination of these situations. For example, the analysis may find that for a single GCM scenario, the irrigation water provided by a new surface water investment is insufficient to support the expected enlargement in cropped area, and many of the GCM scenarios show a decline in irrigation water available, while some also show an increase or little change. Those that show the problematic outcome (i.e., insufficient water) or worse results, indicate that the project is vulnerable should those futures occur. By using a large number of scenarios, the project team can have more confidence in the level of concern associated with the vulnerability (i.e., large number of problematic scenarios versus few).

By using a large number of scenarios, the project team can have more confidence in the level of concern associated with the vulnerability (i.e., large number of problematic scenarios versus few).

A practical framework to summarize the results of the vulnerability analysis, particularly for high tier projects with a large number of results, is to generate a risk matrix that considers impact and likelihood. Impacts refer to the effects of the climate hazard on the project's performance. Likelihood can be thought of as a "weight of evidence" that provides insights as to the level of concern associated with the vulnerabilities. Likelihoods can be assessed in relative terms, based on whether the results of each GCM run fall within the general range of all results or is an outlier, and whether the climatic conditions have been observed in the historical baseline.

Figure 5.8 presents an illustrative example of a risk matrix adapted from Ray and Brown (2015), where higher impacts and higher likelihoods lead to higher levels of risk. All projects found to be vulnerable, particularly those at higher levels of risk, should advance to the next step of the framework to examine whether the project's resilience can be improved.

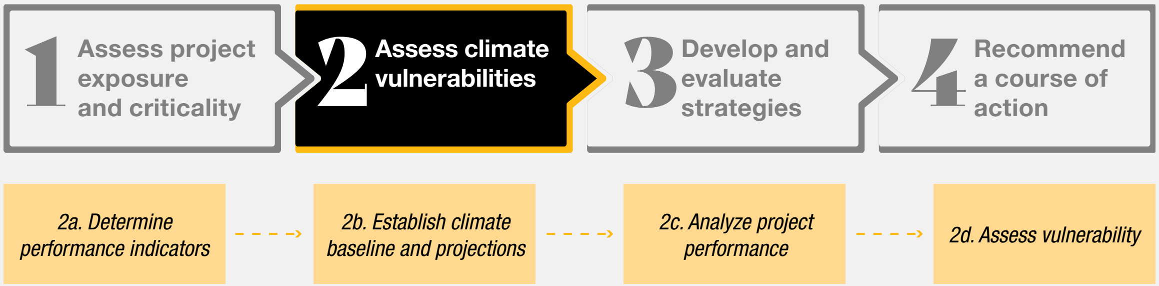
Figure 5.8. Sample Risk Matrix



High impact; outlier result with little or no evidence that conditions are possible	**High impact;** many results within this range of values	**High impact;** many modeled results within this range of values, evidence from historical records
Medium impact; outlier result with little or no evidence that conditions are possible	**Medium impact;** many results within this range of values	**Medium impact;** many modeled results within this range of values, evidence from historical records
Low impact; outlier result with little or no evidence that conditions are possible	**Low impact;** many results within this range of values	**Low impact;** many modeled results within this range of values, evidence from historical records

Outcome: The result of this step is an understanding of the climate vulnerability of the project as currently designed. Comparison between the performance of the project under a historical baseline and under various climate futures provides an estimate of the degree of vulnerability of the project to climate change. It is possible that some project designs may be found to already be climate resilient in their performance given climate uncertainty and these projects can exit the framework here.

Case Study Demonstration of Step 2: **Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda**



1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

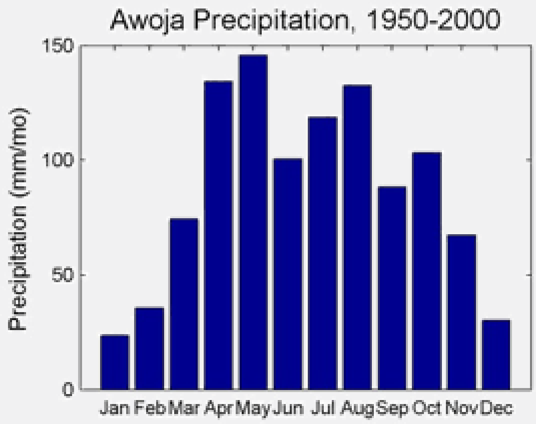
2a. Determine performance indicators → *2b. Establish climate baseline and projections* → *2c. Analyze project performance* → *2d. Assess vulnerability*

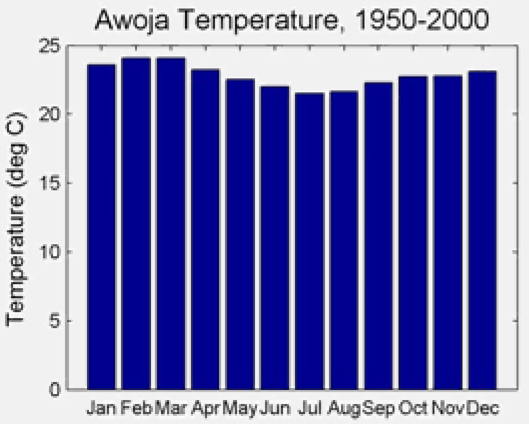
Performance indicators: Several performance indicators were used in the assessment of the project's climate resilience, including irrigation water demand that is met, annual hydropower generated, annual crop and/or hydropower revenues, infrastructure costs and net present value of different investments.

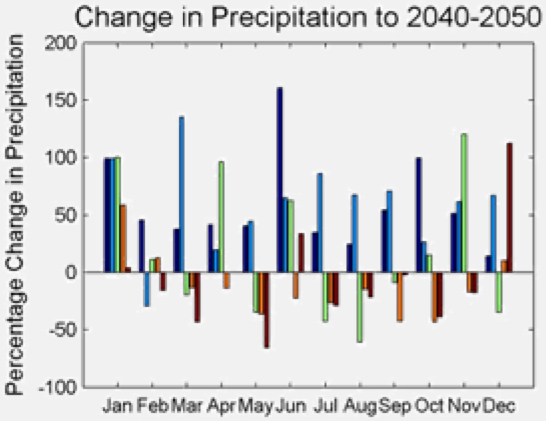
Climate baseline and projections: Historical climate data used in the analysis was drawn from the Princeton dataset (a publicly available global gridded dataset of precipitation, temperature, and other meteorological variables available for 1948 to 2008) and the river runoff baseline was from observed station data in the Awoja catchment.

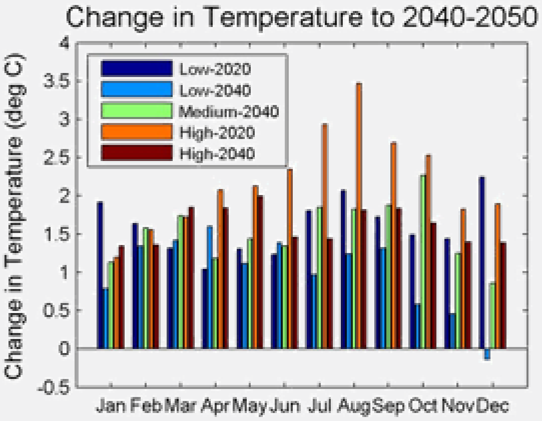
At the time when this study was completed, 56 bias-corrected and spatially disaggregated climate model runs were available from the 2007 Intergovernmental Panel on Climate Change's 4th Assessment models, and 17 models were available from the 2014 5th Assessment. It was infeasible to process all 73 of these model runs through the Mike Hydro framework and therefore a subset of five scenarios was selected in consultation with local stakeholders, as well as a base case climate scenario that assumes no climate change. The figure below shows the historical monthly precipitation and temperature pattern between 1950 and 2000 (upper panel), and the changes under each of the five climate scenarios when comparing to the 2040-2050 period (lower panel).

Case Study Demonstration of Step 2 (continued): Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda







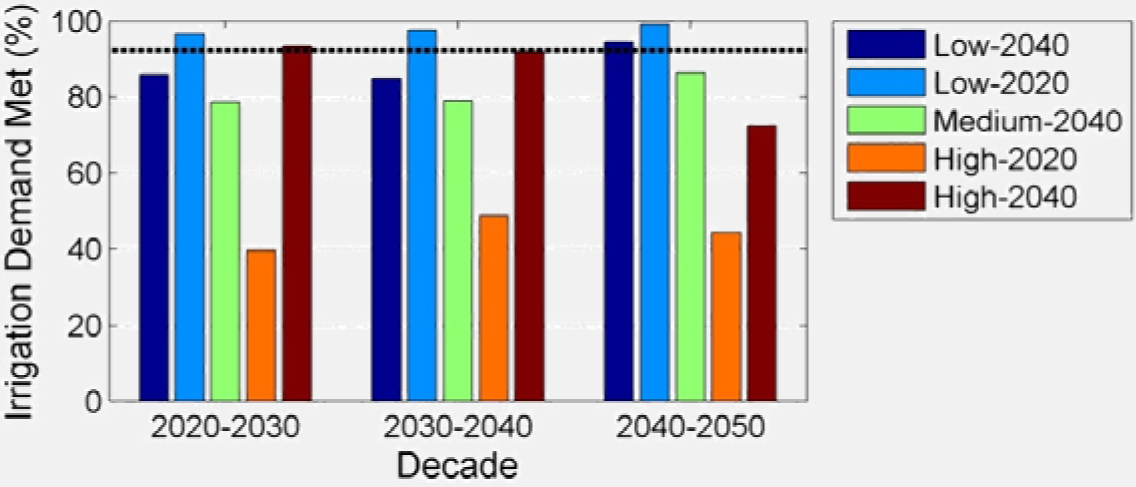


Analyze project performance and assess vulnerability: Using the modeling framework described in Step 1, the climate vulnerabilities of possible run-of-river hydropower and irrigation investments in the Awoja catchment were evaluated. The analysis found that these facilities can be highly vulnerable to climate change, and that as a result, climate change increases the risk of many planned investments.

Water deliveries to planned irrigation systems vary widely without reservoir storage in place. The figure below presents the average decadal Awoja-wide percentage of irrigation demand that would be met under each of the five climate change scenarios, relative to deliveries that would occur under the baseline climate (i.e., consistent with the historical climate, shown by the dashed black line). Deliveries range from approximately 40 percent under an unfavorable future ("high impact 2020") scenario to nearly 100 percent under a favorable ("low impact 2020") scenario. Relative to the baseline scenario, four out of five of the climate change scenarios tended to produce lower irrigation deliveries, demonstrating that the delivery reliability of irrigation water is highly sensitive to future climate conditions in several sub-catchments.

Case Study Demonstration of Step 2 (continued): Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda

Figure 3-12A **Average Awoja-wide percentage of irrigation demand met under each climate change scenario for the period 2020-2050; the black dashed line is the average historical baseline demand that was met (Source: Industrial Economics, Incorporated 2014)**



How climate change will affect planned hydropower generation depends on the magnitude of changes in river flows, but also on whether river flow exceeds the maximum turbine capacity in the proposed run-of-river facility. If flows entering a facility during the majority of months exceed its maximum turbine capacity, then generation will be relatively unaffected by changes in flow because the facility can continue to operate at maximum capacity even if flows decline. Of the five Awoja sub-catchments that contain planned run-of-river hydropower facilities, generation in three sub-catchments (Kelim, Chebonet-Atari, and Simu-Sisi) is expected to be largely unaffected by climate change because monthly flows exceed maximum turbine capacity. The other two sub-catchments (Sipi and Muyembe), on the other hand, are expected to show much greater sensitivity to climate change, with changes in generation ranging from a decrease of 60 percent under the high impact 2020 scenario to an increase of 40 percent under the low impact 2020 scenario. These results indicate that while the planned run-of-river hydropower projects generally continue to perform well economically in spite of climate change impacts, some sub-catchments are more vulnerable than others. In aggregate, investment in more climate-vulnerable hydropower facilities can have important impacts on the vulnerability or resilience of the energy system as a whole.

5.2.3. Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience

Objective: This next step in the framework develops a set of possible strategies by which to adapt the project to climate hazards to improve its resilience. The analysis seeks to provide insights about the performance of the project given climate change as compared to the adapted project given climate change, and considers three activities.

Activity 3a: Identify individual interventions to enhance the climate resilience of the project. Building resilience involves strengthening the capacity of the water resources system to cope with climate hazards. As such, the assessment should start from the results of the analysis in Step 2, and search for interventions that can mitigate the project's vulnerabilities by decreasing the magnitude and recurrence of failure scenarios. In general, these practices to enhance resilience fall into four different categories (adapted from the Food and Agriculture Organization 2010):

- **Structural:** structural modifications to the project in terms of its capacity, dimensions, materials used, etc. and the inclusion of protective infrastructure. For example, increase the size of a dam spillway; add a sediment monitoring system to minimize storage loss in a reservoir.
- **Technology:** use of technology to improve the resilience of a project. For example, weather monitoring and information systems, early warning systems, using satellite-based remote sensing to estimate water demand.
- **Management and planning:** water, land use and maintenance planning. For example, developing planning protocols that consider robustness to climate variability and change, water allocation policies that accommodate flexibility in times of water scarcity, and master plans and strategies at national and subnational levels that prioritize resilient investments.
- **Knowledge:** capacity building and training, establishment of training programs for water engineers in concepts of robustness. For example, building capacities in methodologies that address issues related to assumptions of climate stationarity.

Table 5.2 lists some measures that can be used to enhance resilience in the water resources sector in Sub-Saharan Africa. In addition, it may be useful to think of adaptation practices as they relate to the specific vulnerabilities identified in Step 2 above. For example, if natural climate variability is found to be the dominant concern, then monitoring, forecasting and risk transfer programs can be helpful to consider; if changes in temperature are found to be of concern, then a more heat-resistant choice of water treatment technology could be pursued in local water treatment facilities. Furthermore, when identifying possible adaptation interventions, it is also good practice to consider the kinds of ongoing maintenance that a particular intervention may require, and whether this kind of upkeep is feasible given local factors.

Finally, it is important to highlight the role of **nature-based solutions,** which harness biodiversity and ecosystems services (for example, a lake or wetland providing water purification functions) to reduce vulnerability and build resilience to climate change. The ecosystems note included in this Compendium Volume provides additional guidance on incorporating such measures into a project.

Table 5.2. Water Practices to Enhance Climate Resilience

System	Frequent / prioritized practices
Agricultural Water Management	• Irrigation efficiency technologies • Land leveling • Crop moisture monitoring and adaptive irrigation • Canal lining
Excess Water Management	• Maintaining natural infrastructure, e.g., wetlands • Preserving floodways and room for rivers • Excess culvert capacity • Flood forecasting systems
Water Supply	• Drought management planning • Water demand management programs • Leak detection and repair • Integrated watershed management programs
Hydropower	• Active sediment monitoring and management systems • Forecast based reservoir operations

Activity 3b: Develop adaptation strategies to enhance resilience. Once a set of promising and feasible adaptation measures has been identified for the project, more comprehensive and integrated strategies to build resilience should be developed by combining individual measures. Strategies should consider different sets of interventions, as well as different degrees of implementation, timing, or locations as appropriate, and should be part of a participatory consultation with stakeholders to identify and validate solutions. For example, one strategy could consider both upgrading irrigation infrastructure to improve water use efficiency as well as developing new reservoir storage to increase supply. Moreover, project evaluators should also pay attention to possible interactions between measures – for instance, joint implementation of both irrigation canal lining and switching to higher irrigation technologies will likely result in more significant impacts to local groundwater recharge than if each of these measures had been pursued separately.

Ultimately, which interventions become part of a strategy will depend on what attributes of resilience need to be enhanced to reduce climate vulnerability, as well as how stakeholders and users define resilience for the particular project in question. **Textbox 5.5** presents a list of key attributes for a water resources system, which can guide the development of adaptation strategies to enhance resilience, with these attributes ideally to be tailored to local circumstances. While these attributes are introduced here as guidelines to consider when developing possible adaptation strategies, they are a powerful tool to strengthen project design, especially when integrated as key resilience concepts into the project narrative from the outset and then used to track progress towards achieving greater resilience. Additional guidance can be found in the note for practitioners titled Integrating Resilience Attributes into Operations (Ospina and Rigaud 2021). In the face of climate uncertainty, it is appropriate that strategies consider a portfolio of measures to mitigate the impacts from multiple climate hazards.

Textbox 5.5: Resilience Attributes for Water

Key capacities to build climate resilience in infrastructure investments in Sub-Saharan Africa's water sector include (adapted from Ospina and Rigaud 2021):

- **Flexibility:** the ability of the system to be nimble and utilize opportunities in responding to uncertainty or other challenges. For instance, adapting infrastructure development plans after a disruptive extreme event.
- **Robustness:** the ability to withstand the impacts of climate extremes and variability, maintaining water supply reliability, while minimizing variability in performance.
- **Redundancy:** the availability of additional or spare resources that can be accessed in case of an extreme, for instance water from a secondary source, or additional areas to hold stormwater.
- **Learning:** the ability to develop knowledge and skills to innovate, adapt, and improve performance, leveraging existing knowledge to develop resilience mechanisms.
- **Inclusion:** building on diversity and inclusion, ensuring that women and vulnerable groups have the necessary tools and resources, both in normal conditions and during crises

Though this guidance note focuses predominantly on climate adaptation (with adaptation considered the priority at present for Sub-Saharan Africa), it is important that adaptation and climate mitigation goals and activities are not treated in isolation, as the resilience of a project can also be impacted by climate mitigation-related considerations. The focus of this note on adaptation should not detract from the identification and quantification of any co-benefits that may accrue from climate mitigation. For instance, there may be opportunities for reducing emissions through investment in hydropower, but the direction and magnitude of those effects are dependent on local factors.

Activity 3c: Evaluate the selected strategies' contribution to the resilience of the project. Having identified a feasible portfolio of individual adaptation measures, the next step involves using the same modeling framework established in the vulnerability assessment described in Step 2 to evaluate the performance of the different adaptation strategies being considered.

Depending on the specific interventions, it is possible that new model parameters or assumptions may need to be defined (looping back to Step 2) before being able to estimate the costs and benefits of different interventions, which may require the gathering of additional data. Comparing the performance of the strategies to the project as originally designed (in Step 2) in terms of how much they reduce the magnitude and recurrence of project failure provides a sense of the degree of climate resilience that different strategies offer. In other words, an adaptation strategy that increases climate resilience is one that results in fewer cases of failure, a reduced impact in the failure scenarios, or both. For example, increasing the capacity of a flood spillway decreases the probability that a dam suffers structural failure. A financial risk transfer program (e.g., insurance) for agriculture can reduce the financial impact of drought on farmers. The extent of these improvements can be tracked using the Risk Matrix previously shown in **Figure 5.8.**

Resilience Spotlight: Flood resilience in the Second Lagos Urban Transport Project in Lagos, Nigeria

The Second Lagos Urban Transport Project, supported jointly by the World Bank and the French Development Agency, built on the successes of Lagos' Bus Rapid Transit corridor, expanding the corridor by 13 kilometers. The original corridor was so successful that the operator was able to recoup its capital investment in the bus fleet within only 18 months. **To ensure the resilience of this next phase of investments to the frequent floods experienced by the city of Lagos, measures to enhance flood resilience were also included in the project. These flood resilience measures included upgrading of pavement in sections of the road that experience submersion during the rainy season, as well as implementing portions of Lagos State's drainage master plan.**

Outcome: At the end of Step 3, the project team will have identified promising portfolios of interventions that enhance the climate resilience of the original project design evaluated in Step 2. The output of this step is an updated set of results showing the project's performance for each adaptation strategy and climate scenario. This output will be the input for the following decision-making step.

Case Study Demonstration of Step 3: Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

3a. Identify individual interventions → *3b. Develop strategies* → *3c. Evaluate resilence of strategies*

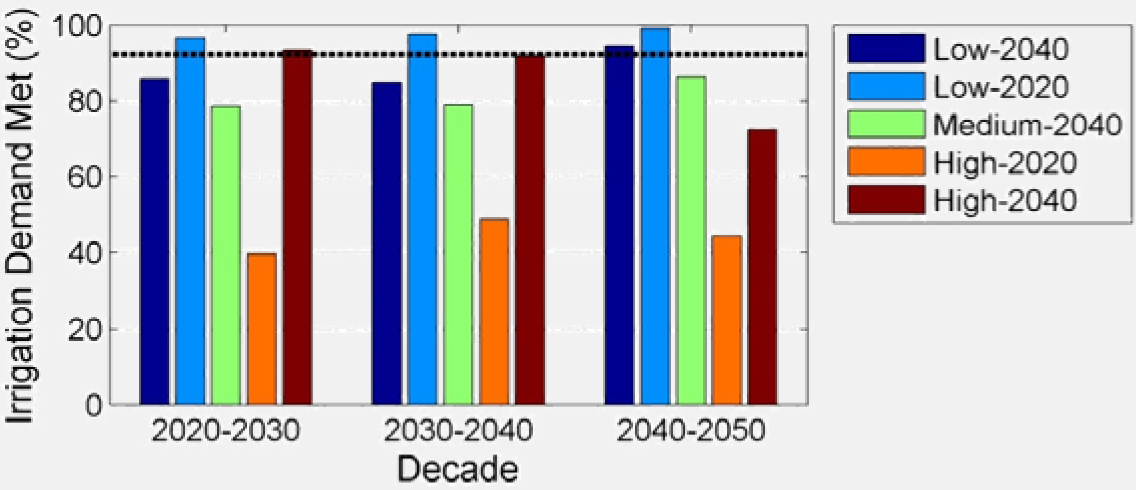
Identify individual interventions and develop adaptation strategies: A number of possible strategies that potentially increase investment resilience were investigated:

1) investment in reservoir storage which provides greater management flexibility by transferring water from wet to dry seasons. This can enable greater water deliveries to irrigation.

2) investment in irrigation efficiency measures to reduce irrigation withdrawal requirements and as a result increase the flexibility of water management across the catchment. This strategy can include transitioning to more efficient technologies, such as from flood irrigation to sprinkler or drip irrigation.

Evaluate the resilience of the different strategies: These two resilience strategies were assessed with the same modelling approach defined in Step 1 and applied in Step 2.

Looking first at the construction of reservoir storage, the figure below presents the percent change in the total irrigation water demand delivered within each of the Awoja sub-catchments that contains planned storage. New storage in the Uketat basin in particular greatly reduces unmet demands under all scenarios except high impact 2020, which shows more modest improvements. As would be expected, the benefits of storage tend to increase under drier scenarios, with the largest benefits observed under the high impact 2040 scenario.

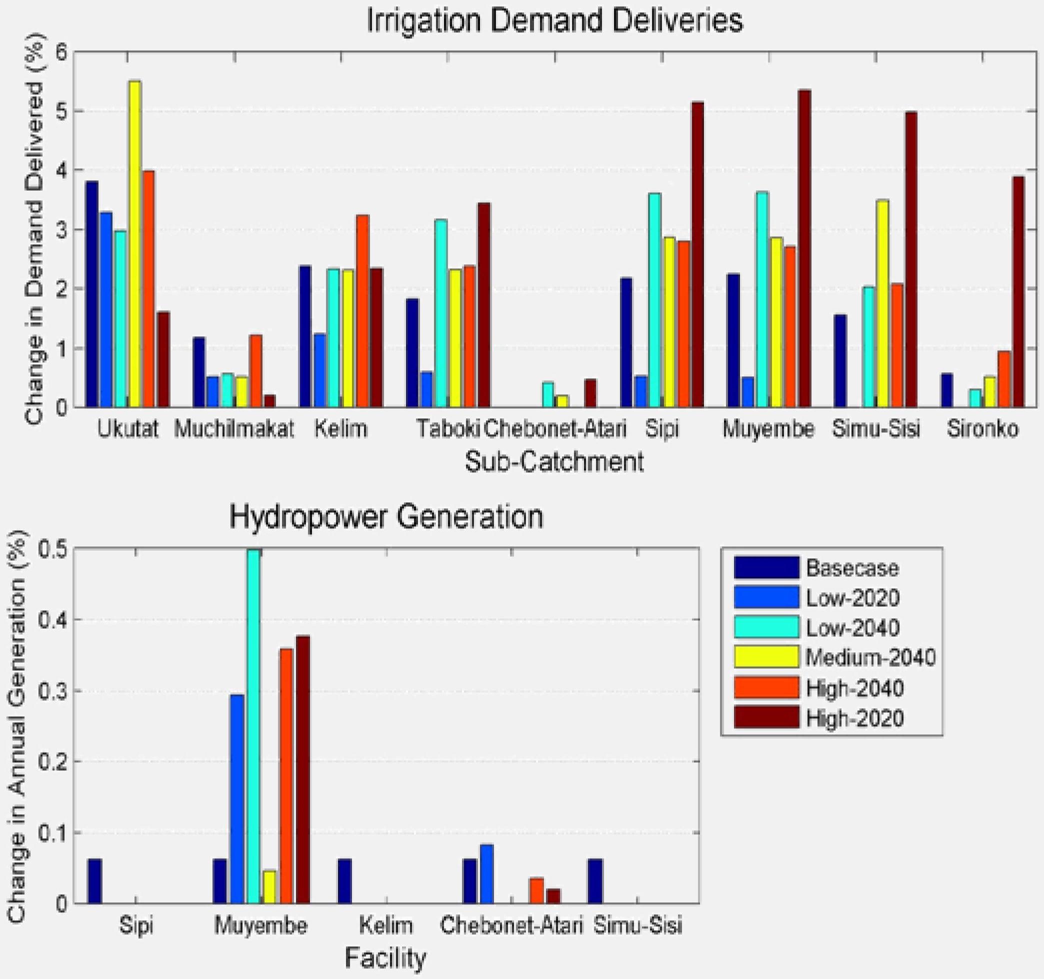


Average change in the percentage of irrigation water demand delivered due to storage construction, 2020-2050 (Source: Industrial Economics, Incorporated 2014)

Case Study Demonstration of Step 3 (continued): Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda

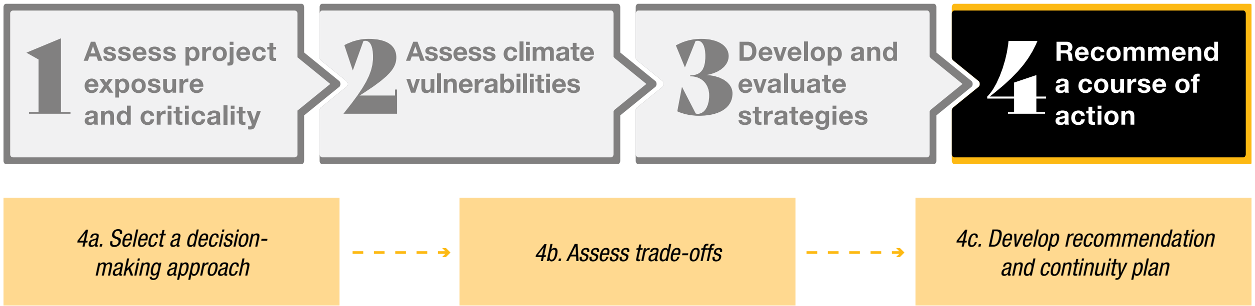
Looking next at irrigation efficiency improvements, gains can be observed in both hydropower generation and the overall fraction of irrigation water deliveries that are met. The figure below shows the effect of a uniform 15 percent improvement in the efficiency of planned irrigation systems on sub-catchment-level irrigation demand deliveries and hydropower generation. Irrigation efficiency improvements are expected to increase irrigation water deliveries by up to 5.5 percent under the medium and high impact climate scenarios, while benefits tend to be more muted under the lower impact climate scenarios. Hydropower generation is only significantly affected in the Muyembe sub-catchment, where management of the planned storage reservoir is influenced by downstream irrigation withdrawals. In Muyembe, the maximum increase is 0.5 percent under the low impact 2040 climate scenario.

Figure 3-15



Average 2020-2050 changes in irrigation demand deliveries and hydropower generation with introduction of irrigation efficiency as a resilience measure (Source: Industrial Economics, Incorporated 2014)

5.2.4. Step 4: Recommend a Course of Action



Objective: Finally, this step will lay out a decision-making approach to identify a course of action from the adaptation strategies considered in Step 3 that considers trade-offs and looks at the full economic lifetime of the project. Three activities are involved.

Activity 4a: Select a decision-making approach that is able to help identify a strategy (from the set developed in Step 3) that is well-suited for a broad range of uncertain conditions. This requires assessing and trading off project performance across a variety of uncertain future conditions, rather than simply maximizing the expected results from averaged future conditions. While the focus in this note is on uncertainty about future climate conditions, resilience analyses in Sub-Saharan Africa are faced with a variety of different uncertainties, including from inadequate historical climate data, the divergence of existing climate projections, as well as changing political and policy environments, external market conditions, or levels of technology adoption. In this context, traditional decision-making methods often fall short because they typically strive to identify an optimal design for an average or most likely set of future conditions. (This group of methods is often described as being founded on **predicting and then acting** – see the technical note on decision making under climate uncertainty included in the Compendium Volume for an overview of these traditional decision analysis methods.)

Given the significant degree of uncertainty associated with future climate conditions, a new group of decision-making methods has been developed that focus on **preparing and adapting,** rather than predicting and acting. This class of methods emphasizes **the identification of flexible decisions that enable ongoing adaptation, or robust decisions that will prove wise across a wide range of future climate conditions.** In general, these methods involve framing the analysis and conducting an exploratory assessment, choosing initial and contingent actions to iterate and perform re-examination, and allowing participation of stakeholders. **Table 5.3** provides a summary of some of these decision-making approaches, grouped based on whether they emphasize the robustness or flexibility of the decision. (See the technical note on decision making under climate uncertainty included in the Compendium Volume for further details.)

Table 5.3. Summary of Approaches for Decision-Making Under Climate Uncertainty

Emphasis of Framework	Description	Examples
Robustness	These approaches focus on achieving acceptable project performance across a wide range of possible future conditions. The emphasis is on the investment decision to be made now and generally follows a conservative approach when incorporating future conditions that are significantly different from the baseline.	• Decision Scaling • Robust Decision Making
Flexibility	These approaches prioritize identifying a design that can adapt in the future given different climate conditions. In general, these value the agility of a design more than its robustness and include consideration of "tipping points" for climate variables that will indicate a change from one set of actions to another.	• Engineering Options Analysis • Adaptation Pathways

The selection of a decision-making framework should be informed by the preference either to account for future uncertainty now through measures that enhance the robustness of the decision or leave options open for future adaptation. This choice should be informed by the available resources today and in the future, the capacity of the project team to control or influence changes in the future, and the optimism that future information will help to clarify the adaptation decision and will arrive in a timely way. For instance, while a floodwall protecting critical infrastructure in a large metropolitan area may benefit more from a robust approach that ensures the infrastructure is designed to withstand low-probability but high-impact flooding events, it may be considered acceptable for a local road to experience increasingly frequent flooding outages as sea level rises before decisions are made as to whether to pursue other more expensive adaptation strategies. In addition, not all individual adaptation actions lend themselves well to being implemented in a flexible way.

As mentioned before, the framework for enhancing the climate resilience of projects that is presented in this note is circular: it is possible that after selecting a decision-making approach, the activities completed during earlier steps in the framework may need to be revisited and adjusted. For instance, having prioritized the flexibility to make incremental adaptation decisions and delay large investments till later (as compared to prioritizing system robustness now), this decision may necessitate returning to Step 3 and identifying additional adaptation interventions that enable flexibility, as well as returning to Step 2 and selecting a few additional uncertainty scenarios to explore if particular climate futures are concerning to decision makers.

Activity 4b: Assess the trade-offs of each strategy. Generally, there is no perfect adaptation strategy, and more beneficial strategies tend to be more expensive. Strategies that are good for mitigating the impacts of one climate hazard, for instance drought, may also fail at properly addressing others such as flooding. Furthermore, strategies that benefit one sector may cause negative downstream impacts to other stakeholders. In this context, the decision-making process must also look at minimizing trade-offs. The starting point of this activity requires identifying, and if possible, quantifying, the trade-offs of each strategy. Typical trade-offs between investment decisions in the sector include making significant capital expenditures today that may not be needed in the future due to climate change, or due to anticipating climate changes that ultimately do not occur. Thus, there are difficult questions as to whether to act or not to address climate vulnerabilities.

The quantitative analysis performed during Steps 2 and 3 can produce two kinds of results: a point estimate of an economic performance indicator (e.g., internal rate of return or net present value) and information related to the variability (i.e., distribution of uncertainty) around the point estimate. Under uncertain future conditions, the point estimate may be no more likely to occur than the wide range of other possible outcomes around it. For this reason, when assessing trade-offs, the project team should consider the distribution of uncertainty around point estimates to promote better decision-making.

Resilience Spotlight: Enhancing the climate resilience of the Nachtigal Hydropower Project in Cameroon

The Nachtigal Hydropower Project in Cameroon is a 420MW greenfield hydroelectric power project. The project consists of a hydroelectric plant with a reservoir on the Sanaga River, a concrete-lined canal, a high-voltage transmission line and construction of an owner's village. The project is expected to support 30% of Cameroon's electricity production, or nearly 10 million people. The project will offer resilience against variable precipitation, by enabling all-season flow and thus reliable electricity generation on the Sanaga River via a new regulating dam and main reservoir upstream. In addition, reservoirs offer more than just resilience for the energy sector: they provide flood control, water for irrigation and urban users, and downstream flow management enabling navigation, among others. **A variety of asset-level, landscape-level and management interventions can help enhance the climate resilience of the hydropower facility itself, including increasing the reservoir design volume, reforestation of upstream catchment areas and better managing of reservoir dredging activities (both of which help maintain long-term reservoir storage).**

In order to weigh the importance of different strategies, the project team should develop a hierarchy of all consequences that result from project failure. These causes of failure correspond to all the reasons why the project does not meet the performance metrics in the face of extreme weather events and climate change, as identified from the vulnerability assessment and addressed through adaptation strategies. For instance, a hydropower facility may not produce the anticipated firm energy if precipitation decreases in the future, while a stormwater culvert may not protect roads if precipitation increases in the future. This list will indicate the order of priority and urgency and should be produced in consultation with and validated by stakeholders of the project.

The project team should then carry out the decision-making process, with the benefits of the strategy (i.e., the performance metrics defined in Step 2 and evaluated in Step 3, considering the distribution of uncertainty of estimates), its direct costs and associated trade-offs, and the hierarchy of priorities as inputs. As mentioned, this process may require revising the analysis done in previous steps as new information is obtained and inputs are gathered from stakeholders. Decisions then could fall into three categories, namely:

1. **Investing in climate-proofing the project at the time the project is being designed or implemented**, which can result in low-regret, no-regret and/or win-win options depending on the projected costs and benefits;

2. **Deferring from investing in climate-proofing but designing the project in such a way it can be more easily climate proofed in the future,** if deemed necessary. For instance, foundations for levees are constructed such that the levees can be heightened in the future;

   Or

3. **Deciding that the project design and monitoring should not take account of climate variables and their impacts at the present time**, and that investment in climate-proofing will be undertaken at a later point, if needed.

The first option sees more substantial investments in climate resilience at the project outset than the latter two options. The second option is commonly referred to as **adaptive management**, where proactive and incremental adaptation investments are introduced over the project's lifetime. The third decision making approach embodies **a wait-and-see mindset** – while this latter approach maximizes flexibility and adaptability, minimizes the hardening of infrastructure today, and may be preferred when funds are limited, and uncertainty is high, it is only suitable for situations where baseline risk is considered acceptably low. As an example of adaptive management, providing room for rivers to flood through land conservation and land use zoning can retain the option of providing flood protection if needed but the reserved land could instead be developed in the future if flood risk were to decrease.

The recommendation of a preferred course of action should cover all components of the project cycle, starting with project identification, focusing on risk screening and identifying critical stakeholders and their roles and responsibilities. The recommendation should focus on those adaptation solutions that are technically feasible to address projected climate vulnerabilities, taking into account the related costs and benefits. In this context, the trade-offs analysis should also inspect the feasibility of a strategy in terms of technical capacities, policy environment, and financial constraints, with particular attention to the extent to which the environment supports or limits their implementation. Potentially, the analysis may require returning to Step 3 and revising the strategies proposed. Project implementation should identify stakeholders with the capacity to implement the preferred adaptation option(s) and include necessary capacity building at the individual and institutional levels. Lastly, the recommendation works best if it draws and builds upon existing country-level and watershed-level plans that identify priority areas for action.

Activity 4c: The development of a recommendation and continuity plan should provide a narrative that justifies the selection of a course of action from the process in the previous activity. Moreover, the continuity plan should describe how project evaluation will be conducted, along with a clear schedule of activities and stakeholder responsibilities into the future, both during and after the implementation phase, including how resources for maintenance and/or continued adaptation will be mobilized, to ensure the investment continues to perform over the course of its life.

Both the narrative and continuity plan should discuss residual climate risks not addressed in the proposed project design that are still material to the project. Since it is not always economical or preferred to address all risks under all potential future conditions, there will generally be a residual risk. However, since the future is uncertain, it is possible for residual risk to grow over time in unanticipated ways to a point where it would be appropriate to address and should be the basis for a monitoring and evaluation plan. For example, the construction of flood defenses requires the calculation of the value of the avoided losses of floods which require assumptions of the exposure to floods in terms of people and assets. However, that exposure will likely change over time due to both population growth and economic growth and thus the value of avoided losses increases, as does the economic value of increased flood defenses. Monitoring and evaluation should focus on assessing how progress toward vulnerability reduction and changes in residual risk will be measured in terms of indicators, tipping points, and thresholds, and how lessons learned can be used to improve current and future projects underpinned by a fit-for-purpose monitoring, evaluation and reporting framework.

This plan should include which actors will be responsible for each action and when, and should cover the full economic life of the project. Developing such a plan is fundamental when selecting a wait-and-see type of strategy that requires future actions. Even when interventions are prioritized in the near-term, as (climate and non-climate) uncertainties resolve over time, the continuity plan provides critical milestones for revising the resilience of the project.

Outcome: After completing these four steps, the project team should be capable of providing an assessment of the vulnerability of the project as initially proposed, and developing a narrative on how much a particular strategy (or set of alternative strategies) can enhance its resilience and, therefore, reduce its vulnerability. The assessment, moreover, should enable the team to understand whether the improvements (and corresponding trade-offs) are acceptable, as well as the costs of following each course of action.

> Both the narrative and continuity plan should discuss residual climate risks not addressed in the proposed project design that are still material to the project. Since it is not always economical or preferred to address all risks under all potential future conditions, there will generally be a residual risk.

Case Study Demonstration of Step 4: Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

4a. Select a decision-making approach → *4b. Assess trade-offs* → *4c. Develop recommendation and continuity plan*

Select a decision-making approach: This study found that in the Awoja catchment, climate change is likely to affect the physical performance of water infrastructure in meeting key objectives, as quantified through changes in irrigation water deliveries and hydropower generation:

- Deliveries to new irrigation areas under conditions consistent with the historical climate are approximately 95 percent, whereas across the climate scenarios, deliveries range from approximately 40 percent under a dry scenario to nearly 100 percent under a wet scenario.
- As a resilience-enhancing measure, new storage reduces these unmet demands, most dramatically in the Uketat sub-catchment.
- How climate change will affect planned hydropower generation depends on the magnitude of changes in river flows, but also on whether median monthly river flow exceeds the maximum turbine capacity in the run-of-river facility. The facilities planned in the Sipi and Muyembe sub-catchments are the most sensitive to climate change, with changes in generation ranging from a decrease of 60 percent under a dry scenario to an increase of 40 percent under a wet scenario. On the other hand, because flow exceeds maximum turbine capacity in the Kelim and Chebonet-Atari facilities, climate change has no effect on generation.
- As a resilience-enhancing measure, irrigation efficiency improvements reduce irrigation withdrawal requirements, and as a result increase flexibility of water management across the catchment. By increasing water management flexibility, irrigation efficiency improvements increase demand deliveries by up to 5.5 percent, while hydropower generation is only significantly affected in the Muyembe sub-catchment.

This study utilized a decision-making approach that explored the existence of **no-regret resilience measures,** namely investments that are economically beneficial regardless of how future climate evolves:

- When exploring reservoir storage as a resilience-building measure, the performance of storage infrastructure depends on assumed capital costs. Planned reservoirs increase irrigation deliveries to downstream areas by between 0 and 50 percent of their total water demand, and while sensitive to climate scenarios and capital cost assumptions, are generally found to be net beneficial investments (i.e. a no regret investment).
- Looking at irrigation efficiency as a resilience-building measure, this investment potentially provides benefits to both irrigation supply reliability and hydropower production by increasing water management flexibility, but in the Awoja, tends to be less favorable economically. Benefits outweigh costs in only three of the sub-catchments, but this may partly result from cost assumptions.

Case Study Demonstration of Step 4 (continued): Potential Climate Change Risks to Water Resource Investments in the Awoja Catchment in Uganda

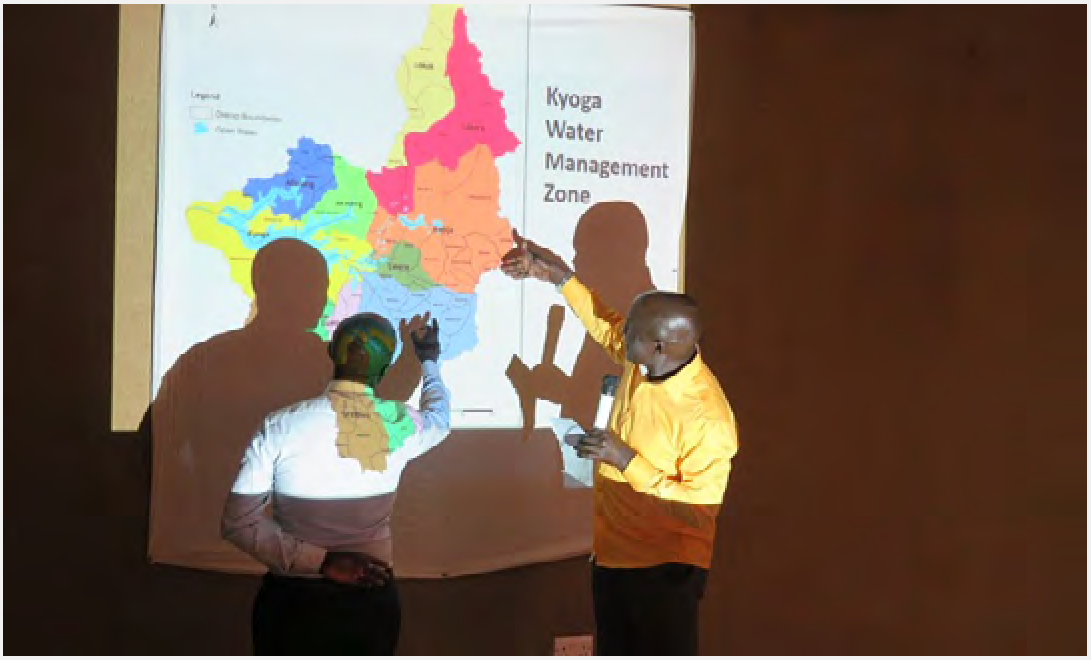
Assess trade-offs: As such, no direct assessment of trade-offs was conducted for this particular analysis.

However, given the possibility of drier future climate scenarios, an evaluation of different possible water investments and resilience measures implicitly explores the question of tradeoffs between different users of water (i.e., hydropower versus irrigated agriculture). Furthermore, the construction of additional reservoir storage must face a tradeoff between benefits to irrigation and hydropower versus the social and environmental costs associated with lost ecosystem services, relocation of local populations etc. The existence and magnitude of such tradeoffs would ideally be examined in more detail before investment decisions are made.

Develop recommendation: A number of proposed irrigation and run-of-river hydropower projects in the Awoja catchment were assessed for their potential vulnerability to climate change.

It was found that while climate change may have a significant effect on the economic performance of irrigation infrastructure investments, hydropower is less vulnerable. Investment in reservoir storage increases the resilience of irrigation deliveries to downstream areas and are generally net beneficial investments. Irrigation efficiency improvements, which potentially improve the resilience of both irrigation supply reliability and hydropower production by increasing water management flexibility, tend to be less favorable investments with benefits outweighing costs in only three of the sub-catchments considered.

Of the two risk mitigation strategies that were assessed, an adaptive approach could see phased investment over time depending on how climate conditions evolve over the coming decade.



Launch of the Awoja Catchment Management Plan in 2019. (Source: Ministry of Water and Environment of the Republic of Uganda 2019).

5.3. Concluding Remarks

This guidance note presents a practical framework for enhancing the climate resilience of infrastructure development projects in Sub-Saharan Africa's water sector. The framework includes four steps: (1) assessing the exposure to climate hazards and determining the criticality of the project; (2) assessing the vulnerability of the project to the identified climate hazards; (3) developing and evaluating strategies to enhance the project's resilience; and (4) recommending a course of action. For each step, the note provides illustrative examples, along with references to additional technical notes for issues that expand beyond the scope of the guidance note and are common to the other sectors covered in the Compendium Volume.

There is no single approach for assessing climate hazards in project evaluation, and this guidance note is based on the authors' understanding of the most appropriate methods available for the water sector in Sub-Saharan Africa. Future climate conditions are uncertain in nature, and the proposed framework was designed for incorporating the vast and evolving field of study in climate science by way of a practical and flexible approach that can adapt to new emerging knowledge.

Special considerations in the water sector include the importance of considering climate variability in addition to changes in mean conditions. Water challenges are felt most critically during periods of extended dry or wet conditions, and slight changes to mean conditions generally have little effect. Thus, managing variability has been and will continue to be the focus of water resources management. At the same time, water infrastructure is typically large scale, long-lived, and involves multiple stakeholders, beneficiaries and external costs. Planning such investments requires analysis of uncertainty and should consider the potential for climate change to cause a planned design to be sub-optimal under future climate conditions.

This note is of an incremental nature: it seeks to inform how to incorporate climate-related uncertainties and the assessment of resilience over existing project evaluation methodologies. Only the fundamentals of economic, climate, and biophysical modeling, as well as of decision-making under uncertainty are covered in this note, and extensive references to external resources are provided to those seeking further detail. The note does not address other uncertainties in project performance such as demographic changes, political and policy environment, or macroeconomic factors. However, although the principles presented in this note can be extended to other uncertainties, specific guidance on these is preferable.

The framework presented in this note will always benefit from further refinement through widespread application in Sub-Saharan Africa, for a wide range of geographies, socio-economic, and climatic conditions. As conditions in the region change, and climate knowledge advances become more accessible, periodic updating of this note will ensure that users continue to be provided with the best guidance possible for enhancing the climate resilience of much-needed infrastructure investments in the region.

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GUIDANCE NOTE:

Enhancing the Climate Resilience of Transport Infrastructure Projects in Sub-Saharan Africa

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Acronym List

AFRI-RES	Africa Climate Resilient Investment Facility
GCM	General Circulation Model (or Global Climate Model)
IPCC	Intergovernmental Panel on Climate Change
RCP	Representative Concentration Pathway

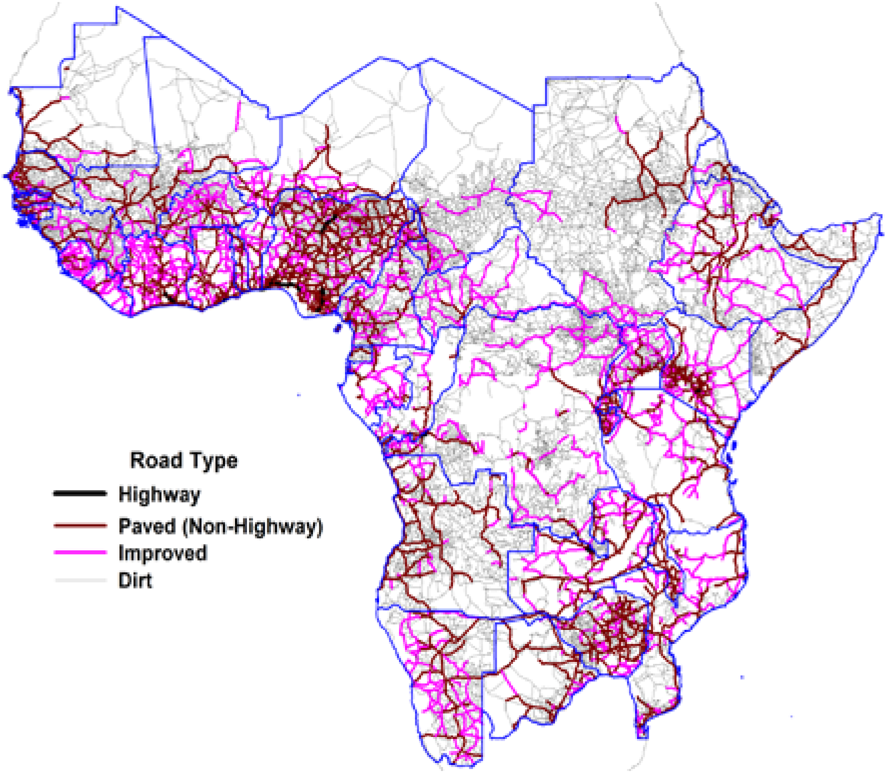
6.1. Introduction and Background

6.1.1. Problem Statement

The transportation sector in Sub-Saharan Africa is key to economic development throughout the region. With over 2 million kilometers of roads, the region has a vast network that stretches from urban areas to rural agricultural provinces in almost every country (see **Figure 6.1**). However, only 28 percent of roads are paved, placing Sub-Saharan Africa at the bottom of global developing regions (Export-Import Bank of India 2018). Additionally, the state of road infrastructure varies across the region in terms of the quality of roads that are available for commercial and personal transport. While a fraction of countries (including South Africa and Burkina Faso) have 70 percent or more of their roads in good condition, less than 50 percent of the road networks across other Sub-Saharan African countries are categorized as being in good condition (Gwilliam et al. 2008). When focusing just on rural roads, this value drops to almost 25 percent, which impacts the transport of goods out of these areas as well as the provision of goods into these areas during much of the year. According to the United Nations, 60 percent of the continent's population lacks adequate transport infrastructure (Export-Import Bank of India 2018) and only one out of three rural Africans have access to an all-season road (Mostafa 2018).

With over 2 million kilometers of roads, the region has a vast network that stretches from urban areas to rural agricultural provinces in almost every country

Figure 6.1. **Road network in Sub-Saharan Africa (2010)**



Source: Storeygard (2016).

The deficit in dependable, all-weather transport infrastructure is estimated to increase the cost of goods in the region by 30 to 40 percent (Export-Import Bank of India 2018). However, a significant investment in transport is required to address this. The African Development Bank estimates that $130 to 170 billion per year is required to overcome this deficit (African Development Bank 2018). Much of this investment is concentrated in areas that have traditionally lagged in infrastructure development, resulting in an ever-increasing gap between areas with good quality transport infrastructure and those with poor quality transport. The result is that **the critical need to develop a regional, all-weather transport network is increasingly difficult to implement.** Additionally, many gravel roads are reaching end of life conditions which is putting further pressure on transport ministries to address the future development of transport networks (Mwaipungu and Allopi 2014).

The geographic diversity of the Sub-Saharan transport network creates an additional challenge for regional planners when designing for future climate change. Sub-Saharan Africa is facing a diverse and uncertain set of impacts from projected climate change according to the Sixth Assessment Report produced by the Intergovernmental Panel on Climate Change (IPCC 2021). The middle of the continent, from Ethiopia in the east to Senegal and neighboring countries in the west, is projected to have up to a 30 percent increase in intense precipitation events which has significant ramifications for paved and unpaved roads. Paved roads will be susceptible to erosion of roadbeds and shoulders as precipitation events exceed design parameters. Unpaved roads will similarly experience erosion, with the wearing surface as well as support bases being additionally impacted. Finally, both paved and unpaved roads will face the potential of increased washouts as more frequent, more intense precipitation events overwhelm streams and bridges throughout the region.

The southern part of the continent is projected to experience 2° to 4C increases in temperature that will impact rail, air, and highway systems either through reductions in lifespan or through operational delays. For rail systems, potential rail deformations will force providers to reduce service in times of intense heat. Similarly, air service will see delays in these same periods as providers face reduced capacity for lift during takeoff. Finally, highways will experience greater delays and maintenance costs as surfaces degrade due to temperatures exceeding design parameters causing premature pavement failures for bituminous roads as well as cracking in both bituminous and concrete pavements.

In addition to temperature and precipitation impacts, the entire coastline is projected to be impacted by increased category 4-5 cyclone activity. Increased storm surge and wave activity will be associated with these extreme events, and these will endanger coastal infrastructure. In February and March 2023, Cyclone Freddy broke records as the longest-lasting tropical cyclone ever recorded, causing widespread loss of life and displacement, as well as prolonged transport disruptions in Madagascar, Mozambique and Malawi.

Furthermore, inland waterways will experience increased flood activity impacting bridges, as scour and overtopping lead to damage and failures. Given the lack of transport system redundancy in many areas, bridge failures may lead to significant delays and potential economic challenges in affected areas.

In addition to these anticipated climate impacts, the adaptive capacity of Sub-Saharan Africa's transport systems and the institutions that govern them is limited. There is a need to **improve the capacities of scientific institutions, central and local governments (including transport offices), stakeholders, and civil society in the region to help them prepare for the implications of climate change on transport networks.** This should be complemented by the development of appropriate tools to support adaptation and damage mitigation (including advanced early warning systems), cross-sectoral cooperation, as well as sharing of experiences and policies. Against this backdrop, this document presents a guidance note that offers practical suggestions for achieving climate-resilient transport infrastructure projects in Sub-Saharan Africa, where resilience is *the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner* (Intergovernmental Panel on Climate Change 2012).

> Given the lack of transport system redundancy in many areas, bridge failures may lead to significant delays and potential economic challenges in affected areas.

6.1.2. Objectives and Scope of This Guidance Note

Funded through the Africa Climate Resilient Investment Facility (AFRI-RES), this document provides guidance on enhancing the climate resilience of transport infrastructure investment projects in Sub-Saharan Africa.[6] It is pedagogically oriented and draws on extensive experience and robust research and analytical methods. **This guidance note provides a framework for evaluating <u>infrastructure project assets</u> to ensure they meet project objectives in spite of possible future climate impacts.** As a result, this note is primarily relevant for climate adaptation, with climate mitigation benefits only considered if they are an explicit objective of the project being considered. The focus of this note is on guidance, serving neither as a comprehensive technical text nor an exhaustive policy handbook, but as brief direction on the most important principles to take into account when seeking to enhance the climate resilience of infrastructure projects in the face of future climate uncertainty. (While the note focuses on uncertainty as it relates to future climate conditions, the principles presented here could be extended to include other sources of uncertainty.) In addition, this note focuses on enhancing the resilience of projects that have been at least roughly scoped in terms of their location and the type of investment to be made, being less relevant for very early-stage projects where the location and type of project are as of yet unknown.

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[6] A partnership with the African Union, United Nations Economic Commission of Africa, Nordic Development Fund, African Development Bank, and the World Bank. This note is part of a series of guidance and technical notes funded by AFRI-RES that focus on climate resilient investment in Sub-Saharan Africa.

These notes build on a range of existing resources produced by the World Bank and others, notably including the Resilience Rating System (World Bank Group 2021) and the disaster and climate risk stress test methodology (Hallegatte et al. 2021). Furthermore, the framework presented in these notes also complements new guidance developed by the World Bank to ensure that future Bank investment projects are in alignment with both the climate mitigation targets set out in the Paris Agreement (United Nations 2015) as well as the country's adaptation goals.

The Resilience Rating System mentioned above distinguishes between two dimensions of resilience, namely **resilience of** the project and **through** the project (World Bank 2021):

- **Resilience of** the project is the extent to which a project's assets have considered climate and disaster risk in their design e.g., road culverts that have been sized so as to safely manage more intense precipitation events than are currently experienced.

> The scope of this note is focused on the resilience of projects, including the resilience of direct project outputs.

Resilience through project outcomes reflects whether a project's objective is to enhance the target sector and beneficiaries' climate resilience through its interventions. For instance, investment in transport infrastructure, particularly on the development and improvement of rural roads in Sub-Saharan Africa, also provide socioeconomic benefits to agriculture systems and public services such as health care and education (World Bank 2021).

The scope of this note is focused on the **resilience of** projects, including the resilience of direct project outputs. While many investments in transport systems can enhance both the resilience of and through projects, **the framework presented in this note focuses on the resilience of particular investment projects** and not on how those investments enhance the resilience of a community or sector that benefits from it.

While **the focus of this note is on the project design level**, it remains **crucial to understand the particular policy, regulatory, and institutional context in which the project is situated.** Hence, all project design decisions should be taken with both the policy landscape and local capacity in mind, acting as either enablers or barriers for implementation. This note is part of a larger Compendium Volume, with these cross-cutting issues discussed in Chapter 2 of the Compendium Volume. Chapter 1 of the Compendium provides a general introduction, with the remainder of the Compendium broken down into two parts: Part 1 houses sector-specific guidance notes (including this one), while Part 2 provides a series of more detailed technical notes.

The scope of this note covers development in the transport sector at large, with the sector categorized into the following sub-systems, all of which are part of the transport system, and interact and depend on each other:

- **Investments in road maintenance and infrastructure:** Road infrastructure requires appropriate decisions around improving paved and unpaved roads in terms of maintenance and adaptation. For example, upgrading unpaved roads to all-season roads or enhancing paved road maintenance schedules to account for greater cracking and erosion due to temperature and precipitation changes.
- **Investments in rail infrastructure:** Rail infrastructure includes physical rails as well as the electronics and safety systems that allow for safe and efficient movement of passengers and freight. Based on the vulnerability of this infrastructure to climate impacts, both elements are addressed to reduce the likelihood that rail infrastructure will fail in the face of changing conditions in the future.
- **Investments in bridge infrastructure:** Bridge infrastructure often serves as critical links in a transport system. The loss or extended removal of a bridge can create delays in the transport network as well as economic hardship to communities dependent on transport infrastructure. Bridge structures should also be analyzed in terms of increased water flows to reduce chances of scour and deck failure.
- **Investments in urban infrastructure:** Urban infrastructure requires specific attention due to the increasing demand for well-maintained and efficient urban transport systems. The rapidly rising population and increasing economic dependence on urban centers require new perspectives on transport system maintenance and operation. This document addresses the need to take a proactive approach to transport system resiliency to reduce the likelihood of failure in critical transport systems, and is complementary to the guidance note focused on urban areas, included within the Compendium Volume.
- **Investments in sea ports, inland water ports, dry ports, and airports**. The vulnerability of ports largely depends on the location of the facilities and their level of use. Disruptions and failure due to water level rises or extreme temperatures can lead to significant losses, particularly when affecting the primary hubs for freight and passenger traffic. Since both the planning and the analysis of this infrastructure is highly specialized, this guidance note will not focus on this sub-system and provide a cursory overview only.

These five systems represent a pragmatic categorization of transport network processes, but these systems are interdependent. **The note is not specific nor prescriptive regarding development in the transportation sector, but rather presents principles that can be applied to the evaluation of infrastructure investment projects of any kind.** Improved adaption to climate change will depend on comprehensive and inclusive policies and strategies that are inter-sectoral, underpinned by a unified framework such as the one presented in this note that allows meaningful coordination and provides adequate climate information services.

6.1.3. Target Audience

There are three primary audiences for this guidance note:

- **Practitioners.** The note will help practitioners develop their staff and internal expertise to perform the necessary climate vulnerability and adaptation analyses.
- **Government Ministerial Staff.** The note will give staff from government ministries an understanding of the steps involved in evaluating and enhancing the resilience of a proposed project, how to be prepared for creative and alternative investment packages, and how to draft Terms of Reference for practitioners to develop climate resilient projects.
- **Donors and Development Banks.** The note will help donors and development banks provide clear direction and guidance to consultants for how to make project designs more resilient to climate change.

Each of these three target audiences differ considerably in their technical focus, operational roles, and objectives. Typical investment projects will see this note used both as high-level guidance by donors and banks, as well as more detailed technical guidance for use within client countries. This note was developed to be accessible to these different audiences, with the general framework presented here supplemented by further detail in the technical notes included in Part 2 of the Compendium Volume.

6.1.4. When to Use This Note

While each of these target audiences will use the note in slightly different ways, within the overall project development process, this guidance note is intended to be used anywhere from the project's **conception** and **planning** stages, as well as during post-project completion **monitoring** (see the orange components of **Figure 6.2**). It is anticipated that in most cases, project teams will utilize this guidance note during the scoping, early design, and final design stages of the project planning process. That said, the earlier in the project lifecycle that climate resilience considerations (as described in this guidance note) are incorporated, the greater the scope and opportunity to improve the performance of the project given climate uncertainty. Furthermore, while not the focus of this note, attention should be paid throughout the project planning process to the policy and institutional landscape, as well as the role of policy shifts and improved local capacity in building resilience.

Figure 6.2. **Applicability of this Guidance note during a typical project life cycle**

6.1.5. Structure of and Roadmap to Using This Note

The remainder of this document is structured as follows: Section 6.2 describes a step-by-step framework used to enhance the resilience of projects in the transport sector to climate hazards. This section is subdivided into four steps, each containing different activities to carry out the analysis. Rigorously completing each activity requires a non-trivial amount of resources in terms of time, data, and analytical know-how. Where these resources are not available, completion of a more rapid qualitative assessment is still useful to undertake in order to provide a high-level understanding of the situation, but such high-level insights alone should not form the basis for recommendations. A case study is provided to illustrate the framework and is intended to be consulted by all users of the note. Lastly, Section 6.3 offers brief concluding remarks.

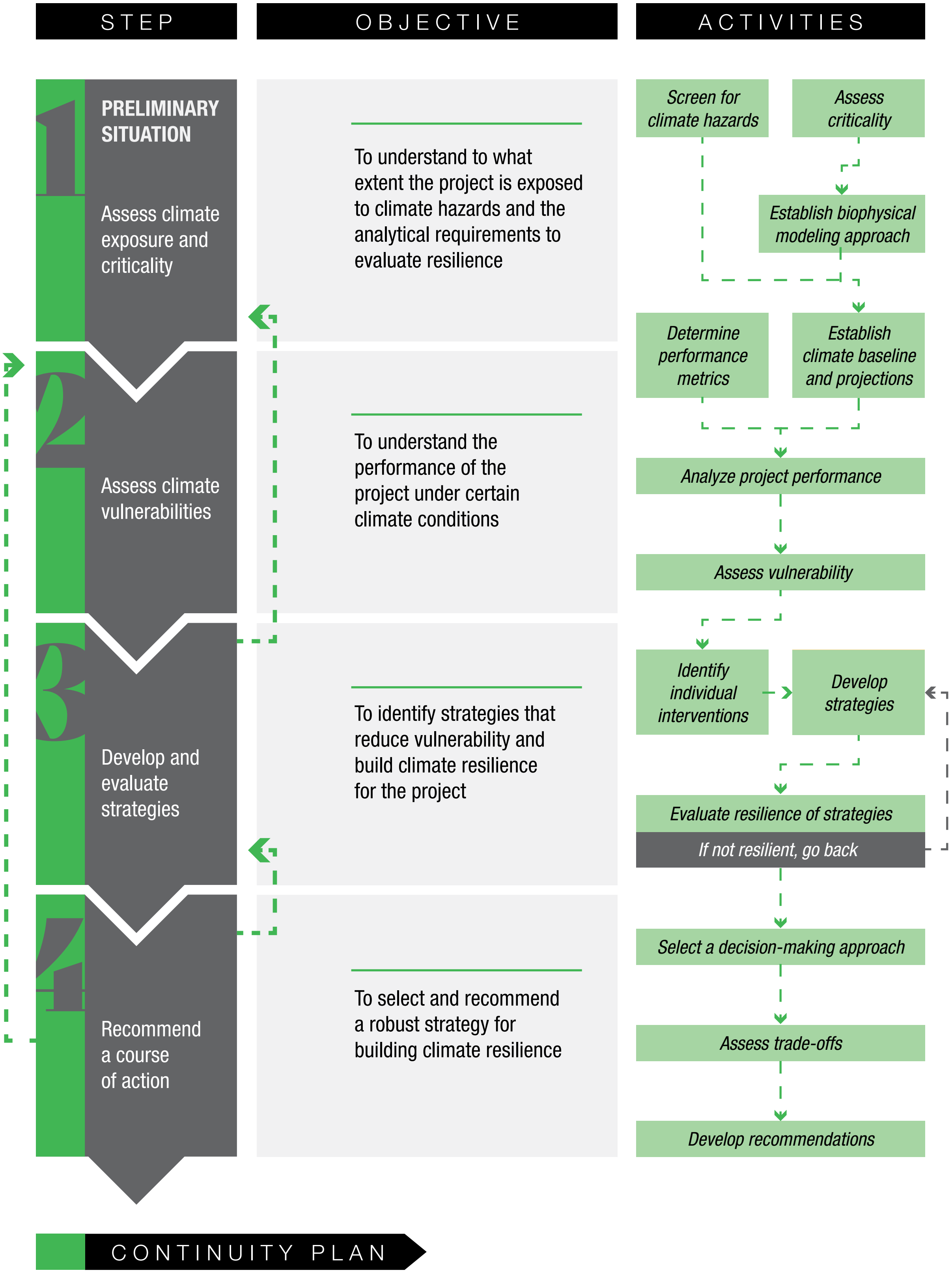
Finally, while the focus of this note is specifically on transport-focused infrastructure investments, many projects include cross-sectoral components and depending on the different investment components included in a project, several of the individual guidance notes beyond this one may need to be consulted. When using this note, **project leads should look beyond their particular project to consider both the broader system as well as any possible inter-system effects in their evaluation process.** For instance, transport infrastructure may be a subcomponent of larger urban and agriculture sector strategies that contributes to resilience gains beyond transportation itself, with those involved in the project benefitting from also consulting the urban areas, and agriculture notes; a team working on a bridge project should consider also consulting the water note; and efforts to build roads in forested areas should additionally review the ecosystems note, with all these notes included in the Compendium Volume.

6.2. A Framework for Enhancing the Climate Resilience of Transport infrastructure Projects in Sub-Saharan Africa

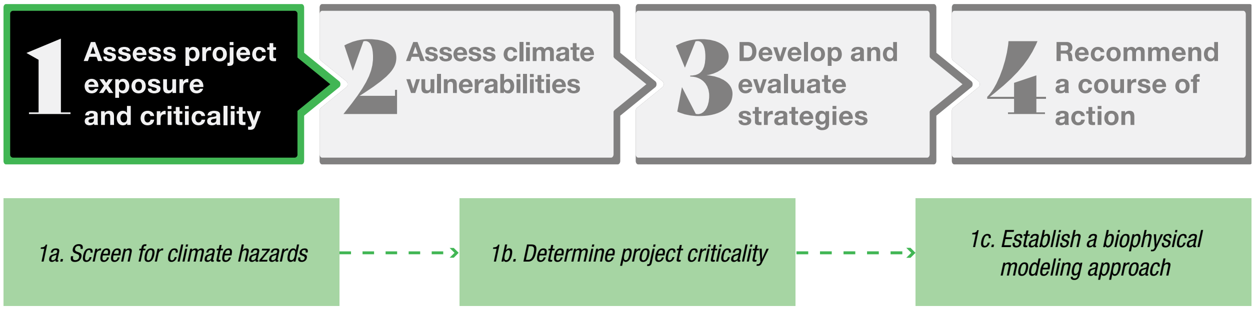
The guidance for developing climate-resilient investments presented in this note builds on a broadly applicable, multi-step framework, summarized in **Figure 6.3**. The framework consists of a series of four steps, each explained in further detail below, with many of the steps linked through important feedback loops. As noted in Chapter 2 of the Compendium Volume, the framework is founded on an initial assessment of the preliminary situation, which examines the **institutional and project context** (including the existence of country-level development plans, support from relevant ministries, and the state of weather and climate change monitoring capabilities) as well as identifies **relevant stakeholders** (including community groups, beneficiaries, technical experts, policymakers, and non-governmental organizations).

> The framework consists of a series of four steps, each explained in further detail below, with many of the steps linked through important feedback loops.

Figure 6.3. Framework for Enhancing the Climate Resilience of Investment Projects



6.2.1. Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality



Objective: The purpose of the first step is twofold. One, the process evaluates whether the project is exposed to any climate hazards, both now and over the course of the project's expected lifespan. And two, the process seeks to determine the level of complexity required for the analysis based on the project criticality.

Activity 1a. Screening for climate hazards. A climate hazard is any climate-driven event that may result in damage and loss to the project. These can be a product of:

- **Extreme weather events:** low-probability but high-impact climatic phenomena (such as floods, droughts, or heat waves), as well as more frequent, lower-intensity events which can also cause significant impacts

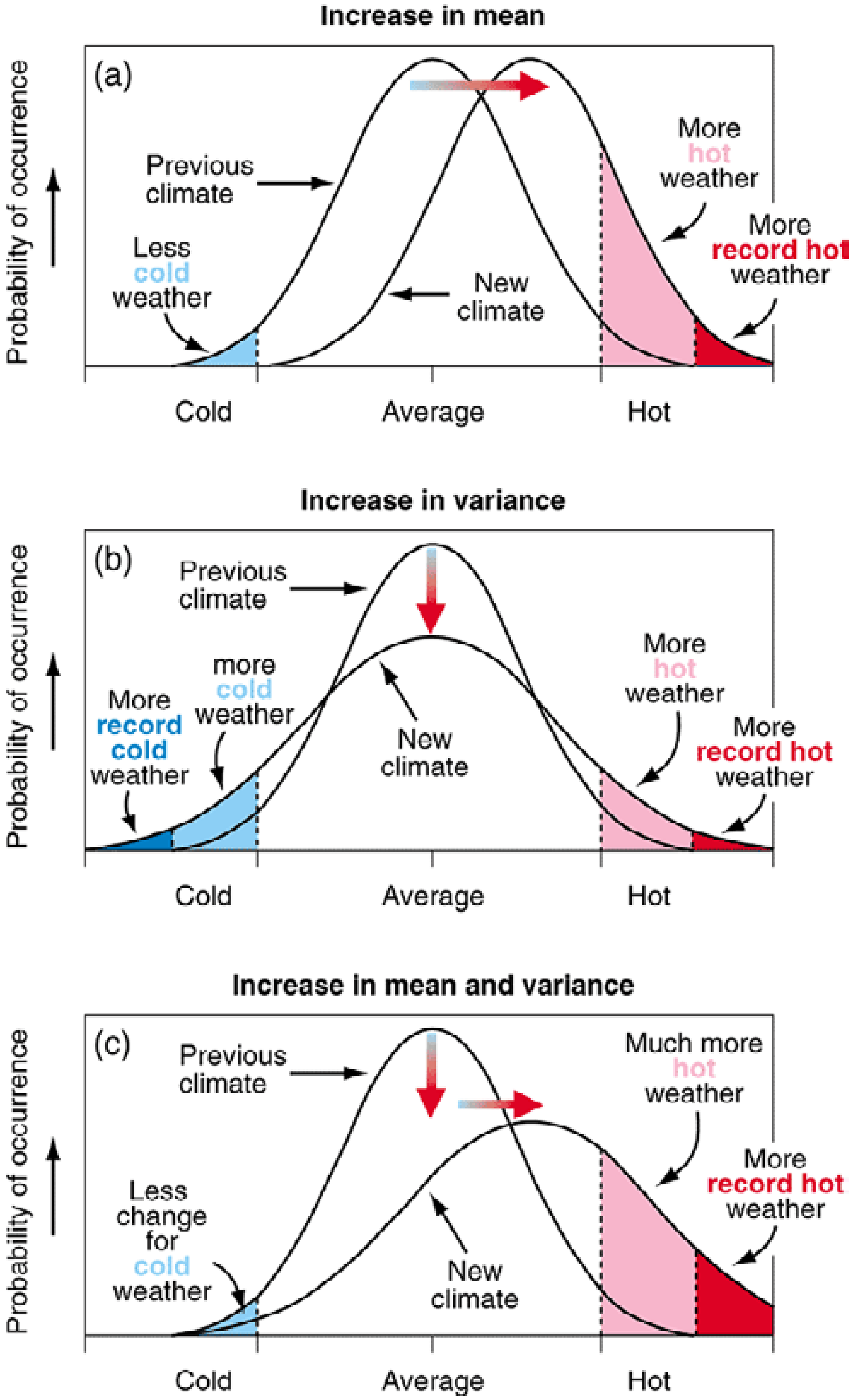
- **Long-term changes to normal climate conditions:** changes relative to the historic baseline

As **Figure 6.4** shows, taken together, climate change can impact both the mean conditions to which a project will be exposed (e.g., higher temperature on average in the future), as well as the frequency and intensity of extreme weather events (e.g., more record hot weather). Exposure to climate hazards refers to whether the hazard is present at the project's location, either because of natural conditions or the absence of protective systems. When considering future exposure over the course of the project's useful lifespan, understanding the uncertain nature of future climate hazards is essential for evaluating the climate resilience of a project.

Screening for climate hazards will help the project team identify the types of hazards that threaten the performance of the project, given the project's location and expected useful lifespan. Climate hazard impacts are transmitted throughout transport systems, ultimately contributing to unreliable transportation networks, supply chain failures, and economic impacts to local and regional markets in Sub-Saharan Africa.

Typical climate variables to consider for transport projects are temperature, precipitation, flooding, extreme events, and sea level rise. These variables can constitute a hazard when their magnitude and/or duration affect the performance of the project. **Textbox 6.1** summarizes key climate hazards for transport networks in Sub-Saharan Africa.

Figure 6.4. Illustration of Climate Change Impacts



Source: Intergovernmental Panel on Climate Change (2001).

Textbox 6.1: Key Climate Hazards That Impact Transport in Sub-Saharan Africa

Temperature: changes in temperature leading to more frequent extreme heat events can cause increased pavement deterioration, rail track deformation and buckling, thermal expansion of bridge joints, and increased forest fires resulting in closure or failure of land-based transport infrastructure.

Precipitation: increased precipitation can reduce the load-carrying capacity of roads, cause excessive scour and erosion, and reduce their lifespan. Increasing drought occurrence can affect the ability to navigate inland waterways. Increased aridity or lower water tables can cause the settlement of infrastructure and roadbeds.

Flooding: flooding of roads, railways, and tunnels can cause road closures or other traffic disruptions. It can also lead to landslides, washout of gravel on roads and railways, erosion of bridges, and increased sediment loading of drainage infrastructure (leading to increased maintenance requirements and costs).

Strong winds and storms: strong winds and storms disrupt operations for all modes of traffic. They can increase the likelihood of structural failures (e.g. bridges are vulnerable to strong winds), create safety hazards (e.g. falling trees block road and railways), and create unreliable transportation services (e.g. air travel services).

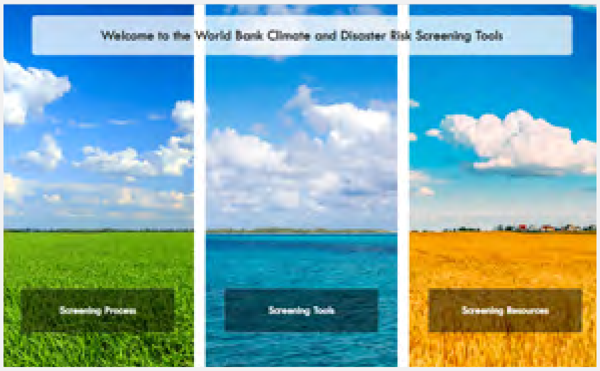
Sea level rise: sea level rise can damage port infrastructure and disrupt port operations, cause the loss of coastal waterway systems, damage low-lying coastal infrastructure, and exacerbate inland flooding from storm surges.

To screen the various climate hazards for a given location, the frequency and severity of historic events are first analyzed. However, it is important to consider the future exposure over the course of the project's useful lifespan. Generally, projects with a short useful lifespan (e.g., road networks) may only need to focus on the impact of extreme weather events consistent with those experienced historically. In contrast, projects with longer lifespans (e.g., bridges) should carefully inspect whether the project is exposed to new hazards and the increased frequency and severity of existing ones. Given the significant degree of uncertainty about future climate conditions, it is recommended to consider the broadest possible range of climate hazards, including those considered less likely, rating the severity of each threat to identify those most relevant for the project.

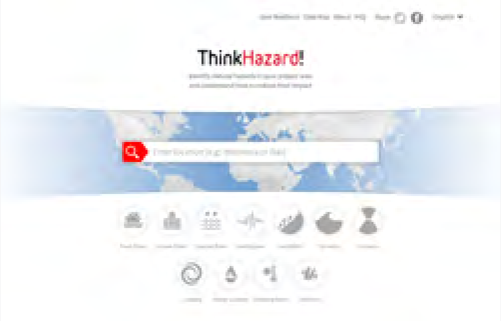
Various tools exist that can be used to screen a project's exposure to climate hazards; **Textbox 6.2** shows a selection of tools that could be used. Note that the individual outputs from these different tools may not be directly comparable to each other due to differences in the design of the tool and the assumptions it makes. In addition, these tools are not designed for detailed asset-level risk analysis but rather offer broad insights about the hazards present at the location of a proposed project. Subject-matter experts and local stakeholders should further supplement the climate risk screening results from these tools, as a mechanism to both validate the identified threats and reduce the risk of omitting relevant hazards.

Textbox 6.2: Climate Hazard Exposure Screening Tools

Climate and Disaster Risk Screening Tool (**World Bank)**. This tool provides a guided method to identify climate hazards and levels of risk to project evaluators at an early stage in the project design process. It focuses on physical and non-physical components of the project, and ranks the threat between low to high, including a no risk and insufficient understanding category. It has a “rapid” (about 30 min) and “in-depth” (about 2 hours) version for multiple sectors, the latter being highly recommended unless the evaluator is familiar with climate science and the project context. The tool relies on the World Bank’s Climate Change Knowledge Portal, which is a web tool that provides processed and synthetized historical and projected climate information from the Intergovernmental Panel on Climate Change. The tool considers extreme temperatures, extreme precipitation, flooding, drought, winds, sea level rise, and storm surge. Users would ideally be in possession of a project concept or design, as well as subject matter expertise for the country and project context. In terms of strengths, the tool guides the user on how to perform the screening and how to use data from other tools. It provides an assessment that includes the hazards at the project location as well as the potential impacts on the project’s infrastructure and service delivery, as well as how institutional and contextual factors interact with hazards and the project’s physical components.

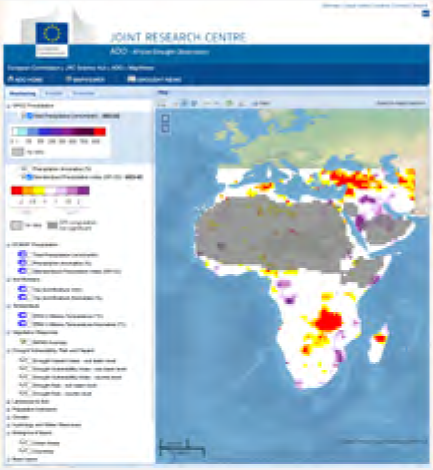


ThinkHazard! (**Global Facility for Disaster Reduction and Recovery)**. A web tool that provides a general assessment of climate hazards at a sub-national scale. The tool covers 12 different hazards including flooding (river, urban, and coastal), extreme heat, water scarcity, and cyclones. The tool presents a qualitative assessment of the level of a particular threat (i.e., low to high) both now and in the future given potential impacts of climate change, describing general impacts of the hazard along with generic recommendations for planning and evaluation. The tool also includes additional local and/or regional online resources when available. All that is required to run the tool is a general project location. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining a list of the relevant hazards to consider in a particular area, without requiring project specific information. It can help place climate hazards in context with other non-climate threats.



Textbox 6.2 (continued): Climate Hazard Exposure Screening Tools

African Drought Observatory (**European Commission Joint Research Centre)**. A web map service to identify potential drought hazard and risk levels in Africa. It offers access to recent drought monitoring data, as well as probabilistic forecasts for near term precipitation. A general project location is required to run the tool. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining an overview of historic climate hazards to consider in a particular area, without requiring project specific information.



Aqueduct Water Risk Atlas (**World Resources Institute)**. A global web map service that provides an assessment of coastal and riverine flood risks. The tool allows the customization of water hazards by time horizon, climate scenario and projection model, and return period. A general project location is required to run the tool. In terms of strengths, it easily allows users to explore how water risks change under different future climate scenarios.

ClimateLinks Screening and Management Tools (**United States Agency for International Development)**. The screening and management tool provides a sectoral toolkit for self-screening and rating of climate risks in the early stages of project design. The risk profiles consist of short briefs for countries and regions that assess the potential impacts of climate change on key economic sectors, including an overview of historical and future climate trends, the policy context, and existing adaptation projects.

Textbox 6.2 (continued): Climate Hazard Exposure Screening Tools

Additional non-web-based tools that could be consulted include:

The CRiSTAL (**International Institute for Sustainable Development**). A project planning tool for identifying climate risks and design components to enhance resilience. It incorporates stakeholder consultation and expert interviews, as well as guidance notes for internal evaluation developed by the African and Asian Development Banks. The tool includes an initial screening step that can be used to understand the potential impacts of climate hazards on the project and local livelihoods in the area. It expands beyond a cursory screening tool, offering guidance for project design and evaluation through a participatory process. A project concept or design is necessary in order to run the tool. In terms of strengths, it guides the user to perform a screening following a questionnaire and provides a community-based perspective of the project, as opposed to the perspective of funders only. It additionally puts climate hazards in context with social, political, and cultural conditions and provides a framework for incorporating local and expert knowledge through consultation.

Activity 1b: Determine the project criticality to establish the appropriate level of effort required to assess project resilience. Evaluating the impacts of the climate hazards identified to be relevant to the project can be complex, data-intensive, and expensive. However, not every project requires the same level of analytical complexity, and to ensure the framework is practical and accessible, projects are classified into two tiers. A low tier method is less data-intensive and simpler than a high tier method, which is generally treated as being able to more accurately model the project's response to climate hazards. For example, a tertiary, local road will likely be considered a low tier investment, whereas a primary highway bridge is a high tier investment. Distinct components within a large project that require separate analysis or modeling could be analyzed separately and may be classified into different tiers. **While the focus of this guidance note is on the project design level, it is crucial to understand the development setting in which the project is situated.** All project design decisions should be mindful of local conditions, including the policy landscape, as well as technical and institutional capacity (see Compendium Volume Chapter 2 for a discussion of these kinds of cross-cutting factors that can enable or hinder a project).

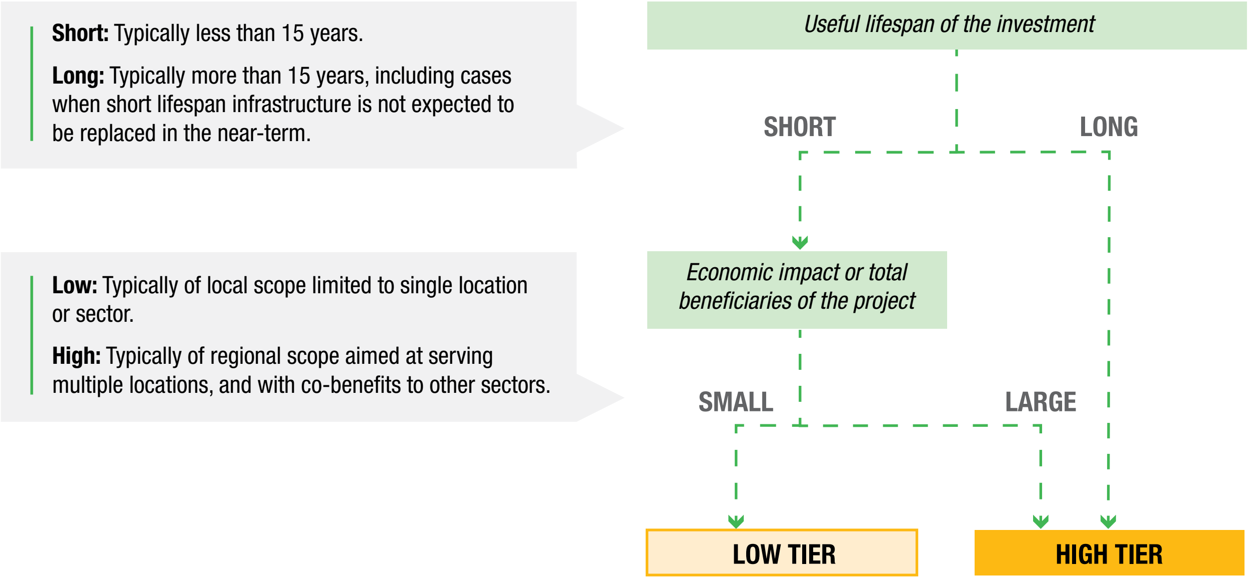
> A low tier method is less data-intensive and simpler than a high tier method, which is generally treated as being able to more accurately model the project's response to climate hazards.

Resilience Spotlight: Building Back Better in the Gaza Province of Mozambique

In 2018, under the Roads and Bridges Management and Maintenance Program, funded by the Climate Investment Funds and the World Bank, work began to rehabilitate flood-damaged roads and vital infrastructure in the southern province of Gaza, where as much as 70% of the transportation network had been damaged by floods. The program relied on **climate-smart approaches to help the transportation network be able to better to withstand future climate hazards**. **Climate resilient upgrades include the use of geocells or high-density plastic webbing, which more evenly distribute road stresses, thereby reducing cracking and water seepage**. In addition, efforts are underway to **develop country-specific road standards that are tailored to the climate conditions experienced by Mozambique's transport system**, which will also contribute to improved climate resilience. The achievement of a more reliable and climate resilient transportation system will be critical for development in the region, enabling access to education, health services and employment opportunities.

The tier of a project can be determined using the sample process shown in **Figure 6.5**, which assesses criticality based on the useful lifespan and total benefits of the project. **Note that this framework is qualitative and flexible in nature, with Figure 6.5 providing guiding principles** (i.e. project lifespan and benefits) and suggested cutoffs to determine short/long lifespan and small/large economic impacts or total beneficiaries to judge the project under evaluation. However, **project teams and stakeholders should consider a more flexible set of criteria, carefully assessing which guiding principles and cutoff values are appropriate for their particular project and inspecting whether using the selected criteria result in an appropriate level of criticality**. For example, when looking at transport investments, high tier projects could also include those that address agricultural product distribution or enhance access to medical facilities. On the other hand, a low-tier project might be the building of a secondary suburban road that provides additional traffic capacity in a growing area. These examples highlight that context is required to appropriately determine the criticality of a project.

Figure 6.5. **Sample Tier Determination Process**



Short: Typically less than 15 years.

Long: Typically more than 15 years, including cases when short lifespan infrastructure is not expected to be replaced in the near-term.

Low: Typically of local scope limited to single location or sector.

High: Typically of regional scope aimed at serving multiple locations, and with co-benefits to other sectors.

Activity 1c. Establish a biophysical modeling approach based on the project tier. The results of the tier determination process serve as the basis for establishing a biophysical modeling approach that simulates the physical behavior of the project under different climatic conditions (e.g., translating changes in future precipitation to altered runoff volumes and subsequent road deterioration). These models (i.e., simplified, conceptual, mathematical representations of a system) require climate variables as inputs and produce outputs of interest that are later used for the socio-economic evaluation. The kind of climate and other input variables required will vary based on the biophysical modeling approach selected.

Selecting a model for a particular analysis always depends on the specifics of the project. For example, the decision to put in a paved road versus a gravel road requires completion of a traditional lifecycle cost-benefit analysis that takes into account the lifespan and cost of replacement of the different options being considered. However, decisions regarding bridge placement require a more sophisticated model that incorporates hydrologic factors, potential impacts from scour, and the associated adaptations as well as costs of delay from bridge repair. Models should be determined based on their capacity to inform and improve the design of the project, particularly from changes in climate inputs.

When selecting a modeling approach, it is not just important that the model relates climate variables to outcomes of interest, but also to consider which individual climate variables the model is sensitive, as well as possible interaction effects among multiple variables. External inputs, such as road quality data or traffic capacity, may have increasing levels of detail for higher tiers. Furthermore, it is important to consider whether system-wide modeling is necessary to understand the risks to or benefits from a project, and in these cases, system-wide modeling would need to be undertaken. **Ultimately, model selection should be conducted considering the scope,**

functionality, availability and processing capacity of a particular model, experience utilizing it, knowledge of its caveats and limitations, and data availability. That said, where existing models and analytical tools already exist for a project that are more analytically rigorous and detailed than the identified tier level, these existing tools should be preferentially used.

Models in the transport sector are primarily focused on detailed engineering of transportation systems and infrastructure. **Figure 6.6** below provides guidance for the selection of a tier-specific modeling approach to be utilized for the biophysical evaluation of the project, with **Table 6.1** presenting further detail on these models. High tier models are typically supplementary analyses that use inputs from the low tier models. Additional resources can be found in Taylor (2020), who provides a summary of overall approaches relevant to the sector, as well as a report by the United Nations Framework Convention on Climate Change (2008) which present details on modeling of infrastructure and coastal resources that may be used for transport infrastructure. Water ports and airports require highly specialized models and expertise, and evaluations are largely dependent on the local conditions and level of use of the infrastructure.

Figure 6.6. Possible Modeling Approaches by Tier

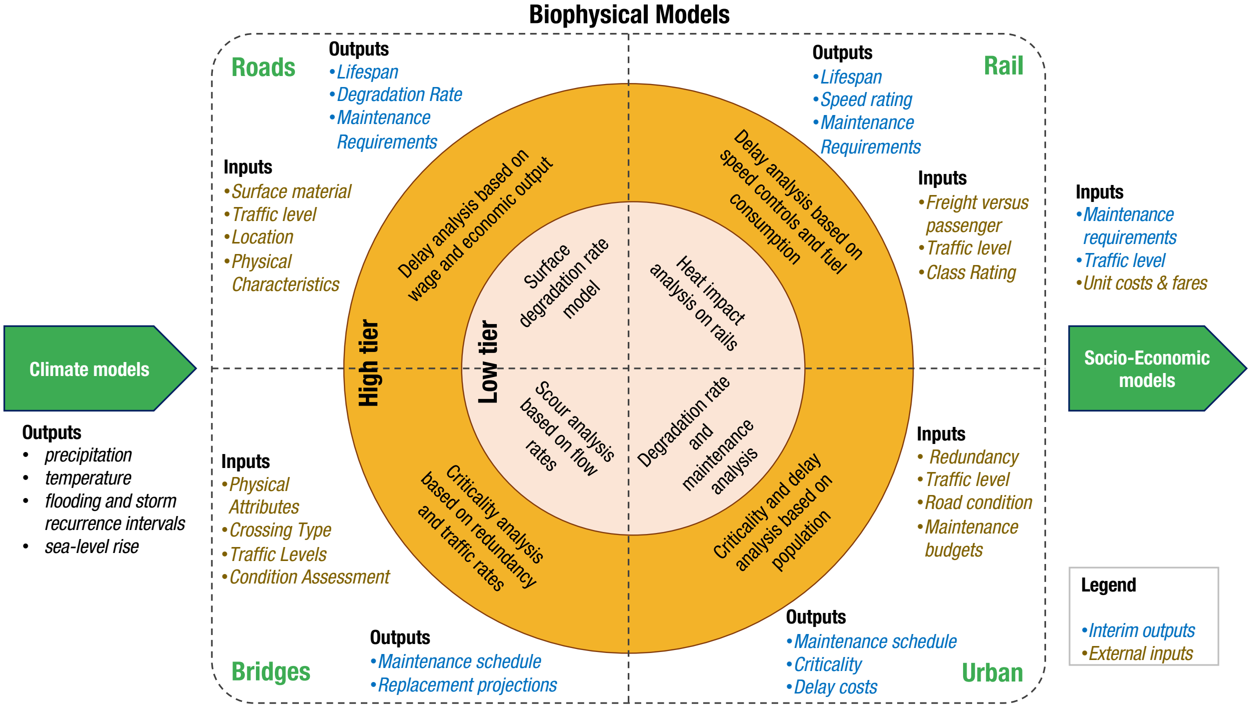


Table 6.1. Modeling details for low and high tier approaches

TIer	Roads	Rail	Bridges	Urban
Low	Focus on impact of precipitation and temperature on surfaces as well as impact of precipitation on road base erosion. Analysis of extreme event frequency for impact on flooding.	Focus on projected extreme temperatures versus historic temperature to determine potential for deformation under extreme temperatures.	Focus on increased flow rates and potential for bridge pier damage due to high flow events. Need for diversion strategies based on potential flow rates.	Maintenance impact based on reduced projected lifespan. Focus on base road impacts plus maintenance budget analysis to determine lifespan impacts. Criticality of roads taken into consideration for traffic impact.
High	Determination of economic impact from specific geographic areas as well as traffic levels.	Differences between passenger and freight costs as well as between specific rail hubs.	Fragility analysis to provide input to long-term maintenance and investment planning.	Include population changes to determine increased dependence and criticality of network in specific areas. Delay analysis to inform criticality analysis.

Outcome: At the end of this step, the project team should have acquired a high-level understanding of the climate hazards the project is exposed to as well as the analytical requirements to adequately conduct a climate impact assessment of the project. Depending on the identified tier, an appropriate modeling approach should be established in consultation with modeling experts. Where a project is composed of separate investment components that are exposed to a different set of hazards, all the activities in Step 1 should be completed for each individual project component in turn.

Case Study Demonstration of Step 1: Kenya's Vision 2030 for Transport Resilience

Background: In 2008, Kenya unveiled their Vision 2030 plan to enhance economic security and establish the country as an industrialized, middle-income country. Within the transport sector, Vision 2030 documented the need to enhance and maintain 200,000 km of existing roads as well as construct and rehabilitate 5,500 km of roads. This vision was updated in 2014 with the "Roads 10,000 Programme", where the focus was on paving about 10,000 km of roads through an annuity financing model of public private partnership. In addition to the challenge of financing this goal, the Kenyan government recognized the negative impacts that climate change may have on transport. Kenya's road network is largely unpaved (65 percent of the network has an earth surface), with the remainder composed of asphaltic concrete (7 percent), surface treated (8 percent) and gravel (20 percent) (Kenya Roads Board 2018). The predominance of unpaved roads presents a challenge as projected increases in precipitation due to climate change places unpaved roads into a weak-link position. The criticality of Kenya's roads is reflected in their National Adaptation Plan as well as the National Climate Change Action Plan where climate-proofing infrastructure includes establishing "efficient, sustainable, world-class transport systems and logistic services that withstand projected impacts of climate change."

1 Assess project exposure and criticality

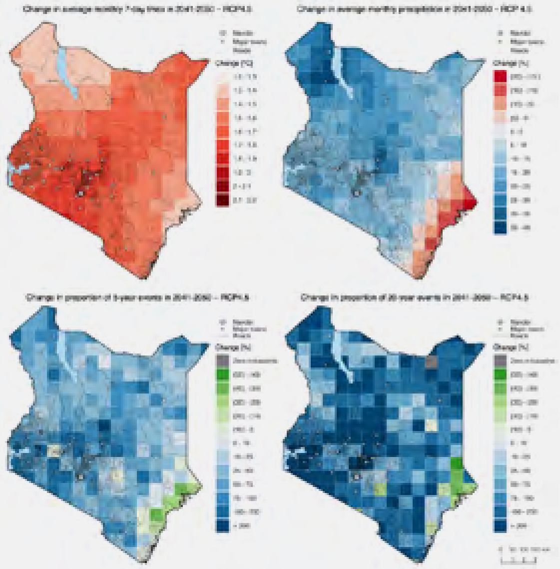
2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

1a. Screen for climate hazards → *1b. Determine project criticality* → *1c. Establish a biophysical modeling approach*

Climate hazards: Road infrastructure is vulnerable to a broad range of climate impacts. Temperature increases result in reductions of lifespan for paved roads, while increased precipitation can result in increased erosion, surface wearing, and washouts for both paved and unpaved roads. Generally, Kenya is predicted to experience higher temperatures, more precipitation and more frequent intense rain events in the future. The maps below present projected changes by 2041-2050.



Left: absolute change in the monthly maximum 7-day moving average temperatures in degrees Celsius. Right: percent difference in monthly precipitation (Source: Industrial Economics, Incorporated 2021)

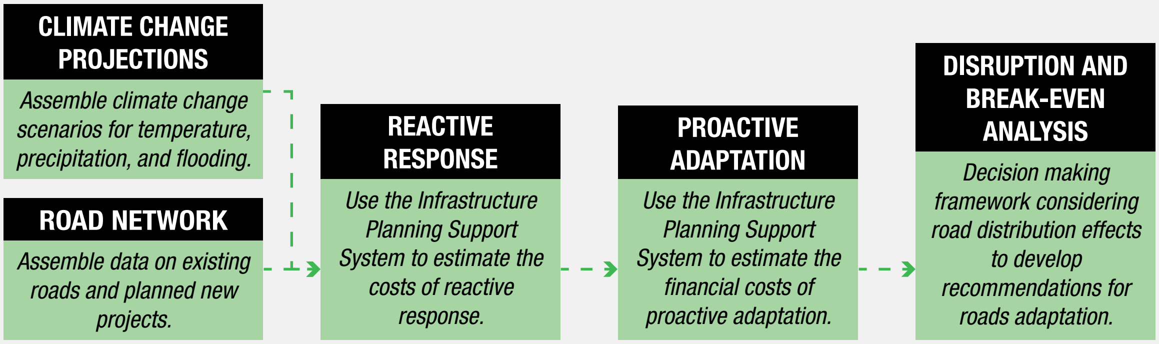
Case Study Demonstration of Step 1 (continued): Kenya's Vision 2030 for Transport Resilience

Overall, the 7-day maximum temperatures are likely to increase across the whole country – see left map above. Precipitation is expected to increase almost everywhere except for the coastal areas along the Indian Ocean – see right map above. Precipitation around major towns could increase between 5 to 35 percent as compared to the historical baseline. Similarly, both 5-year and 20-year local flooding events are expected to become more frequent, with the latter increasing over 100 percent in the vicinity of most major towns.

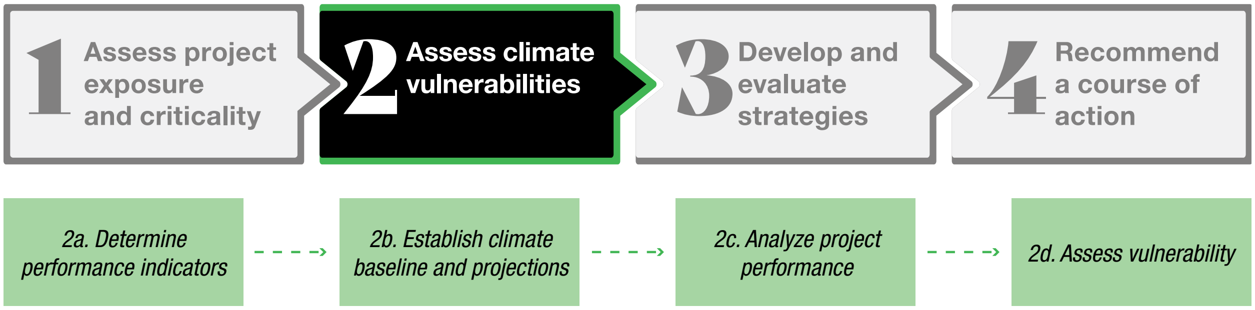
Project criticality: These road investments are considered a high-tier project as they are key to economic and social goals for Kenya, enhancing domestic and regional trade through the upgrading of national and local road networks. This criticality is reflected by the Kenyan government establishment of a 50-year transport plan that integrates the network throughout the country. The goal of the plan is to enhance the standard of living in both rural and urban areas by leveraging road networks to enhance agricultural transport to markets, enhance access to education and medical facilities, and ensure year-round transportation connectivity between population centers in support of increased trade. As such, these roads are required to be resilient to ensure continued access during climate-related events.

Biophysical modelling approach: Overall, the biophysical modelling approach taken in this case study incorporated climate change projections and road network data as inputs. These inputs were processed through the Infrastructure Planning Support System – a quantitative, engineering-based analysis tool – to model the impacts of climate change on current and planned future roads and bridges, as well as to quantify the costs to address climate change adaptation needs. Costs were evaluated for two different approaches: **a reactive "no adaptation" approach** which analyzes the impact of a changing future climate on roads built to current design standards; and **a proactive "adaptation" approach** which reduces future risk and damages by changing design standards at the time that upgrades or re-construction are undertaken. These results are then complemented with an analysis that additionally takes into account the cost of disruptions (beyond just the financial costs described above) to the transport network for both approaches, coupled with a "break-even" value framework to develop recommendations.

The core of the analysis is the estimation of quantitative impacts resulting from climate change. Conceptually, the cost estimation process follows a three-step process of damage estimation, cost impact and adaptation analysis. In the first step, the level of potential damage is determined based on the difference between future conditions defined by climate scenarios and the historic environment, and how that difference affects the as-designed condition of the infrastructure. This analysis involves looking forward across the lifespan of the infrastructure being analyzed and assessing how climate change will affect it. Once potential damages have been determined, the Infrastructure Planning Support System estimates the costs associated with the two different investment strategies, namely reactive response and proactive adaptation, with both these strategies analyzed with the goal of achieving the original design life of the infrastructure in spite of climate change impacts.



6.2.2. Step 2: Assess the Vulnerability of the Project to the Identified Climate Hazards



Objective: After the project screening and assessment of the necessary analytical complexity, the next step is to **assess the project's vulnerability to climate hazards**. This process seeks to identify how a project performs under extreme climate conditions and, incrementally, under a future with climate change (which can further impact the frequency and intensity of extreme events), as compared to current conditions. This same framework will also be used later to assess the performance of possible adaptation options to build climate resilience. The process involves four different activities, each described below.

Activity 2a. Determine performance indicators and targets to assess the climate vulnerability of the project. On the one hand, these metrics would include the economic return of the project measured as net present value, benefit-cost ratio, or internal rate of return, and minimum acceptable returns or hurdle rates as targets (e.g., a net present value above zero, an economic rate of return above a minimum return). On the other hand, indicators that characterize and assess the success (or failure) of the project and the contribution to accessibility or connectivity should be considered. **Textbox 6.3** provides a sample list of possible indicators for transport-focused investments. Depending on their nature, some may be quantitative outputs from the biophysical or socio-economic models, while others may require additional calculation assumptions. For instance, estimating pollution emissions requires assumptions about the mean energy mix and efficiency of the transport fleet. When feasible, performance indicators should incorporate metrics established by the broader policy environment and development strategy, particularly when those address climate resilience already.

Textbox 6.3: Performance Indicators in Transport

- Connectivity (cost, time, and reliability of transport network)
- Level of service, congestion, or travel times
- Safety (i.e., road fatalities)
- Transportation fares and affordability
- Local air pollution or noise pollution
- Energy use and fleet efficiency
- Mass transit supply and use
- Supply of vehicles
- Travel distances or volumes (passengers and cargo)
- Coverage in rural or underserved areas
- Accessibility to jobs or amenities

Whereas typical project evaluation methods consider means and weighted averages as performance metrics, given the large degree of uncertainty associated with future climate conditions, an evaluation of climate resilience should look at a range of expected values across different potential future climate scenarios (for instance, as defined in reports from the IPCC), as well as thresholds that cause a project to fail, in order to identify project designs that perform well across a range of different future conditions.

> Depending on the project, baseline climate data would include historical hydro-meteorological records such as temperature, rainfall, low flows, and high flows.

Activity 2b. Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions. The climate baseline describes the default conditions applicable to the initial design of the project, representing the reference point for the analysis. During later stages in this step, a subset of baseline conditions will be perturbed, and performance between baseline and future conditions will be compared for assessing vulnerability.

Resilience Spotlight: The Second Lagos Urban Transport Project in Lagos, Nigeria

The Second Lagos Urban Transport Project, supported jointly by the World Bank and the French Development Agency, built on the successes of Lagos' Bus Rapid Transit corridor, expanding the corridor by 13 kilometers. The original corridor was so successful that the operator was able to recoup its capital investment in the bus fleet within only 18 months. This second phase of the project included the rehabilitation and widening of the road from four to six lanes, the construction of pedestrian overpasses, a bus depot, terminals, a road bridge, as well as improved interchange and transfer facilities. **To ensure the resilience of these investments to the frequent floods experienced by the city of Lagos, measures to enhance flood resilience were also included in the project. These flood resilience measures included upgrading of pavement in sections of the road that experience submersion during the rainy season, as well as implementing portions of Lagos State's drainage master plan.**

In order to generate a baseline, the project team must first evaluate the availability and quality of historical data (possibly using statistical tools to fill in any data gaps), keeping in mind the expected lifetime of the project. An appropriate time frame for establishing a climate baseline from observed data in the transport sector would be 30 years of historic records. In cases with limited data, a baseline of the last 10-20 years could be acceptable, however, the shorter the period used the greater the possibility that the period used is not representative of the long-term climate. Depending on the project, baseline climate data would include historical hydro-meteorological records such as temperature, rainfall, low flows, and high flows. The World Bank's Climate Change Knowledge Portal is a good place to start to obtain existing historical data for a particular area.

As such, for projects with short lifetimes (generally less than 10 years), the range of natural climate variability is the dominant concern, over and above the long-term impacts of changes to mean conditions as caused by climate change. For example, the development of an unpaved road into a newly developed agricultural area will require rehabilitation less than 10 years from completion, regardless of climate impacts. Projects with longer time horizons, however, are subject to greater uncertainty and should consider a wide range of future climate conditions. For instance, the development of a new airport runway is an expensive and labor-intensive process that results in a long-term asset, and long-term projections of wind speeds, precipitation, and storm surge, among other climatic variables should be taken into account.

There is a great deal of uncertainty about future climate conditions, particularly for long time horizons, which makes the question of which climate futures to consider a non-trivial decision point in the evaluation process. Future climate is uncertain not just because of natural stochastic variability in the climate (i.e., one rainy season can be wetter than another), but also because of uncertainty about how future greenhouse gas emissions will grow, and uncertainty about how the climate system will respond to future emissions levels. One way of exploring these various sources of uncertainty is through the use of different future scenarios or pathways. While tempting to focus in on just one or a few individual climate futures, there are compelling reasons to consider a broader range of possible conditions: a single climate future describes only one possible version of the future, with many other possibilities going unexamined, making it difficult to draw well-substantiated conclusions.

Detailed, quantitative simulations of future climate can be obtained from projections modeled through GCMs. Recent World Bank guidance (2022) focuses specifically on the selection of future climate projections and recommends considering **an optimistic and a pessimistic scenario of greenhouse gas concentrations** as driven by global greenhouse gas emissions trajectories and climate mitigation policies, as well as **several scenarios that represent a "dry and hot" and a "wet and warm" future**. The first set of scenarios allows one to assess the impact of uncertain global climate mitigation efforts on project outcomes, whereas the second set helps assess local climate risks and overall uncertainty in climate model outputs on project outcomes. The latter is important because different models simulate different climate outcomes for the same emissions scenario due to their reliance on different modeling approaches. In addition, as a general rule, an analysis should consider different GCMs in order to capture the range of possibilities predicted by climate scientists. Attention should be paid to the range of future conditions described by these model ensembles (by considering confidence intervals, for example) rather than just their averages. **Textbox 6.4** provides guidance on where to obtain climate projections, with further details presented in the technical note on working with climate projections included in the Compendium Volume.

An even more rigorous analysis suitable for high tier projects would include considering the full range of future climate uncertainty (as compared to selecting a number of individual climate scenarios) through stochastic estimations of climate variables from a weather generator. The Decision Tree Framework (Ray and Brown 2015) provides additional guidance on how to use a weather generator in project evaluation.

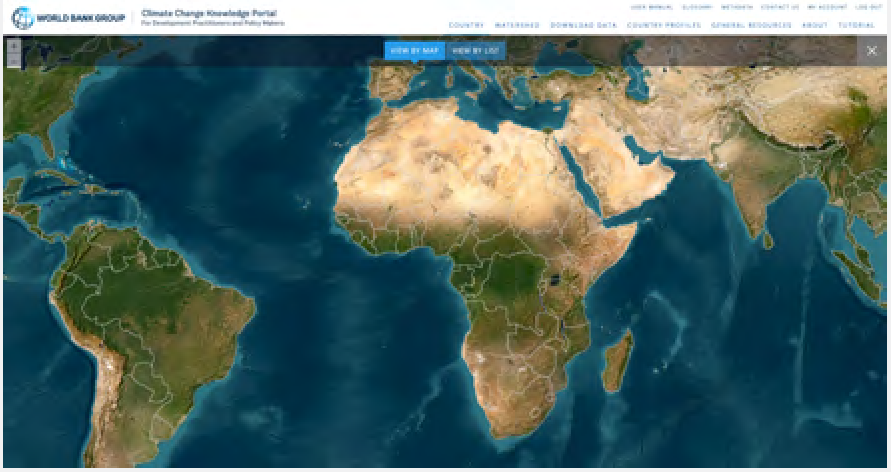
Finally, through stakeholder consultation and expert advice, the project team should assess the degree of uncertainty suggested by the range of climate scenarios considered, as well as to what extent these uncertainties are tolerable and/or should be mitigated.

Activity 2c. Analyze the project's performance under the selected climate scenarios. The output of Activity 2b is then directed into socio-economic models that convert biophysical outputs into costs and benefits, identifying the performance of the project for both baseline and future scenarios. For example, the potential damage to a highway will result in delays while the asset is repaired. This delay will in turn result in reduced revenue to local businesses as individuals choose to frequent other establishments that may be easier to access. The lost revenue in turn may impact employment at the retail establishment which then expands into numerous downstream impacts. These results, along with the performance in the metrics established in Activity 2a, serve as the basis for the evaluation.

Textbox 6.4: Where to Obtain Climate Projections

The output of future climate simulations can be obtained from various sources:

The World Bank's Climate Change Knowledge Portal has both historical data and future climate simulations available for every country/sub-national unit/drainage basin in the world. All information contained within the Knowledge Portal is consistently produced and thus directly comparable. As well as being free of charge, it is well-suited to project teams who are not used to working with raw, unprocessed output from climate models and it saves time on data searches and data processing.



National meteorological agencies often also provide localized climate information, which can be accessed through the World Meteorological Organization's website.

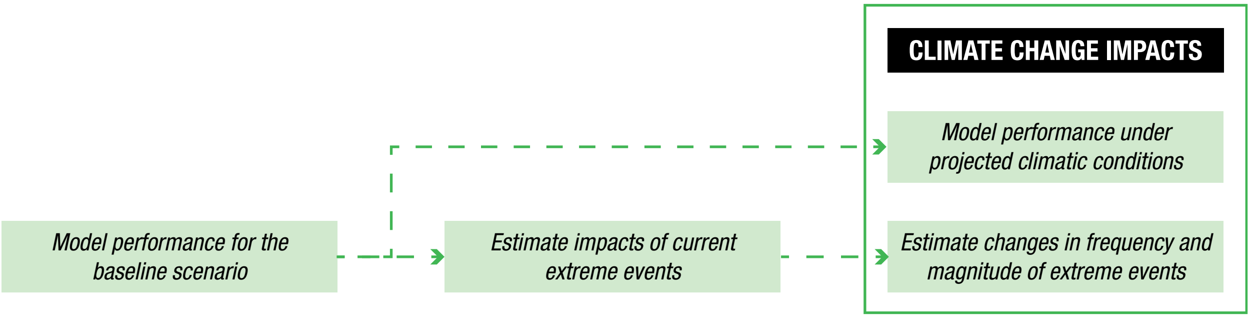
Global observations and computer simulations from the Intergovernmental Panel on Climate Change's various assessment reports, can be obtained from their Data Distribution Centre. Similar information can also be collected from the KNMI/World Meteorological Organization Climate Explorer. These latter two sources provide raw, unprocessed model outputs, which require significant time and expertise to process and bias correct, before they can be utilized in project analyses.

Transport-related investments are generally evaluated using standard evaluation practices such as Cost-Benefit or Cost-Effectiveness analyses, considering both direct costs and benefits (such as reduced maintenance costs or increased revenues), as well as indirect costs and benefits (such as road disruptions). Economic analysis takes the view of a social (e.g., government) planner, and ideally considers all changes in welfare in the assessment. The technical note on economic modeling included in the Compendium Volume provides a primer on these models and the quantification of externalities, as well as on approaches required for cases in which the project's performance results in changes in macroeconomic variables further down the value chain (e.g., changes in commodity prices). For more road-specific economic evaluation, the World Bank's *To Pave or Not To Pave* report (2021) provides an overview of typical economic valuation methods, including cost-benefit, cost-effectiveness, and muti-criteria analysis.

Following the analytical approach determined in Step 1, the analysis should model the impacts of climate hazards following the process in **Figure 6.7.** Climate change impacts should be modeled for all the future scenarios considered in the previous activity and compared against the baseline. Hallegatte et al. (2021) and Asian Development Bank (2015) provide further guidance on how to incorporate the effects of climate change and extreme weather events in cost-benefit analysis. For projects with long time horizons, it is recommended to look at the result at multiple timestamps (e.g., midcentury and end of century).

When conducting the assessment of a new development, a counterfactual representing a no-investment scenario, would be appropriate to assess whether the investment is better than a no-action scenario, as well as to measure the overall contribution (i.e., benefits minus costs) of the investment.

Figure 6.7. **Evaluation Process for Climate Hazards**



Activity 2d. Assess the vulnerability of the project in the form of a stress test. The analysis should then explore the performance of the project under the range of possible climate futures selected in Activity 2b to assess whether the project fails under those conditions based on the results from Activity 2c. This stress test will help the project team identify thresholds for failure, as well as failure scenarios (e.g., when the project does not meet the minimum economic returns) and the extent of the failure (i.e., difference between the results and a target measure). The vulnerability of the project is then assessed by looking at all the results generated in the previous activity for each future scenario. The following questions guide the vulnerability assessment:

- **Does the project meet the minimum performance targets?** When looking at economic return metrics, these generally require the project to have a positive Net Present Value and/or meet an Internal Rate of Return hurdle rate (see the technical note on economic modeling included in the Compendium Volume for a primer on economic evaluation). A project can also be vulnerable to a climate hazard when minimum performance in other metrics is not met under at least one scenario. For example, a project may fail if does not result in improved reliability and reduced travel disruptions.

- **To what degree does the project meet the minimum performance targets?** The extent of the failure can be measured through the range of results across different climate futures. This analysis may indicate the presence of scenarios with results below an acceptable threshold, which may render the project vulnerable if consequences can be catastrophic. For example, flooding events that interrupt the operations, if even for a limited time, of large transportation hubs like ports or train yards may have severe consequences on value chains, aside from the direct damages caused by the floodwaters themselves.

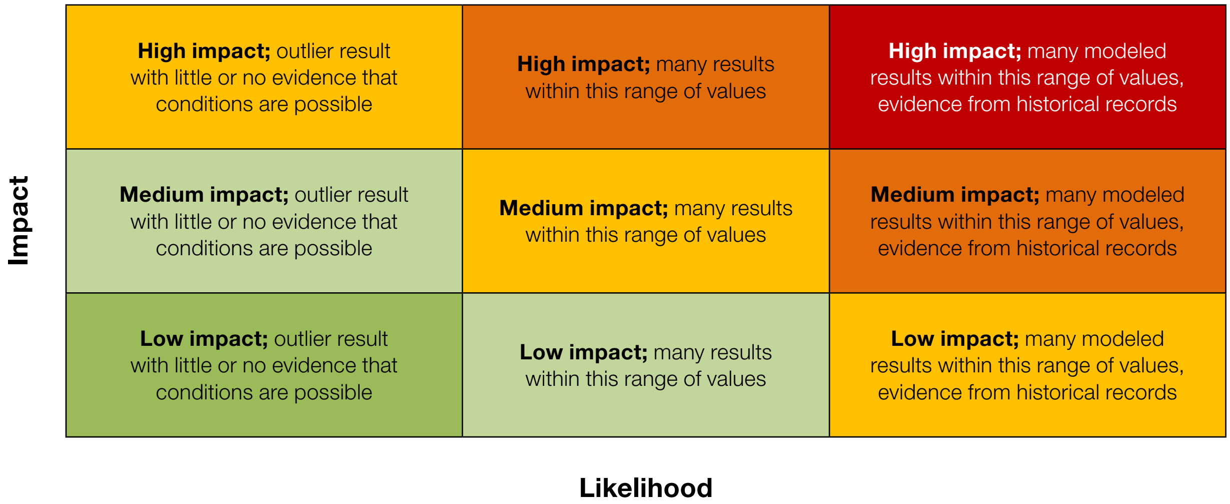
On the basis of these questions, a project can be considered vulnerable to climate change impacts if in the future (i) the results for individual climate scenarios are worse than the baseline, (ii) there is a greater number of failure scenarios than in the baseline, (iii) the potential range of results worsens, or (iv) a combination of these situations. For example, the development of a new rail corridor should be evaluated in terms of whether temperature or precipitation-related delays will result in the inability to transport sufficient freight and passengers to meet project targets. The analysis may find that for a single GCM scenario, the performance of the investment is sufficient to meet project targets. However, other scenarios show greater changes in future temperatures and precipitation patterns, resulting in the investment no longer meeting its targets. Those scenarios

that show a problematic outcome indicate that the project is vulnerable should those futures occur. By using a large number of scenarios, the project team can have more confidence in the level of concern associated with the vulnerability (i.e., large number of problematic scenarios versus few).

A practical framework to summarize the results of the vulnerability analysis, particularly for high tier projects with a large number of results, is to generate a risk matrix that considers impact and likelihood. Impacts refer to the effects of the climate hazard on the project's performance. Likelihood can be thought of as a "weight of evidence" that provides insights as to the level of concern associated with the vulnerabilities. Likelihoods can be assessed in relative terms, based on whether the results of each GCM run fall within the general range of all results or is an outlier, and whether the climatic conditions have been observed in the historical baseline.

Figure 6.8 presents an illustrative example of a risk matrix adapted from Ray and Brown (2015), where higher impacts and higher likelihoods lead to higher levels of risk. All projects found to be vulnerable, particularly those at higher levels of risk, should advance to the next step of the framework to examine whether the project's resilience can be improved.

Figure 6.8. **Sample Risk Matrix**



High impact; outlier result with little or no evidence that conditions are possible	**High impact;** many results within this range of values	**High impact;** many modeled results within this range of values, evidence from historical records
Medium impact; outlier result with little or no evidence that conditions are possible	**Medium impact;** many results within this range of values	**Medium impact;** many modeled results within this range of values, evidence from historical records
Low impact; outlier result with little or no evidence that conditions are possible	**Low impact;** many results within this range of values	**Low impact;** many modeled results within this range of values, evidence from historical records

Outcome: The result of this step is an understanding of the climate vulnerability of the project as currently designed. Comparison between the performance of the project under a historical baseline and under various climate futures provides an estimate of the degree of vulnerability of the project to climate change. It is possible that some project designs may be found to already be climate resilient in their performance given climate uncertainty and these projects can exit the framework here.

Case Study Demonstration of Step 2: Kenya’s Vision 2030 for Transport Resilience

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

2a. Determine performance indicators → *2b. Establish climate baseline and projections* → *2c. Analyze project performance* → *2d. Assess vulnerability*

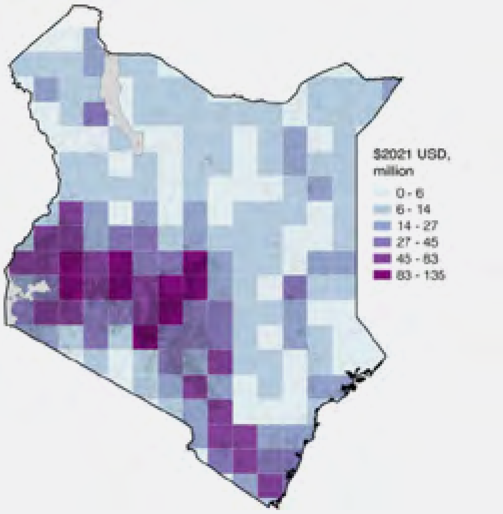
Performance indicators: The decision point for determining climate action in the roads sector is the break-even point for adaptation investments. Since roads have a shorter design life than other infrastructure elements such as water treatment plants or urban stormwater systems, climate adaptation measures must produce positive impacts within a shorter timeframe. Specifically, when considering adaptation, consideration must be given as to whether waiting for the next rehabilitation cycle would be advantageous economically versus taking near-term actions. This includes making climate-related repairs that are required prior to more extensive adaptation intervention. This decision may differ geographically, as well as by road type. For example, paved roads in one geographic region may have a different plan based on different temperature and precipitation change projections, while unpaved roads in different regions may have different plans based on precipitation projections. In all cases, the key performance indicator focuses on the return on investment for adaptation given the combination of direct repair costs and indirect delay costs.

Climate baseline and projections: The study considered the historical climate for Kenya and a total of 39 alternative representations of the future climate. Historical climate sequences were obtained from the Terrestrial Hydrology Research Group at Princeton University. Suitable data for developing the climate futures was provided by the Intergovernmental Panel on Climate Change’s Fifth Assessment Report. Two emissions pathways were considered, namely RCP (which stands for Representative Concentration Pathway) 4.5 and RCP 8.5. These pathways correspond to a “medium” and “high” greenhouse gas emissions scenario, respectively. Combining and downscaling the general circulation models and emissions scenarios yielded a total of 39 combinations, 20 for RCP 4.5 and 19 for RCP 8.5. These results were processed to produce a daily time series for a 50-year period, representing 2001–2050 at a ½ degree gridded resolution across Kenya.

Temperature was measured by the maximum 7-day moving average in degrees Celsius and rainfall by total precipitation, in millimeters. These two variables were projected daily for the 50-year period considered and averaged by month. The study forecast the change in flood risk from precipitation events in relation to the change in high daily precipitation. For the cost analysis, the baseline scenario considered temperature, rainfall, and flood return periods for the years 1970-1999. Reactive response and proactive adaptation scenarios considered the period between 2021-2050.

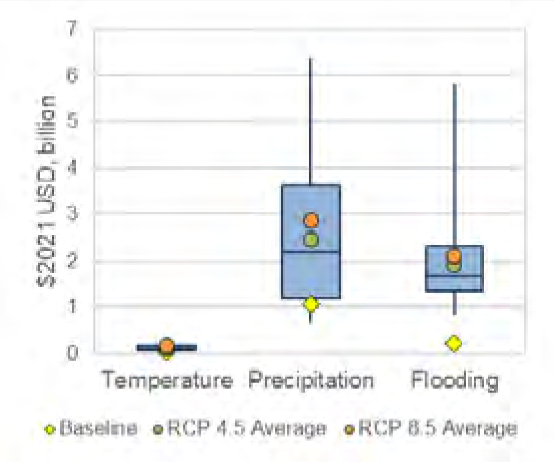
Analyze project performance: The analysis was performed by geographic region and road type. In total, reactive response costs for Kenya’s existing stock of roads averages $4.5 billion for the RCP 4.5 scenarios and $5.1 billion for RCP 8.5 scenarios for the period between 2021-2050. These amounts represent a cost increase of about 250 percent for the 30-year period between 2021-2050, relative to the baseline. The spatial distribution of costs is largely correlated with the density of roads. As the map below shows, the total reactive response costs are significantly higher in the western, central and southern areas of Kenya compared with the rest of the country, a pattern that is consistent with the population distribution across the country. However, when looking at the costs per km of road, these regions are not necessarily the most vulnerable.

Case Study Demonstration of Step 2 (continued): Kenya's Vision 2030 for Transport Resilience



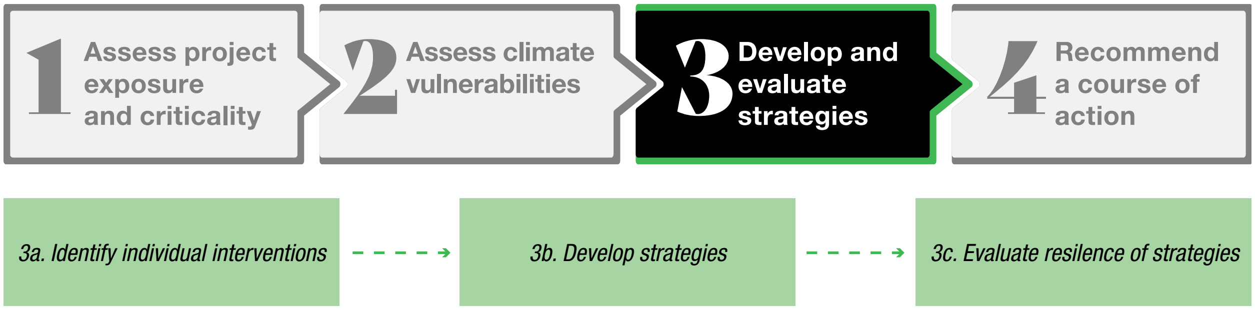
Total reactive response costs for all climate stressors, averaged across the 39 modeled future climate scenarios for the current road network, in discounted (6 %) million USD (Source: Industrial Economics, Incorporated 2021)

Assess vulnerability: Across Kenya, roads are not equally exposed to each climate stressor. Overall, costs associated with changes in future precipitation represent the highest share of reactive response costs, with precipitation costs ranging from US$ 0.7 to 6.4 billion depending on the scenario (see the middle column in the figure below). In contrast, costs associated with temperature impacts have a much smaller share in reactive response costs (3 percent of the total). This is for two reasons: first, this stressor impacts paved roads only; second, there are high temperatures in Kenya already, hence the incremental cost of further rising temperatures is marginal. Temperature costs are US$ 0.12 billion on average for the whole period (see the left column in the figure below), while precipitation and flooding costs are US$ 2.7 and 3 billion, respectively. Costs associated with flooding represent 42 percent of the total average reactive response costs and see the highest incremental increase as compared to the baseline (see the right-hand column in the figure below). Minimum future costs for temperature and flooding impacts are always higher than baseline costs, indicating that expenses should be expected to increase for every scenario.



Distribution of total reactive response costs for the current road network by climate stressor, in discounted (6%) USD 2021 billion. The box indicates the range of costs from the 25th to the 75th percentile; the line in the box represents the median; and the whiskers extending from the box indicate the range of costs from the minimum to the maximum among the 39 different climate scenarios considered. Averages for RCP 4.5 and RCP 8.5 scenarios are represented by colored circles. The baseline cost, representing the cost of maintenance that meets international engineering standards under conditions consistent with the historic climate, is indicated by a yellow diamond. (Source: Industrial Economics, Incorporated 2021)

6.2.3. Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience



Objective: This next step in the framework develops a set of possible strategies by which to adapt the project to climate hazards to improve its resilience. The analysis seeks to provide insights about the performance of the project given climate change as compared to the adapted project given climate change, and considers three activities.

Activity 3a: Identify individual interventions to enhance the climate resilience of the project. Building resilience involves strengthening the capacity of transport systems to cope with climate hazards. As such, the assessment should start from the results of the analysis in Step 2, and search for interventions that can mitigate the project's vulnerabilities by decreasing the magnitude and recurrence of failure scenarios. In general, these practices to enhance resilience are focused on the individual primary transport sub-systems (Cervigni et al. 2015):

- **Roads:** structural modifications to road surfaces and support layers including materials used, drainage systems, and structural designs. For example, stabilizing slopes with gabion boxes, concrete reinforcements, vegetation (e.g., grass and tree planting), and routine preventative maintenance. Furthermore, upgrading an earth road to a gravel or an unpaved road to paved, can enhance all-weather capacity.
- **Rail:** raising railways in low lying areas exposed to flooding and the use of emerging technologies to enhance resilience and provide greater granularity for potential vulnerabilities. For example, increasing the use of temperature sensors can reduce the need for slowdown or stoppage orders on extreme heat days.
- **Bridges:** build protective infrastructures such as flow diverters, dikes, or debris catchments. Structural improvements to bridges to increase opening sizes and elevate decks, raise or replace low clearance bridges, strengthen connections, and realign stream channels.
- **Urban:** enhancements to structures of all transport systems to reduce vulnerability to urban flooding as well as localized extreme temperatures due to heat island effects. Requirement to focus on critical system components due to user demand.

Table 6.2 lists some adaptation measures that can be used in Sub-Saharan Africa to enhance resilience. However, in addition to adaptation on existing road infrastructure, interventions should consider prioritizing new areas that are less exposed to a more strenuous future climate (or not exposed at all) to develop new infrastructure. Finally, it is important to highlight the role of **nature-based solutions,** which harness biodiversity and ecosystems services to reduce vulnerability and build resilience to climate change. For instance, the restoration of a forest upstream, which moderates overland flow and reduces flood peaks, could serve as an adaptation measure for a flood-prone road segment. The ecosystems note included in this Compendium Volume provides additional guidance on incorporating such measures into a project.

Table 6.2. Transport Practices to Enhance Climate Resilience

System	Practices
Roads (Including Urban)	• Increase capacity of roadway ditches; install lining in ditches • Add, improve, or replace culverts • Install check dams, half-round or spillway pipes, or rock channels • Construct walls to protect slopes from erosion, sloughing, or slumping • Raise roadway elevations and adjust angle of road slopes • Construct shoulder protection and pave downstream shoulders • Replace gravel roads with asphalt or concrete to prevent damage • Add vegetation (grass or trees) to slopes and other exposed road areas
Railways	• Install temperature sensors to reduce the need for slowdown or stoppage • Update rails to enhance resilience to temperature increases • Reinforce, raise, or replace rail bridges to resist greater flow rates • Enhance barriers in landslide prone segments
Bridges	• Construct wingwalls, dikes, approach berms, flow diverters, etc. to redirect flow • Realign piers and abutments or the stream channel • Elevate bridge decks to a level sufficient to pass anticipated flows • Increase bridge opening sizes • Construct relief openings or high-water overflow crossings • Install flow detectors • Construct debris catchments and deflectors • Strengthen bridge connections
Sea Ports, Inland Water Ports, Dry Ports, and Airports	• Place facilities at higher elevations to protect from sea-level rise and storm surge • Use heat-resistant materials for airways and runways • Enhance drainage for extreme precipitation events • Enhance surface infrastructure to enhance storm surge resilience
Cross-cutting	• Routinely inspect infrastructure and identify if any repairs or retrofits are needed to prevent failure

Sources: van Steenbergen et al. (2019), Barandiarán et al. (2019)

An overarching framework for approaching climate resilient transport practices is climate proofing infrastructure. Climate-proofing can provide a broad risk-based approach that can be applied to the development of transport projects (Asian Development Bank 2005). The Green Roads for Water Guidelines also provide a helpful framework for how to develop solutions for addressing the interlinked challenges of transport development and climate change by focusing on how to adapt roads to serve as not only effective transport, but to also optimize water harvesting, flood retention, sedimentation, and erosion control (van Steenbergen et al. 2019). The World Bank's Making Transport Climate Resilient reports (2010) also provide a framework to developing solutions that address transport challenges and climate change by using a risk-based approach to understand climate change impacts, focusing on improving the resilience of the existing transport network, and eliminating increases of costs to road users. Other sector-specific resources include Palin et. al (2021) for rail adaptation, Burbidge (2018) for air, and Kong et. al (2013) for ports.

Activity 3b: Develop adaptation strategies to enhance resilience. Once a set of promising and feasible adaptation measures has been identified for the project, more comprehensive and integrated strategies to build resilience should be developed by combining individual measures. Strategies should consider different sets of interventions, as well as different degrees of implementation, timing, or locations as appropriate, and should be part of a participatory consultation with stakeholders to identify and validate solutions. For example, one strategy could consider both upgrading existing infrastructure to higher standards to better withstand extreme precipitation, as well as pursuing catchment restoration to help attenuate flood peaks. Moreover, project evaluators should also pay attention to possible interactions between measures.

Textbox 6.5: Resilience attributes for transport

Key capacities to build climate resilience in infrastructure investments in Sub-Saharan Africa's transport sector include (adapted from Ospina and Rigaud 2021):

- **Robustness:** the ability to withstand the impacts of climate extremes and variability, maintaining transport systems' reliability and the functioning of supporting processes and infrastructure, while minimizing variability in performance.
- **Redundancy:** the availability of additional or spare resources that can be accessed in case of an extreme event.
- **Rapidity:** the speed at which critical resources such as transport infrastructure (e.g., roads and bridges) and supporting systems (e.g., urban transit), or supply chain assets (e.g., fuel resources) can be assessed.
- **Flexibility:** the ability of the system to be nimble and utilize opportunities in responding to uncertainty or other challenges. For instance, adapting infrastructure development plans after a disruptive extreme event.
- **Inclusion:** building on diversity and inclusion, ensuring that women and vulnerable groups have the necessary tools and resources, both in normal conditions and during crisis.

Ultimately, which interventions become part of a strategy will depend on what attributes of resilience need to be enhanced to reduce climate vulnerability, as well as how stakeholders and users define resilience for the particular project in question. **Textbox 6.5** presents a list of key attributes for a transport system, which can guide the development of adaptation strategies to enhance resilience, with these attributes ideally to be tailored to local circumstances. While these attributes are introduced here as guidelines to consider when developing possible adaptation strategies, they are a powerful tool to strengthen project design, especially when integrated as key resilience concepts into the project narrative from the outset and then used to track progress towards achieving greater resilience. Additional guidance can be found in the note for practitioners titled Integrating Resilience Attributes into Operations (Ospina and Rigaud 2021). In the face of climate uncertainty, it is appropriate that strategies consider a portfolio of measures to mitigate the impacts from multiple climate hazards, along with insurance and contingency plans for when conditions exceed the capacity of the adapted system to cope.

Though this guidance note focuses predominantly on climate adaptation (with adaptation considered the priority at present for Sub-Saharan Africa), it is important that adaptation and climate mitigation goals and activities are not treated in isolation, as the resilience of a project can also be impacted by climate mitigation-related considerations. For instance, more climate-resilient materials for road surfaces may be more greenhouse gas emissions intensive to produce as compared to the alternatives. The focus of this note on adaptation should not detract from the identification and quantification of any co-benefits that may accrue from climate mitigation.

Resilience Spotlight: Enhancing the Climate Resilience of the New Kazungula Road, Rail and Pedestrian Bridge Between Botswana and Zambia

On Monday, 10 May 2021, the new Kazungula Bridge over the Zambezi River was opened by the Presidents of Botswana and Zambia. The 923-meter bridge connects Botswana and Zambia and is an important link in southern Africa's transportation network. The bridge includes two car lanes in each direction, a single railway track, and pedestrian walkways on both sides. It replaces the pontoon boats that used to service this crossing location.

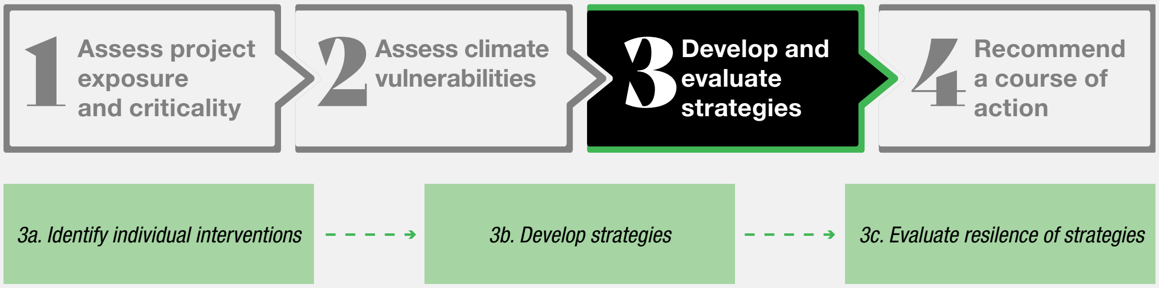
To help ensure the continued effective functioning of this new bridge in the face of altered future climate conditions, a number of resilience-enhancing measures could be considered. Bridges are often vulnerable to increasing river discharge under climate change, with **the addition of resilience measures such as approach berms, flow diverters, wingwalls, and debris catchments helping to protect bridge piers from damage during future high river discharge events. The railway track on the bridge will likely be most impacted by higher air temperatures in the future, with the addition of temperature sensors one possible resilience-enhancing measure to consider.**

Activity 3c: Evaluate the selected strategies' contribution to the resilience of the project. Having identified a feasible portfolio of individual adaptation measures, the next step involves using the same modeling framework established in the vulnerability assessment described in Step 2 to evaluate the performance of the different adaptation strategies being considered.

Depending on the specific interventions, it is possible that new model parameters or assumptions may need to be defined (looping back to Step 2) before being able to estimate the costs and benefits of different interventions, which may require the gathering of additional data. Comparing the performance of the strategies to the project as originally designed (in Step 2) in terms of how much they reduce the magnitude and recurrence of project failure provides a sense of the degree of climate resilience that different strategies offer. In other words, an adaptation strategy that increases climate resilience is one that results in fewer cases of failure, a reduced impact in the failure scenarios, or both. For example, strengthening bridge piers on a high-volume bridge can reduce the potential impact of a critical river crossing being damaged by a flood event. The extent of these improvements can be tracked using the Risk Matrix previously shown in **Figure 6.8**.

Outcome: At the end of Step 3, the project team will have identified promising portfolios of interventions that enhance the climate resilience of the original project design evaluated in Step 2. The output of this step is an updated set of results showing the project's performance for each adaptation strategy and climate scenario. This output will be the input for the following decision-making step.

Case Study Demonstration of Step 3: Kenya's Vision 2030 for Transport Resilience



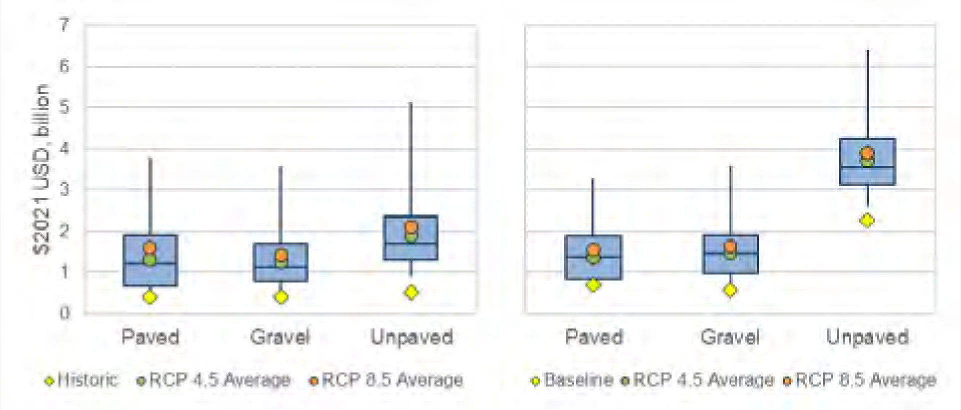
Identify individual interventions to improve project resilience: As shown below, paved, gravel and unpaved roads each have distinct adaptation actions that reflect differences in their construction and climate vulnerability.

Road Type	Climate Stressor	Effect	Proactive Adaptation Measure
Paved roads	Temperature	Increased temperature leads to accelerated aging of binder.	Construct dense seals (e.g., Sand Seal, Otta Seal, Cape Seal). Typically, Cape Seals are used on heavily trafficked roads.
		Increased temperature leads to rutting (of asphalt) and bleeding and flushing (of seals).	Adoption of base bitumen binders with higher softening points (including polymer modification) for surface seals and asphalt.
	Precipitation	Increased precipitation leads to increased average moisture content in subgrade layers and reduced load- carrying capacity.	Add wider paved shoulders to improve surface drainage.
			Increase base strength (thickness and/or quality) from the typical 150 mm to 225-300 mm depending on precipitation levels, to increase protection of subgrade layers.
	Flooding (in excess of design flood)	Wash-aways and overtopping of road.	Increase flood design return period by increasing the size of culverts to accommodate new 1 in 50-year flood level (in most cases will require raising the road to allow larger culvert to fit).
Gravel roads	Precipitation	Increased precipitation leads to increased average moisture content in subgrade layers, and reduced load- carrying capacity.	Increase gravel wearing course thickness to increase cover and protect subgrade layers.
			Upgrade to paved road
	Flooding (in excess of design flood)	Wash-aways and overtopping of road.	Increase flood design return period by increasing the size of culverts (in most cases will require raising the road to allow larger culvert to fit).
Unpaved roads	Precipitation	Increased precipitation leads to increased average moisture content in subgrade layers, and reduced load carrying capacity.	Upgrade to gravel (or paved) road and increase gravel wearing course thickness to increase cover and protect subgrade layers.
	Flooding (in excess of design flood)	Wash-aways and overtopping of road.	Increase flood design return period by increasing the size of culverts to accommodate new 1 in 50-year flood level (in most cases will require raising the road to allow larger culvert to fit).

Case Study Demonstration of Step 3 (continued): Kenya's Vision 2030 for Transport Resilience

Develop adaptation strategies: Given that the options to improve resilience differ between road types and the stressors that impact the individual road types vary by geographic regions, an effective strategy requires decisions that are both local in nature and stressor-specific. The optimum solution breaks down the potential impacts to individual road types in local regions. Once the impact of an individual stressor within a local region has been determined, an adaptation solution can be put in place, based on what makes sense from an economic and an engineering perspective.

Evaluate the resilience of the different strategies: The reactive adaptation costs across different road surface types are fairly similar (see left figure below). The proactive adaptation costs for unpaved roads are about 90 percent higher than the reactive response costs (see right figure below) and represent a higher share of the total cost (56 percent). For unpaved roads, proactive adaptation is an expensive option as those costs include upgrading to gravel roads on top of the associated stressor-specific adaptation cost. Average costs for gravel roads are 15 percent higher for proactive adaptation as compared to the reactive response costs, while the costs for paved roads do not show a significant increase when going from reactive response to proactive adaptation. While the total reactive response costs for paved roads are comparable to the costs for gravel and unpaved roads, paved roads represent only 8 percent of the total road km in Kenya, and therefore have the highest reactive costs per km. This is partly because they are affected by all three climate stressors and have higher unit costs for repair and maintenance.



Figures shows the distribution of total reactive response (left) and proactive adaptation costs (right) for the current road surface type, in discounted (6 percent) USD 2021 billion. The box indicates the range of costs from the 25th to the 75th percentile; the line in the box represents the median; and the whiskers extending from the box indicate the range of costs from the minimum to the maximum among the 39 different climate scenarios. Averages for RCP 4.5 and RCP 8.5 scenarios are represented by colored circles. The baseline cost, representing the cost of maintenance that meets international engineering standards under conditions consistent with the historic climate, is indicated by a yellow diamond.

Case Study Demonstration of Step 3 (continued): Kenya's Vision 2030 for Transport Resilience

However, when disruption and delay are taken into account (see figures below), proactive adaptation strategies always have a lower number of disruption days relative to reactive response, due to the proactive investment in measures to help prevent anticipated negative impacts from climate change.

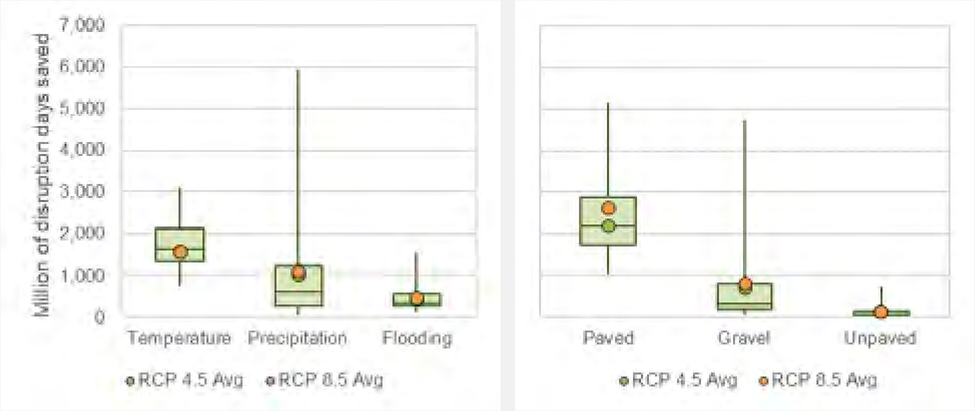
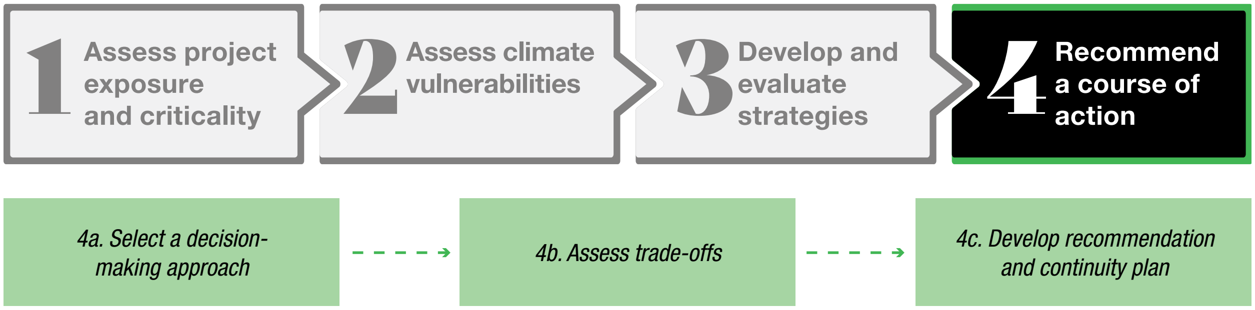


Figure shows the distribution of the difference in disruption days between proactive adaptation and reactive response, in million days, by climate stressor (left) and by road type (right).

6.2.4. Step 4: Recommend a Course of Action



Objective: Finally, this step will lay out a decision-making approach to identify a course of action from the adaptation strategies considered in Step 3 that considers trade-offs and looks at the full economic lifetime of the project. Three activities are involved.

Activity 4a: Select a decision-making approach that is able to help identify a strategy (from the set developed in Step 3) that is well-suited for a broad range of uncertain conditions. This requires assessing and trading off project performance across a variety of uncertain future conditions, rather than simply maximizing the expected results from averaged future conditions. While the focus in this note is on uncertainty about future climate conditions, resilience analyses in Sub-Saharan Africa are faced with a variety of different uncertainties, including from inadequate historical climate data, the divergence of existing climate projections, as well as changing political and policy environments, external market conditions, or levels of technology adoption. In this context, traditional decision-making methods often fall short because they typically strive to identify an optimal design for an average or most likely set of future conditions. (This group of methods is often described as being founded on **predicting and then acting** – see the technical note on decision making under climate uncertainty included in the Compendium Volume for an overview of these traditional decision analysis methods.)

Given the significant degree of uncertainty associated with future climate conditions, a new group of decision-making methods has been developed that focus on **preparing and adapting,** rather than predicting and acting. This class of methods emphasizes **the identification of flexible decisions that enable ongoing adaptation, or robust decisions that will prove wise across a wide range of future climate conditions.** In general, these methods involve framing the analysis and conducting an exploratory assessment, choosing initial and contingent actions to iterate and perform re-examination, and allowing participation of stakeholders. **Table 6.3** provides a summary of some of these decision-making approaches, grouped based on whether they emphasize the robustness or flexibility of the decision. (See the technical note on decision making under climate uncertainty included in the Compendium Volume for further details.)

Table 6.3. Summary of Approaches for Decision-Making Under Climate Uncertainty

Emphasis of Framework	Description	Examples
Robustness	These approaches focus on achieving acceptable project performance across a wide range of possible future conditions. The emphasis is on the investment decision to be made now and generally follows a conservative approach when incorporating future conditions that are significantly different from the baseline.	• Decision Scaling • Robust Decision Making
Flexibility	These approaches prioritize identifying a design that can adapt in the future given different climate conditions. In general, these value the agility of a design more than its robustness and include consideration of "tipping points" for climate variables that will indicate a change from one set of actions to another.	• Engineering Options Analysis • Adaptation Pathways

The World Bank's *To Pave or Not To Pave* report (2021) presents a further decision-making approach focused in particular on road paving projects. The approach, called SPADE-PLUS, weighs multiple decision factors, giving importance to those not easily quantifiable. This approach goes beyond climate considerations, with climate change adaptation and co-benefits being only one of the components of the analysis. The climate resilience evaluation included in SPADE-PLUS may be integrated with the approaches proposed in **Table 6.3**.

The selection of a decision-making framework should be informed by the preference either to account for future uncertainty now through measures that enhance the robustness of the decision or leave options open for future adaptation. This choice should be informed by the available resources today and in the future, the capacity of the project team to control or influence changes in the future, and the optimism that future information will help to clarify the adaptation decision and will arrive in a timely way. For instance, while a critical multi-modal transportation hub may benefit more from a robust approach that ensures the infrastructure is designed to withstand low-probability but high-impact flooding events, it may be considered acceptable for a local coastal road to experience increasingly frequent flooding as sea level rises before decisions are made as to whether to relocate the road or pursue other more expensive adaptation strategies.

As mentioned before, the framework for enhancing the climate resilience of projects that is presented in this note is circular: it is possible that after selecting a decision-making approach, the activities completed during earlier steps in the framework may need to be revisited and adjusted. For instance, having prioritized the flexibility to make incremental adaptation decisions and delay large investments till later (as compared to prioritizing system robustness now), this decision may necessitate returning to Step 3 and identifying additional adaptation interventions that enable flexibility, as well as returning to Step 2 and selecting a few additional uncertainty scenarios to explore if particular climate futures are concerning to decision makers.

Activity 4b: Assess the trade-offs of each strategy. Generally, there is no perfect adaptation strategy, and more beneficial strategies tend to be more expensive. Strategies that mitigate flood risks up to a certain probability may suffice for some types of infrastructure, while more critical components of the network may warrant a higher investment to reduce the residual risks even further. Furthermore, strategies that benefit one sector may cause negative impacts to other stakeholders. In this context, the decision-making process must also look at minimizing trade-offs. The starting point of this activity requires identifying, and if possible, quantifying, the trade-offs of each strategy. Typical trade-offs between investment decisions in the roads sector include the strengthening of existing assets versus expanding rural road access. It is often unclear whether significant capital expenditures made today may not be needed in the future due to climate change, or due to anticipating climate changes that ultimately do not occur. Thus, there are difficult questions as to whether to act or not to address climate vulnerabilities.

Resilience Spotlight: Paving the way to a climate resilient road network in the Central African Republic

A project to upgrade rural roads in the Central African Republic has taken a novel approach to enhancing the climate resilience of the road investment. **By designing and implementing a community-based road maintenance system, the climate resilience of the road works is greatly improved,** with studies showing that routine maintenance is the first line of defense against climate impacts (Cervigni et al. 2015). Building on this approach, **rain barriers were also constructed to protect the roads during the rainy season, with these barriers operated by locally recruited and trained employees.** This long-term, climate-smart approach is expected to significantly improve the durability of the road investments made under the project.

The quantitative analysis performed during Steps 2 and 3 can produce two kinds of results: a point estimate of an economic performance indicator (e.g., internal rate of return or net present value) and information related to the variability (i.e., distribution of uncertainty) around the point estimate. Under uncertain future conditions, the point estimate may be no more likely to occur than the wide range of other possible outcomes around it. For this reason, when assessing trade-offs, the project team should consider the distribution of uncertainty around point estimates to promote better decision-making.

In order to weigh the importance of different strategies, the project team should develop a hierarchy of all consequences that result from project failure. These causes of failure correspond to all the reasons why the project does not meet the performance metrics in the face of extreme weather events and climate change, as identified from the vulnerability assessment and addressed through adaptation strategies. For instance, if precipitation events of average magnitude (and therefore of frequent occurrence) are found to cause greater disruption in total than occasional, high magnitude floods, a standard paving plan for a large area may be a more worthwhile strategy than reinforcing a small subset of already paved highways to be able to withstand high magnitude flood events. This list will indicate the order of priority and urgency and should be produced in consultation with and validated by stakeholders of the project.

The project team should then carry out the decision-making process, with the benefits of the strategy (i.e., the performance metrics defined in Step 2 and evaluated in Step 3, considering the distribution of uncertainty of estimates), its direct costs and associated trade-offs, and the hierarchy of priorities as inputs. As mentioned, this process may require revising the analysis done in previous steps as new information is obtained and inputs are gathered from stakeholders. Decisions then could fall into three categories, namely:

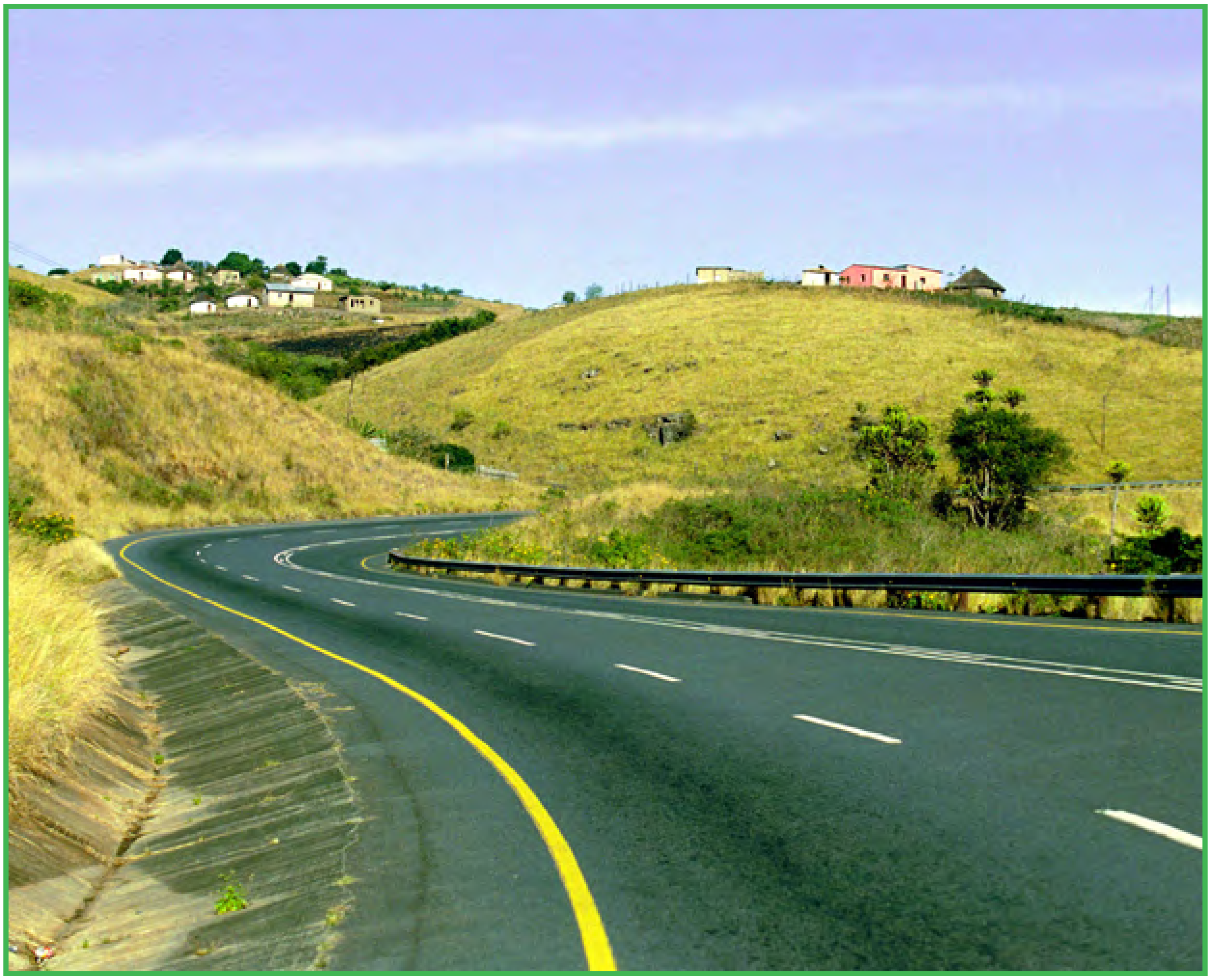
1) **Investing in climate-proofing the project at the time the project is being designed or implemented**, which can result in low-regret, no-regret and/or win-win options depending on the projected costs and benefits;

2) **Deferring from investing in climate-proofing but designing the project in such a way it can be more easily climate proofed in the future**, if deemed necessary; Or

3) **Deciding that the project design and monitoring should not take account of climate variables and their impacts at the present time**, and that investment in climate-proofing will be undertaken at a later point, if needed.

The first option sees more substantial investments in climate resilience at the project outset than the latter two options. The second option is commonly referred to as **adaptive management**, where proactive and incremental adaptation investments are introduced over the project's lifetime. The third decision making approach embodies **a wait-and-see mindset** – while this latter approach maximizes flexibility and adaptability, minimizes the hardening of infrastructure today, and may be preferred when funds are limited, and uncertainty is high, it is only suitable for situations where baseline risk is considered acceptably low. As an example of adaptive management, bridges could be put in place with decks that take into account higher river flows, but extra diversionary elements around piers could be deferred until higher flows are actually encountered.

> The recommendation of a preferred course of action should cover all components of the project cycle, starting with project identification, focusing on risk screening and identifying critical stakeholders and their roles and responsibilities. The recommendation should focus on those adaptation solutions that are technically feasible to address projected climate vulnerabilities, taking into account the related costs and benefits.



The recommendation of a preferred course of action should cover all components of the project cycle, starting with project identification, focusing on risk screening and identifying critical stakeholders and their roles and responsibilities. The recommendation should focus on those adaptation solutions that are technically feasible to address projected climate vulnerabilities, taking into account the related costs and benefits. In this context, the trade-offs analysis should also inspect the feasibility of a strategy in terms of technical capacities, policy environment, and financial constraints, with particular attention to the extent to which the environment supports or limits their implementation. Potentially, the analysis may require returning to Step 3 and revising the strategies proposed. Project implementation should identify stakeholders with the capacity to implement the preferred adaptation option(s), and include necessary capacity building at the individual and institutional levels. Lastly, the recommendation works best if it draws and builds upon country-level plans that identify priority areas, such as existing national transportation and infrastructure masterplans, as well as clean energy transition plans that indirectly impact fleet characteristics.

Activity 4c: The development of a recommendation and continuity plan should provide a narrative that justifies the selection of a course of action from the process in the previous activity. Moreover, the continuity plan should describe how project evaluation will be conducted, along with a clear schedule of activities and stakeholder responsibilities into the future, both during and after the implementation phase, including how resources for maintenance and/or continued adaptation will be mobilized, to ensure the investment continues to perform over the course of its life.

Both the narrative and continuity plan should discuss residual climate risks not addressed in the proposed project design that are still material to the project. Since it is not always economical or preferred to address all risks under all potential future conditions, there will generally be a residual risk. However, since the future is uncertain, it is possible for residual risk to grow over time in unanticipated ways to a point where it would be appropriate to address and should be the basis for a monitoring and evaluation plan. For example, precipitation-related risks may not be considered relevant today if most climate scenarios point out to a drier future but may become significant if the climate evolves differently than predicted. Monitoring and evaluation should focus on assessing how progress toward vulnerability reduction and changes in residual risk will be measured in terms of indicators, tipping points, and thresholds, and how lessons learned can be used to improve current and future projects underpinned by a fit-for-purpose monitoring, evaluation and reporting framework.

This plan should include which actors will be responsible for each action and when, and should cover the full economic life of the project. Developing such a plan is fundamental when selecting a wait-and-see type of strategy that requires future actions. Even when interventions are prioritized in the near-term, as (climate and non-climate) uncertainties resolve over time, the continuity plan provides critical milestones for revising the resilience of the project.

> This plan should include which actors will be responsible for each action and when, and should cover the full economic life of the project. Developing such a plan is fundamental when selecting a wait-and-see type of strategy that requires future actions.

Outcome: After completing these four steps, the project team should be capable of providing an assessment of the vulnerability of the project as initially proposed, and developing a narrative on how much a particular strategy (or set of alternative strategies) can enhance its resilience and, therefore, reduce its vulnerability. The assessment, moreover, should enable the team to understand whether the improvements (and corresponding trade-offs) are acceptable, as well as the costs of following each course of action.

Case Study Demonstration of Step 4: Kenya's Vision 2030 for Transport Resilience

4a. Select a decision-making approach → *4b. Assess trade-offs* → *4c. Develop recommendation and continuity plan*

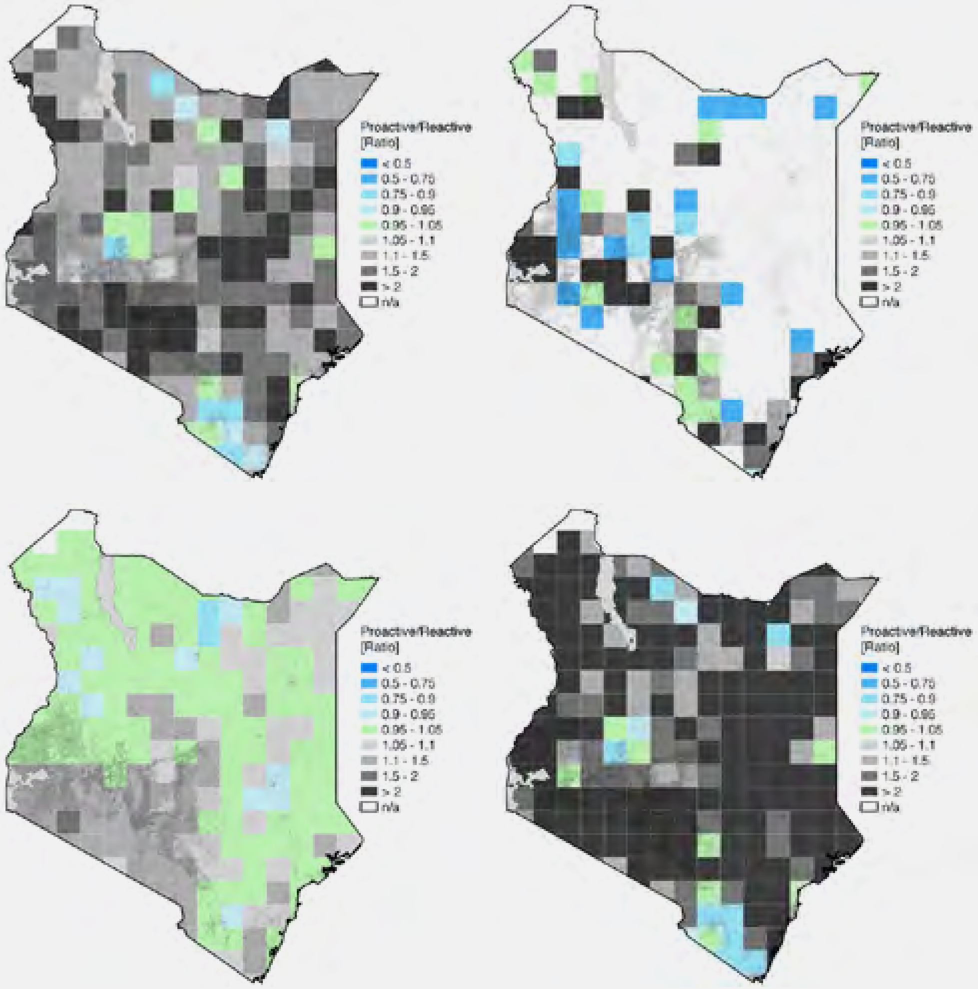
Select a decision-making approach: In making a decision as to which strategy to select, a break-even analysis was adopted. The break-even analysis divided the incremental costs of proactive adaptation over reactive response by the number of disruption days. The resulting values represent value of time thresholds for road users at which investing in proactive adaptation would break even. When the value of time is higher than the break-even value, proactive adaptation is justified economically. This is an adaptive approach in that it does not pursue project robustness at any cost, but rather prioritizes adaptation investments as they become economically justified over time.

When it comes to the calculated break-even values, unpaved roads have the lowest potential as they have high break-even values (averaging around US$ 30 per day). In contrast, paved and gravel roads have break-even values below US$ 3 per day, with average values less than US$1 per day. In terms of climate stressors, investing in proactive measures to mitigate temperature and precipitation impacts show great opportunities, with very low average break-even values of US$ 0.5 per day for precipitation, and US$ 0.002 for temperature. Opportunities for flooding are more limited, with break-even values ranging between US$ 0.8-18 per day. The economic case for these measures would depend on the value of time for the specific region.

Assess trade-offs: The underlying trade-offs in the resilience analysis is short-term costs versus long-term benefits and degree of impact. While it is possible to make every road resilient to every climate stressor, economically this is not a feasible or appropriate decision. Trade-offs need to be considered in terms of costs versus benefits, with the decision to adapt correlating with the economic benefit of the strategy. In terms of the Kenyan roads analysis, the key trade-off is generally between climate stressors. Specifically, flooding is often the least economically appropriate to adapt to now while it is often the most visible impact. In contrast, temperature impacts are almost always economically beneficial to adapt to, even though the effects tend to be slow-evolving over multiple years. Thus, it is key that trade-offs are examined in terms of the economic impact and not necessarily in terms of which impacts are most visible.

Case Study Demonstration of Step 4 (continued): Kenya's Vision 2030 for Transport Resilience

Develop recommendation: As a final recommendation, proactive adaptation of Kenya's roads is generally projected to be more expensive than reactive response overall. Spatially, in most parts of Kenya, total proactive adaptation costs for all three climate stressors have a negative financial case, with the exception of a few isolated regions (see the top left map below). These results are largely driven by high flood-related proactive adaptation costs. Temperature-related investments (top right map below) are only relevant in areas with paved road and where temperature increases enough to exceed current road design thresholds. Temperature has the best financial case out of all three climate stressors in support of proactive adaptation. Flooding presents the most negative results, showing that it is generally more than twice as expensive to invest in proactive adaptation rather than reactive response, except for particular spots throughout Kenya that are particularly impacted by flood damages (bottom right map). Costs associated with precipitation measures (bottom left map) lie in between those of temperature and flooding, with proactive adaptation breaking even in most grid cells (values between 0.95-1.05).

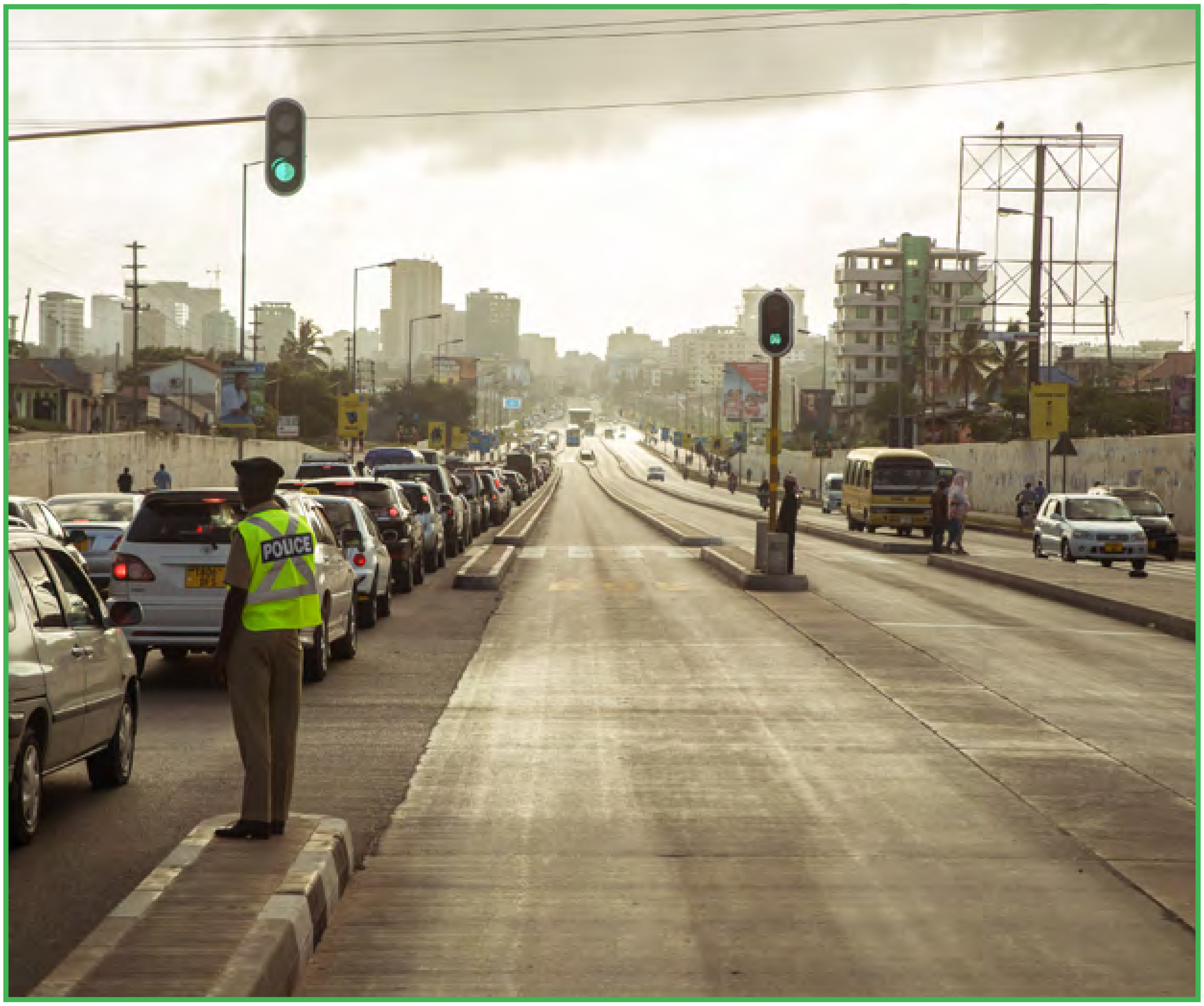


Maps show the ratio of proactive adaptation costs over reactive response costs across the 39 modeled future scenarios for the current road network. The top left map shows total reactive response costs for all climate stressors combined. The top right map shows reactive response unit costs per km for temperature, bottom left shows reactive response unit costs per km for precipitation and bottom right shows reactive response unit costs per km for flooding.

Case Study Demonstration of Step 4 (continued): Kenya's Vision 2030 for Transport Resilience

When additionally taking into account the costs associated with disruption of the road network, the break-even analysis shows that investments in proactive adaptation are largely beneficial in economic terms for every investment but flooding-related ones for unpaved roads. This indicates that, overall, investing in proactive adaptation is economically beneficial when considering the savings in disruption times, despite the financial cost of adapting.

In conclusion, investing in proactive measures for temperature and precipitation is a good strategy almost everywhere in the country. Central and western counties see the highest difference between daily incomes and break-even values. In contrast, pre-emptive investments to reduce flood risks are generally not an appropriate strategy, except for a few higher-income areas in Kenya (for instance, Nyandarua, Elgeyo-Marakwet, Nairobi, and Lamu counties).



6.3. Concluding Remarks

Well-functioning transport systems are critical to Sub-Saharan Africa's growth and economic development. With only one out of three rural Africans currently having access to an all-season road, the deficit in all-weather transport infrastructure increases the cost of goods in the region and a significant investment in both new transport infrastructure and the maintenance/upgrading of existing systems is required. All elements of Sub-Saharan Africa's transport system are vulnerable to a changing climate and both adaptation and climate mitigation measures will be required to move the goods and people of the region. As such, it is crucial that resilience to climate extremes, whether it be floods, extreme heat, sea-level rise or other extreme events, be built into transport projects at all scales.

This guidance note presents a practical framework for enhancing the climate resilience of infrastructure development projects in Sub-Saharan Africa's transport sector. The framework includes four steps: (1) assessing the exposure to climate hazards and determining the criticality of the project; (2) assessing the vulnerability of the project to the identified climate hazards; (3) developing and evaluating strategies to enhance the project's resilience; and (4) recommending a course of action. For each step, the note provides illustrative examples, along with references to additional technical notes for issues that expand beyond the scope of the guidance note and are common to the other sectors covered in the Compendium Volume.

There is no single approach for assessing climate hazards in project evaluation, and this guidance note is based on the authors' understanding of the most appropriate methods available for the transport sector in Sub-Saharan Africa. Future climate conditions are uncertain in nature, and the proposed framework was designed for incorporating the vast and evolving field of study in climate science by way of a practical and flexible approach that can adapt to new emerging knowledge.

This note is of an incremental nature: it seeks to inform how to incorporate climate-related uncertainties and the assessment of resilience over existing project evaluation methodologies. Only the fundamentals of economic, climate, and biophysical modeling, as well as of decision-making under uncertainty are covered in this note, and extensive references to external resources are provided to those seeking further detail. The note does not address other uncertainties in project performance such as demographic changes, political and policy environment, or macroeconomic factors. However, although the principles presented in this note can be extended to other uncertainties, specific guidance on these is preferable.

The framework presented in this note will always benefit from further refinement through widespread application in Sub-Saharan Africa, for a wide range of geographies, socio-economic, and climatic conditions. As conditions in the region change, and climate knowledge advances become more accessible, periodic updating of this note will ensure that users continue to be provided with the best guidance possible for enhancing the climate resilience of much-needed infrastructure investments in the region.

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GUIDANCE NOTE:

Enhancing the Climate Resilience of Ecosystems Projects in Sub-Saharan Africa

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Acronym List

AFRI-RES	Africa Climate Resilient Investment Facility
GCM	General Circulation Model (or Global Climate Model)
IPCC	Intergovernmental Panel on Climate Change

7.1. Introduction and Background

7.1.1. Problem Statement

Natural ecosystems and their biodiversity provide critically important ecosystem services in Sub-Saharan Africa, both to its largely rural populations and its rapidly growing urban populations. As defined by the Millennium Ecosystems Assessment, **ecosystem services are the benefits people obtain from ecosystems**, including services such as food and water; regulating services such as regulation floods or land degradation; supporting services such as nutrient cycling; and cultural services such as recreational or spiritual benefits (Millennium Assessment 2003).

Many rural households in Sub-Saharan Africa are strongly dependent on the harvesting of fuel, wild foods, and raw materials from surrounding ecosystems, much of which is destined for urban markets. Urban, peri-urban, peri-rural and rural households alike benefit from a range of regulating ecosystem services that save on infrastructure costs, reduce the cost of living and reduce risks to property and life. In addition, local economies as well as people's health and wellbeing are linked to the presence of intact biodiversity through the experiential and tourism opportunities that it provides.

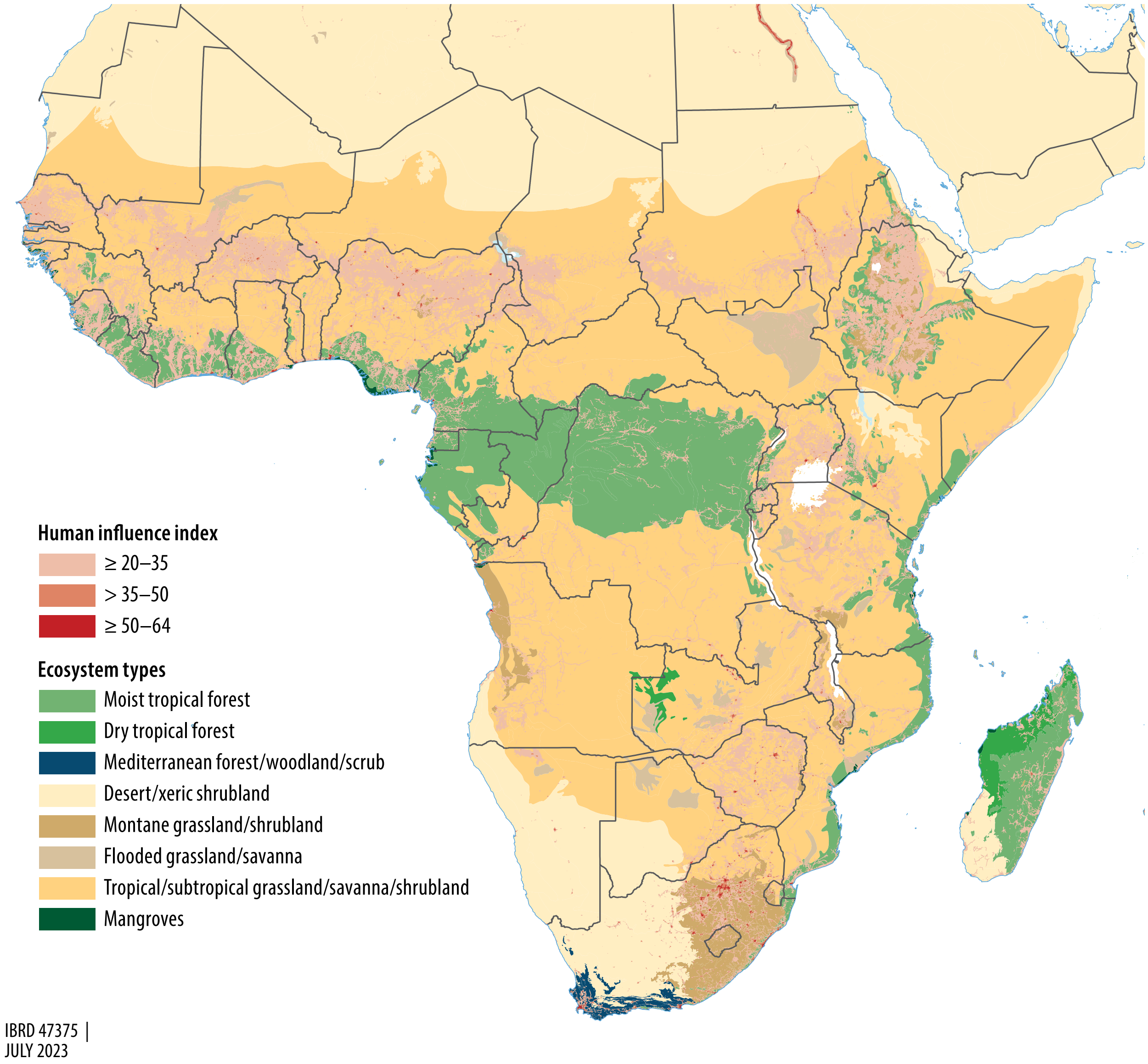
Given the increasing risks of crop failure, water shortages, and extreme climatic events due to climate change, the demand for and dependence on natural ecosystems is set to increase. Such systems will become more and more critical to society's resilience to adverse climate conditions, where resilience is *the ability to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner* (Intergovernmental Panel on Climate Change 2012). Furthermore, global threats to biodiversity pose a significant opportunity for Africa, in that securing these assets could strengthen its comparative advantage for tourism.

> Many rural households in Sub-Saharan Africa are strongly dependent on the harvesting of fuel, wild foods, and raw materials from surrounding ecosystems, much of which is destined for urban markets.

However, **increasingly rapid ecosystem degradation and loss are undermining current benefits and potential future resilience**. This is attributed to a lack of consideration of ecological integrity in the planning of transport, water, and energy infrastructure, as well as through excessive expansion of agricultural land, overexploitation of resources, pollution, invasive alien species, and climate change. **Figure 7.1** shows the Human Influence Index (representing population pressure, human land use, and transportation infrastructure) over ecosystems across the region. With the expansion of the urban and rural built environment in Sub-Saharan Africa predicted to increase 600 percent by 2030**, the need for proper management and infrastructure development in the region is critical to ensure ecosystem conservation** (Trimble and van Aarde 2014)given the inherent inadequacies of these PAs to cater for all species in conjunction with the effects of climate change and human pressures on PAs, the future of biodiversity depends heavily on the 88 % of land that is unprotected. The study of biodiversity patterns and the processes that maintain them in human-modified landscapes can provide a valuable evidence base to support science-based policy-making that seeks to make land outside of PAs as amenable as possible for biodiversity persistence. We discuss the literature on biodiversity in sub-Saharan Africa's human-modified landscapes as it relates to four broad ecosystem categorizations (i.e. rangelands, tropical forest, the Cape Floristic Region, and the urban and rural built environment.

Key natural ecosystems that are critically important for the provision of regulating ecosystem services are sometimes termed **ecological infrastructure**. This terminology conveys their importance in reducing the costs of grey infrastructure. For example, if the catchment area of a dam or reservoir is degraded, then a larger dam will be needed than if the catchment is intact, as it will need to be designed to deal with more extreme flows and higher levels of sedimentation. Managing catchments to reduce these environmental issues is also known as investing in **nature-based solutions**. In addition, maintaining the productivity and value of ecosystems is critical to people's livelihoods, especially where these include pastoralism and gathering of resources for household use. Thus, managing ecosystems for resource productivity is also a form of **ecosystem-based adaptation**, along with managing for regulating services. Managing for cultural services can also contribute to resilience, in terms of their contribution to both mental health and economic opportunities. However, there are management trade-offs to be considered, as managing for certain types of benefits may involve suppressing other types of benefits.

Figure 7.1. Map of Sub-Saharan Africa ecosystems and Human influence index



Source: Trimble and van Aarde (2014)

In order to capitalize on nature's potential contribution to societal resilience under climate change, objectives need to be clear, and strategies need to be found to address the anthropogenic threats to ecosystem extent and condition, including climate change itself. Furthermore, there is a need to improve the capacities of scientific institutions, local governments, stakeholders, and civil society in the region to help them understand the implications of climate change on droughts and water scarcity, flooding, food scarcity, and biodiversity. This should be complemented by the development of integrated management strategies and cross-sectoral cooperation, as well as sharing of experiences and policies. Against this backdrop, this document presents a guidance note that offers practical suggestions for achieving climate-resilient ecosystem service investment projects in the Sub-Saharan African context.

7.1.2. Objectives and Scope of This Guidance Note

Funded through the Africa Climate Resilient Investment Facility (AFRI-RES), this document provides guidance on enhancing the climate resilience of ecosystem service investment projects in Sub-Saharan Africa.[7] It is pedagogically oriented and draws on extensive experience and robust research and analytical methods. This guidance note provides **a framework for evaluating project assets to ensure they meet project objectives in spite of possible future climate impacts**. As a result, this note is primarily relevant for climate adaptation, with climate mitigation benefits only considered if they are an explicit objective of the project being considered. The focus of this note is on guidance, serving neither as a comprehensive technical text nor an exhaustive policy handbook, but as brief direction on the most important principles to take into account when seeking to enhance the climate resilience of infrastructure projects in the face of future climate uncertainty. (While the note focuses on uncertainty as it relates to future climate conditions, the principles presented here could be extended to include other sources of uncertainty such as demographic changes, the political and policy environment, and macroeconomic factors.) In addition, this note focuses on enhancing the resilience of projects that have been at least roughly scoped in terms of their location and the type of investment to be made, being less relevant for very early-stage projects where the location and type of project are as of yet unknown.

These notes build on a range of existing resources produced by the World Bank and others, notably including the Resilience Rating System (World Bank Group 2021) and the disaster and climate risk stress test methodology (Hallegatte et al. 2021). Furthermore, the framework presented in these notes also complements new guidance developed by the World Bank to ensure that future Bank investment projects are in alignment with both the climate mitigation targets set out in the Paris Agreement (United Nations 2015) as well as the country's adaptation goals.

The Resilience Rating System mentioned above distinguishes between two dimensions of resilience, namely **resilience of** the project and **through** the project (World Bank 2021):

- **Resilience of** the project is the extent to which a project's assets have considered climate and disaster risk in their design e.g., land management practices and restoration practices that account for increasing temperatures in the future.
- **Resilience through** project outcomes reflects whether a project's objective is to enhance the target sector and beneficiaries' climate resilience through its interventions e.g., increased soil moisture on agricultural land from land management practices.

The scope of this note is focused on the **resilience of** projects, including the resilience of direct project outputs (e.g., electricity generation or total revenues). While many investments in ecosystem services can enhance both the resilience of and through projects, **the framework presented in this**

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[7] A partnership with the African Union, United Nations Economic Commission of Africa, Nordic Development Fund, African Development Bank, and the World Bank. This note is part of a series of guidance and technical notes funded by AFRI-RES that focus on climate resilient investment in Sub-Saharan Africa.

note focuses on the resilience of particular investment projects and not on how those investments enhance the resilience of a community or sector that benefits from it.

While **the focus of this note is on the project design level**, it remains **crucial to understand the particular policy, regulatory, and institutional context in which the project is situated.** Hence, all project design decisions should be taken with both the policy landscape and local capacity in mind, acting as either enablers or barriers for implementation. This note is part of a larger Compendium Volume, with these cross-cutting issues discussed in Chapter 2 of the Compendium Volume. Chapter 1 of the Compendium provides a general introduction, with the remainder of the Compendium broken down into two parts: Part 1 houses sector-specific guidance notes (including this one), while Part 2 provides a series of more detailed technical notes.

The scope of this note covers developments in the biodiversity or ecosystems sector at large, including projects **to secure or restore natural ecosystem integrity and biodiversity or the creation of modified ecosystems**, in order to avoid the costs associated with ecosystem degradation or to protect and enhance the functioning of grey infrastructure. In economic analysis, changes in biodiversity and ecosystems are evaluated in terms of changes in the regulating, cultural, and provisioning services that they supply, impacts on the economic sectors that benefit from these, and resulting changes in human welfare:

- **Regulating services** include the maintenance of hydrological processes, water, and air quality amelioration, and global, regional, and local climate regulation, as well as support to agriculture and fisheries through pollination and nursery areas.
- **Cultural services** include the opportunity for experiential activities focused on natural habitats and biodiversity.
- **Provisioning services** include harvested wild resources as well as inputs to agricultural systems. Note that agricultural systems are considered in more detail in a separate note included in the Compendium Volume.

The note is not specific nor prescriptive regarding interventions in a particular ecosystem service or conservation approach, but rather presents principles that can be applied to the evaluation of investment projects of any kind. Improved adaption to climate change will depend on comprehensive and inclusive policies and strategies that are inter-sectoral, underpinned by a unified framework such as the one presented in this note that allows meaningful coordination and provides adequate climate information services.

> This guidance note provides a framework for evaluating project assets to ensure they meet project objectives in spite of possible future climate impacts.

7.1.3. Target Audience

There are three primary audiences for this guidance note:

- **Practitioners.** The note will help practitioners develop their staff and internal expertise to perform the necessary climate vulnerability and adaptation analyses.
- **Government Ministerial Staff.** The note will give staff from government ministries an understanding of the steps involved in evaluating and enhancing the resilience of a proposed project, how to be prepared for creative and alternative investment packages, and how to draft Terms of Reference for practitioners to develop climate resilient projects.
- **Donors and Development Banks.** The note will help donors and development banks provide clear direction and guidance to consultants for how to make project designs more resilient to climate change.

Each of these three target audiences differ considerably in their technical focus, operational roles, and objectives. Typical investment projects will see this note used both as high-level guidance by donors and banks, as well as more detailed technical guidance for use within client countries. This note was developed to be accessible to these different audiences, with the general framework presented here supplemented by further detail in the technical notes included in Part 2 of the Compendium Volume.

7.1.4. When To Use This Note

While each of these target audiences will use the note in slightly different ways, within the overall project development process, this guidance note is intended to be used anywhere from the project's **conception** and **planning** stages, as well as during post-project completion **monitoring** (see the orange components of **Figure 7.2**). It is anticipated that in most cases, project teams will utilize this guidance note during the scoping, early design, and final design stages of the project planning process. That said, the earlier in the project lifecycle that climate resilience considerations (as described in this guidance note) are incorporated, the greater the scope and opportunity to improve the performance of the project given climate uncertainty. Furthermore, while not the focus of this note, attention should be paid throughout the project planning process to the policy and institutional landscape, as well as the role of policy shifts and improved local capacity in building resilience.

Figure 7.2. Applicability of this Guidance note during a typical project life cycle

7.1.5. Structure of and Roadmap to Using This Note

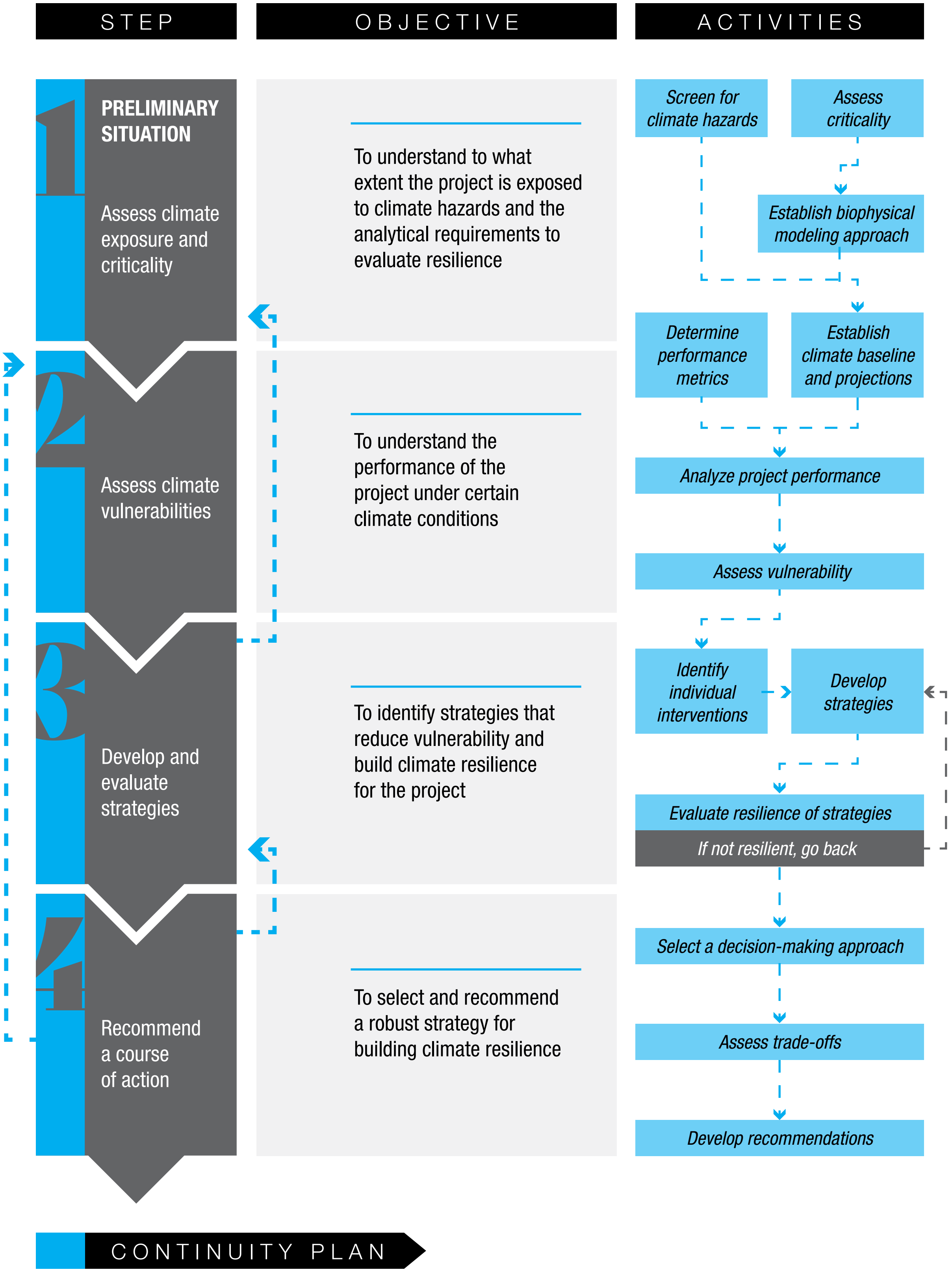
The remainder of this document is structured as follows: Section 7.2 describes a step-by-step framework used to enhance the resilience of ecosystem service projects to climate hazards. This section is subdivided into four steps, each containing different activities to carry out the analysis. Rigorously completing each activity requires a non-trivial amount of resources in terms of time, data, and analytical know-how. Where these resources are not available, completion of a more rapid qualitative assessment is still useful to undertake in order to provide a high-level understanding of the situation, but such high-level insights alone should not form the basis for recommendations. A case study is provided to illustrate the framework and is intended to be consulted by all users of the note. Lastly, Section 7.3 offers brief concluding remarks.

Finally, while the focus of this note is specifically on ecosystem-focused investments, many projects include cross-sectoral components and depending on the different investment components included in a project, several of the individual guidance notes beyond this one may need to be consulted. When using this note, **project leads should look beyond their particular project to consider both the broader system as well as any possible inter-system effects in their evaluation process.** For instance, those involved in a proposed catchment water security project would benefit from also consulting the water, agriculture, and cities notes; a team working on securing vegetation in an irrigation area should consider also consulting the water note; and efforts to advance forest restoration in areas that use fuelwood products should additionally review the energy note, with all these notes included in the Compendium Volume. While all of these individual guidance notes are built around a common framework, this note is somewhat unique in that it focuses on resilient ecosystem projects as compared to the resilient **infrastructure** focus of the other guidance notes, with the particular features of resilient ecosystems expanded on throughout Section 7.2 below.

7.2. A Framework for Enhancing the Climate Resilience of Ecosystems Investment Projects in Sub-Saharan Africa

The guidance for developing climate-resilient investments presented in this note builds on a broadly applicable, multi-step framework, summarized in **Figure 7.3.** The framework consists of a series of four steps, each explained in further detail below, with many of the steps linked through important feedback loops. As noted in Chapter 2 of the Compendium Volume, the framework is founded on an initial assessment of the preliminary situation, which examines the **institutional and project context** (including the existence of country-level development plans, support from relevant ministries and the state of weather and climate change monitoring capabilities) as well as identifies **relevant stakeholders** (including community groups, beneficiaries, technical experts, policymakers, and non-governmental organizations).

Figure 7.3. Framework for Enhancing the Climate Resilience of Investment Projects



STEP	OBJECTIVE	ACTIVITIES
1 PRELIMINARY SITUATION Assess climate exposure and criticality	To understand to what extent the project is exposed to climate hazards and the analytical requirements to evaluate resilience	*Screen for climate hazards* *Assess criticality* *Establish biophysical modeling approach*
2 Assess climate vulnerabilities	To understand the performance of the project under certain climate conditions	*Determine performance metrics* *Establish climate baseline and projections* *Analyze project performance* *Assess vulnerability*
3 Develop and evaluate strategies	To identify strategies that reduce vulnerability and build climate resilience for the project	*Identify individual interventions* *Develop strategies* *Evaluate resilience of strategies* *If not resilient, go back*
4 Recommend a course of action	To select and recommend a robust strategy for building climate resilience	*Select a decision-making approach* *Assess trade-offs* *Develop recommendations*

7.2.1. Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

1a. Screen for climate hazards → *1b. Determine project criticality* → *1c. Establish a biophysical modeling approach*

Objective: The purpose of the first step is twofold. One, the process evaluates whether the project is exposed to any climate hazards, both now and over the course of the project's expected lifespan. And two, the process seeks to determine the level of complexity required for the analysis based on the project criticality.

Activity 1a. Screening for climate hazards. A climate hazard is any climate-driven event that may result in damage and loss to the project. These can be a product of:

- **Extreme weather events:** low-probability but high-impact climatic phenomena (such as floods, droughts, or heat waves), as well as more frequent, lower-intensity events which can also cause significant impacts
- **Long-term changes to normal climate conditions:** changes relative to the historic baseline

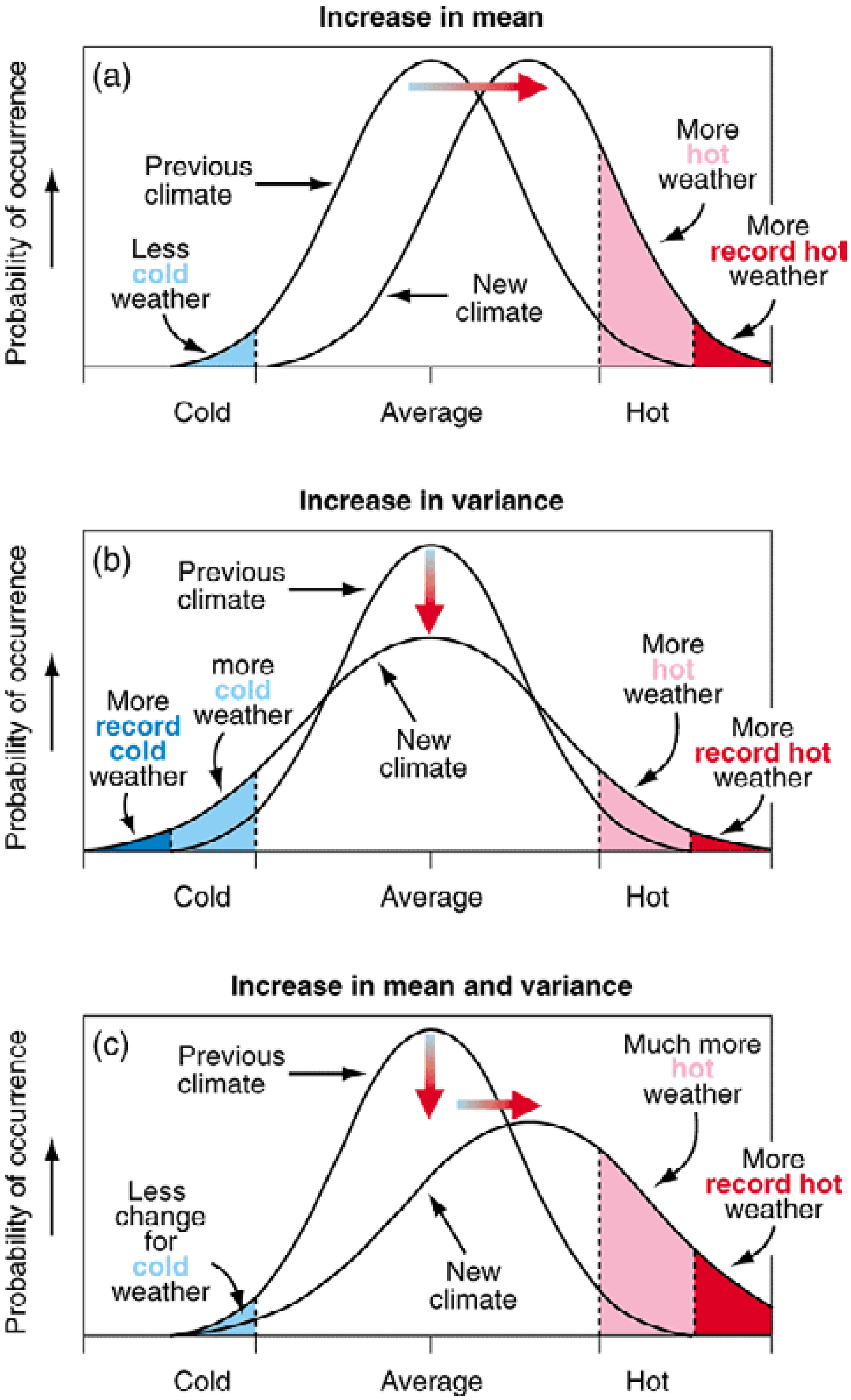
Resilience Spotlight: Bringing green and grey together in the city of Beira, Mozambique

Mozambique is the third-most climate-hazard exposed country in Africa. It is at high risk of impacts from not just floods and droughts, but also cyclones. The coastal city of Beira is plagued by recurrent flooding due to coastal storms, made worse by poorly planned settlements and inadequate housing. Over the course of the last decade, the city has implemented a number of different measures to improve the flood resilience of the area, as documented by the city's resilience master plan. Through the Cities and Climate Change Project, the World Bank and its development partners have financed a number of these investments including **improvements to grey infrastructure such as drainage systems, as well as green nature-based solutions focused on restoring the Chiveve River's capacity to mitigate floods.** Restoration of the Chiveve has seen the formerly polluted river and riverbanks transformed into a green urban park that provides recreational spaces in addition to retaining and absorbing floodwaters. **The climate resilience of these investments in the Chiveve were safeguarded by conducting ongoing community rehabilitation of its degraded mangroves and native flora.** By investing in green and grey interventions together, the objective was to enhance climate resilience while simultaneously improving the quality of life for the inhabitants of Beira.

> Exposure to climate hazards refers to whether the hazard is present at the project's location, either because of natural conditions or the absence of protective systems.

As **Figure 7.4** shows, taken together, climate change can impact both the mean conditions to which a project will be exposed (e.g., higher temperature on average in the future), as well as the frequency and intensity of extreme weather events (e.g., more record hot weather). Exposure to climate hazards refers to whether the hazard is present at the project's location, either because of natural conditions or the absence of protective systems. When considering future exposure over the course of the project's useful lifespan, understanding the uncertain nature of future climate hazards is essential for evaluating the climate resilience of a project.

Figure 7.4. **Illustration of Climate Change Impacts**



Source: Intergovernmental Panel on Climate Change (2001).

Screening for climate hazards will help the project team identify the types of hazards that threaten the performance of the project, given the project's location and expected useful lifespan. Climate hazard impacts are transmitted throughout ecosystems, ultimately contributing to food insecurity, biodiversity loss, and poverty traps for rural households in Sub-Saharan Africa.

Typical climate variables to consider for ecosystems projects are temperature, precipitation, sea level rise, strong winds, and atmospheric carbon dioxide. These variables can constitute a hazard when their magnitude and/or duration affect species distributions, ecosystem structure, and functioning. **In the context of ecosystem projects, it is also important to think of the potential for tipping points to occur** – tipping points occur when an ecosystem shifts to a new state of ecological balance, such as saltwater intruding into a new area, or a lake experiencing ongoing eutrophication. A tipping point may result in the irreversible loss of ecosystem services and are thus important to consider when evaluating the resilience of a proposed ecosystem project. Tipping points are most often the result of inadequate or ineffective ecosystem management and may be accelerated given the impacts of climate change. **Textbox 7.1** summarizes key climate hazards for biodiversity and ecosystems in Sub-Saharan Africa.

Textbox 7.1: Key climate hazards that impact biodiversity and ecosystems in Sub-Saharan Africa

Temperature: Changes in temperature leading to heat stress in plant and animal species can lead to significant changes in their distribution. Each species has a range of tolerance, those with narrower tolerances or living at the edge of their tolerance ranging being more vulnerable to temperature rise. In general, species shifts will be towards cooler latitudes and altitudes. This will lead to changes in ecological communities, ecosystem structure and functioning.

Precipitation: Changes in rainfall regimes affect the magnitude and timing of water flows. This affects the fundamental nature of river habitats, water levels and stratification within lakes and estuaries, and salinity in coastal ecosystems. These result in shifts in species distributions and changes the structure of communities and functioning of ecosystems. The amount and seasonality of rainfall also affects the suitability for different growth forms and affects the frequency of fires that shape vegetation communities, especially the balance between grassland and woodland or forest ecosystems.

Sea level rise: Coastal ecosystems, including intertidal areas, estuaries and mangrove forests will be vulnerable to sea level rise. The degree of vulnerability depends on the extent to which they can migrate inland. This is often limited by topography or by man-mad structures and settlements, or by the speed of sea level rise relative to their capacity to shift. Sea level rise and the associated coastal flooding may also result in salt-water intrusion of groundwater sources.

Strong winds and storms: Strong winds can increase the intensity of flood events, and increase damages to coastal ecosystems through increased wave action.

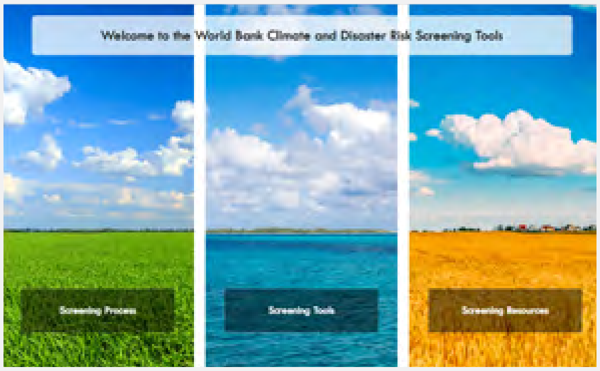
Carbon dioxide concentrations: Increasing atmospheric carbon concentrations favors plant species with particular types of photosynthetic pathways. This can lead to a change in the dominance of different growth forms in ecosystems, affecting their overall productivity. In marine systems, this leads to acidification, which impacts corals in particular.

To screen the various climate hazards for a given location, the frequency and severity of historic events are first analyzed. However, it is important to consider the future exposure over the course of the project's useful lifespan. Generally, projects with a short project lifespan may only need to focus on the impact of extreme weather events consistent with those experienced historically. In contrast, projects with longer lifespans should carefully inspect whether the project is exposed to new hazards and the increased frequency and severity of existing ones. That said, **ecosystems projects often experience significant lag-times between project investment and project benefits**, so it is important to consider the specifics of the project to determine an appropriate time horizon. For instance, the planting of trees to prevent erosion may be a fairly short-term investment that provides erosion-control benefits immediately. However, if habitat creation is also a desired outcome of the project, this will take much longer as this objective may only be met once the trees are mature. Given the significant degree of uncertainty about future climate conditions, it is recommended to consider the broadest possible range of climate hazards, including those considered less likely, rating the severity of each threat to identify those most relevant for the project.

Various tools exist that can be used to screen a project's exposure to climate hazards; **Textbox 7.2** shows a selection of tools that could be used. Note that the individual outputs from these different tools may not be directly comparable to each other due to differences in the design of the tool and the assumptions it makes. In addition, these tools are not designed for detailed asset-level risk analysis but rather offer broad insights about the hazards present at the location of a proposed project. Subject-matter experts and local stakeholders should further supplement the climate risk screening results from these tools, as a mechanism to both validate the identified threats and reduce the risk of omitting relevant hazards.

Textbox 7.2: Climate Hazard Exposure Screening Tools

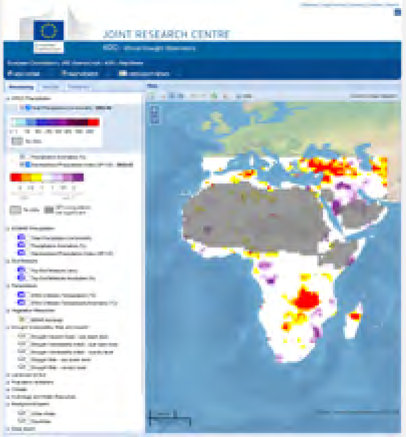
Climate and Disaster Risk Screening Tool **(World Bank).** This tool provides a guided method to identify climate hazards and levels of risk to project evaluators at an early stage in the project design process. It focuses on physical and non-physical components of the project, and ranks the threat between low to high, including a no risk and insufficient understanding category. It has a “rapid” (about 30 min) and “in-depth” (about 2 hours) version for multiple sectors, the latter being highly recommended unless the evaluator is familiar with climate science and the project context. The tool relies on the World Bank’s Climate Change Knowledge Portal, which is a web tool that provides processed and synthetized historical and projected climate information from the Intergovernmental Panel on Climate Change. The tool considers extreme temperatures, extreme precipitation, flooding, drought, winds, sea level rise, and storm surge. Users would ideally be in possession of a project concept or design, as well as subject matter expertise for the country and project context. In terms of strengths, the tool guides the user on how to perform the screening and how to use data from other tools. It provides an assessment that includes the hazards at the project location as well as the potential impacts on the project’s infrastructure and service delivery, as well as how institutional and contextual factors interact with hazards and the project’s physical components.



ThinkHazard! **(Global Facility for Disaster Reduction and Recovery).** A web tool that provides a general assessment of climate hazards at a sub-national scale. The tool covers 12 different hazards including flooding (river, urban, and coastal), extreme heat, water scarcity, and cyclones. The tool presents a qualitative assessment of the level of a particular threat (i.e., low to high) both now and in the future given potential impacts of climate change, describing general impacts of the hazard along with generic recommendations for planning and evaluation. The tool also includes additional local and/or regional online resources when available. All that is required to run the tool is a general project location. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining a list of the relevant hazards to consider in a particular area, without requiring project specific information. It can help place climate hazards in context with other non-climate threats.

Textbox 7.2 (continued): Climate Hazard Exposure Screening Tools

African Drought Observatory **(European Commission Joint Research Centre).** A web map service to identify potential drought hazard and risk levels in Africa. It offers access to recent drought monitoring data, as well as probabilistic forecasts for near term precipitation. A general project location is required to run the tool. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining an overview of historic climate hazards to consider in a particular area, without requiring project specific information.



Aqueduct Water Risk Atlas **(World Resources Institute).** A global web map service that provides an assessment of coastal and riverine flood risks. The tool allows the customization of water hazards by time horizon, climate scenario and projection model, and return period. A general project location is required to run the tool. In terms of strengths, it easily allows users to explore how water risks change under different future climate scenarios.

ClimateLinks Screening and Management Tools **(United States Agency for International Development).** The screening and management tool provides a sectoral toolkit for self-screening and rating of climate risks in the early stages of project design. The risk profiles consist of short briefs for countries and regions that assess the potential impacts of climate change on key economic sectors, including an overview of historical and future climate trends, the policy context, and existing adaptation projects.

Textbox 7.2 (continued): Climate Hazard Exposure Screening Tools

Additional non-web-based tools that could be consulted include:

The CRiSTAL **(International Institute for Sustainable Development).** A project planning tool for identifying climate risks and design components to enhance resilience. It incorporates stakeholder consultation and expert interviews, as well as guidance notes for internal evaluation developed by the African and Asian Development Banks. The tool includes an initial screening step that can be used to understand the potential impacts of climate hazards on the project and local livelihoods in the area. It expands beyond a cursory screening tool, offering guidance for project design and evaluation through a participatory process. A project concept or design is necessary in order to run the tool. In terms of strengths, it guides the user to perform a screening following a questionnaire and provides a community-based perspective of the project, as opposed to the perspective of funders only. It additionally puts climate hazards in context with social, political, and cultural conditions and provides a framework for incorporating local and expert knowledge through consultation.

Activity 1b: Determine the project criticality to establish the appropriate level of effort required to assess project resilience. Evaluating the impacts of the climate hazards identified to be relevant to the project can be complex, data-intensive, and expensive. However, not every project requires the same level of analytical complexity, and to ensure the framework is practical and accessible, projects are classified into two tiers. A low tier method is less data-intensive and simpler than a high tier method, which is generally treated as being able to more accurately model the project's response to climate hazards. For example, clearing invasive alien plants could be considered a low tier investment on the basis of its relatively short lifespan and local scale of influence, whereas a project involving changing the management of natural resources could be a high tier investment. Distinct components within a large project that require separate analysis or modeling could be analyzed separately and may be classified into different tiers. **While the focus of this guidance note is on the project design level, it is crucial to understand the development setting in which the project is situated.** All project design decisions should be mindful of local conditions, including the policy landscape, as well as technical and institutional capacity (see Compendium Volume Chapter 2 for a discussion of these kinds of cross-cutting factors that can enable or hinder a project).

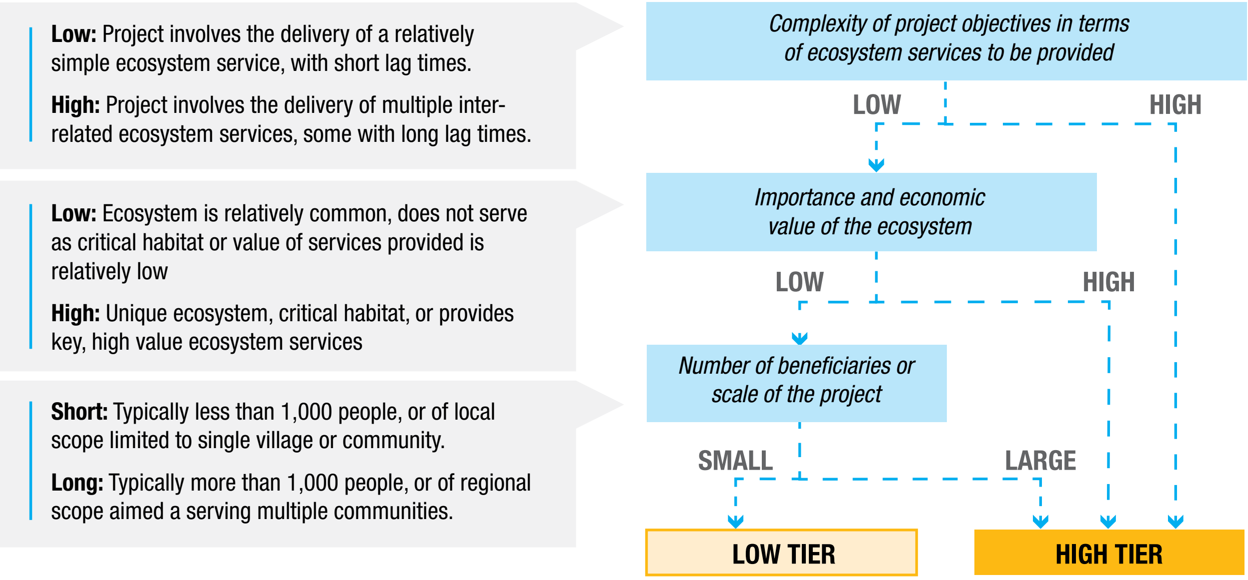
The tier of a project can be determined using the sample process shown in **Figure 7.5**, which assesses criticality based on the complexity of the desired outcome in terms of ecosystem services provided, the importance and economic value of the ecosystems in question, and the number of stakeholders involved in the project. **Note that this framework is qualitative and flexible in nature**, with **Figure 7.5** providing sample guiding principles to determine the tier of a project (i.e., project complexity, ecosystem importance, and number of beneficiaries). **Project teams and stakeholders should consider a flexible set of criteria, carefully assessing which guiding principles and cutoff values are appropriate for their particular project and inspecting whether using the selected**

criteria results in an appropriate level of criticality. For example, when looking at ecosystem investments, high tier projects could also include those that

- address critical water security risks,
- offer significant benefits in terms of poverty alleviation especially in areas that have deep pockets of poverty,
- focus on an ecosystem that is considered at high risk of undergoing an irreversible tipping point that would alter its physical state as well as the services it provides, or
- involve a particularly complex investment.

These examples highlight that context is required to appropriately determine the criticality of a project.

Figure 7.5. Sample Tier Determination Process



Low: Project involves the delivery of a relatively simple ecosystem service, with short lag times.

High: Project involves the delivery of multiple inter-related ecosystem services, some with long lag times.

Low: Ecosystem is relatively common, does not serve as critical habitat or value of services provided is relatively low

High: Unique ecosystem, critical habitat, or provides key, high value ecosystem services

Short: Typically less than 1,000 people, or of local scope limited to single village or community.

Long: Typically more than 1,000 people, or of regional scope aimed a serving multiple communities.

Activity 1c. Establish a biophysical modeling approach based on the project tier. The results of the tier determination process serve as the basis for establishing a biophysical modeling approach that simulates the physical behavior of the system under different climatic conditions (e.g., translating changes in future precipitation to altered ecosystem productivity or water supply reliability). These models (i.e., simplified, conceptual, mathematical representations of a system) require climate variables as inputs and produce outputs of interest that are later used for the socio-economic evaluation. The kind of climate and other input variables required will vary based on the biophysical modeling approach selected.

Selecting a model for a particular analysis always depends on the specifics of the project. For example, designing interventions to address water security will require complex hydrological modeling, while urban green space interventions to reduce temperatures during heat waves will require an entirely different modeling chain that captures interactions between vegetation, infrastructure and air temperature. Models should be determined based on their capacity to inform and improve the design of the project, particularly from changes in climate inputs. In addition, models are typically quite specific to individual ecosystem services, so the primary ecosystem benefit that will result from a project should guide the selection of model. **Figure 7.6** below provides guidance for the selection of a tier-specific modeling approach to be utilized for the biophysical evaluation, with **Table 7.1** presenting a shortlist of accessible biophysical models that are typically used to guide investments in ecological restoration and conservation. Broadly, these models involve the estimation of climate hazards and management interventions on biodiversity, ecosystem health, and functioning, and the impacts on society through resulting changes in provisioning, regulating, and/or cultural services.

Figure 7.6. Possible Modeling Approaches by tier

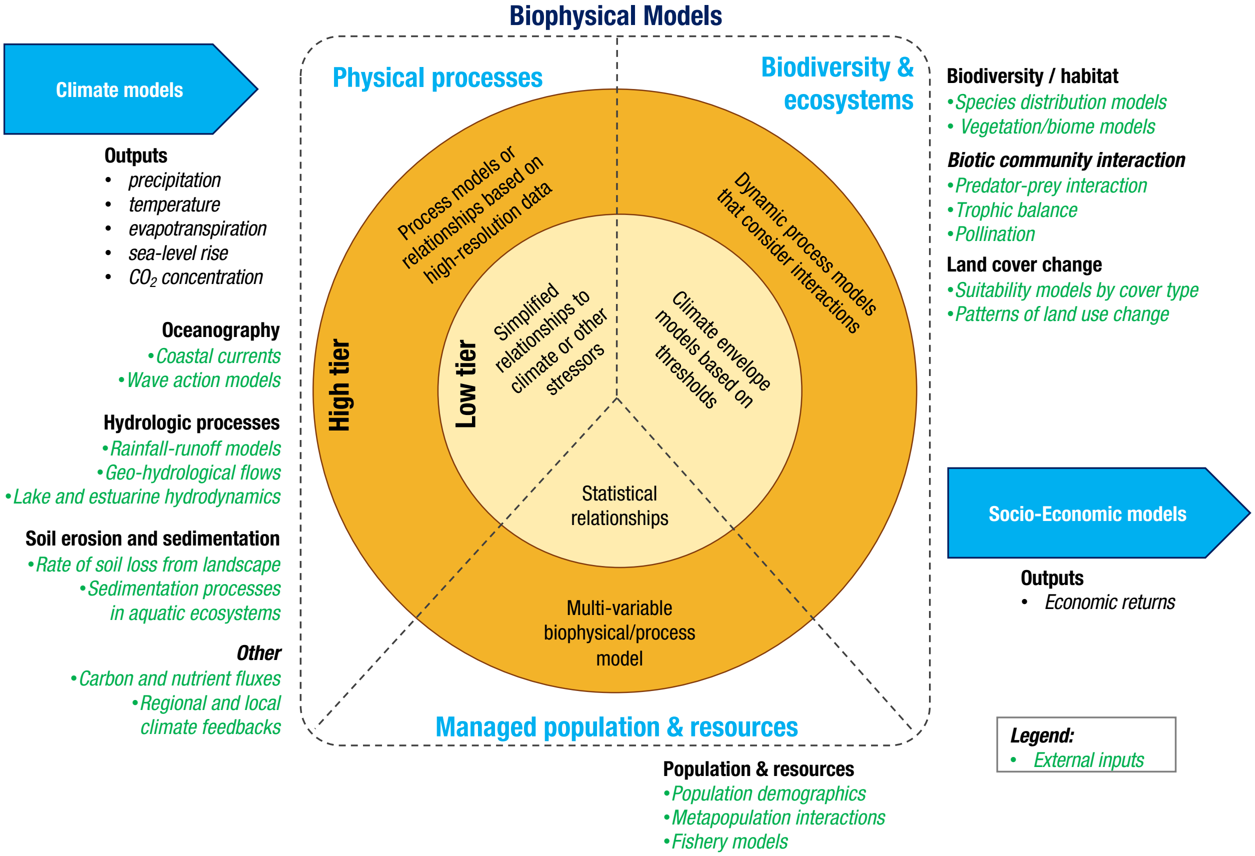


Table 7.1. Sample Modeling Approaches for Each Tier

TIer	Biophysical Processes		Managed Populations and Ecosystems	
	Hydrology	**Nutrient Modelling**	**Ecosystems**	**Fisheries**
Low	Reduced form monthly or annual relationship between precipitation, runoff, and potential evapotranspiration. Land use from geospatial techniques.	Estimated effects using measured pollutant inputs and ecosystem uptake rates.	Climate envelope models based on the environmental and climatic limits of existing species or ecosystem ranges.	Statistical relationship between annual temperature and river flows, and resulting yields.
High	Calibrated daily or monthly rainfall-runoff model, and spatially explicit land use model evaluating erosion and water quality effects.	Panel data modelling of the changes in water or air quality in relation to changes in ecosystem extent or quality.	Dynamic models that include species interactions, photosynthetic pathways, and carbon-dioxide fertilization effects.	Biophysical/process model of climatic effects on yields, considering water temperature, acidification, changes in food, and management practices feedbacks.

Modeling the impacts of climate change or project interventions on ecosystem services often involves a combination of biophysical models that relate to relevant underlying biophysical processes such as hydrology, the impacts of these changes on species and habitats, and the combined effects of the latter on ecosystem composition and functioning, populations, and resource stocks. Depending on the complexity of the problem, a project may involve one or several different types of models that interact with one another. Furthermore, the changes experienced by an ecosystem may be significant enough that an ecological tipping point may occur – while tipping points remain difficult to model and predict, ideally the chosen model sequence would produce output that can be examined for early warning signals or indicators that a tipping point threshold is being approached. Ecosystems can also undergo natural adaptation in response to gradual or chronic changes in external conditions, with this slow natural evolution in ecosystem composition an additional factor to take into account when choosing or developing a model for the analysis. Additionally, it is important to consider whether system-wide modeling (which includes all of the processes described above as well as the feedback between them) is necessary to understand the risks to or benefits from a project.

When selecting a modeling approach, it is not just important that the model relates climate variables to outcomes of interest, but also to consider which individual climate variables the model is sensitive, as well as possible interaction effects among multiple variables. External inputs may have increasing levels of detail for higher tiers. **Ultimately, model selection should be conducted considering the scope, functionality, availability, and processing capacity of a particular model, experience utilizing it, knowledge of its caveats and limitations, and data availability.** That said,

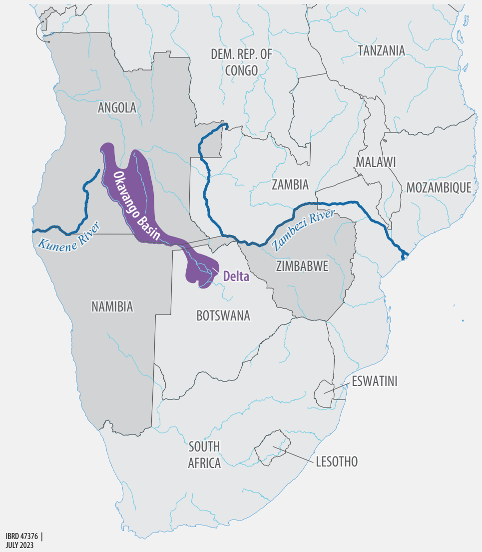
Depending on the complexity of the problem, a project may involve one or several different types of models that interact with one another.

where existing models and analytical tools already exist for a project that are more analytically rigorous and detailed than the identified tier level, these existing tools should be preferentially used.

Finally, a particular challenge when conducting modeling for projects located in Sub-Saharan Africa is the limited data available for the region, with many existing data time series either covering a limited period of time or incomplete. In some cases, the absence of local-scale data may limit the kind of modeling that can be completed – for instance, if local station temperature data does not exist for stations across an urban center, the modeling of urban heat island effects is not appropriate. Such data availability constraints result in an incomplete assessment of the true range of climate risks to the project. In recent years, data from earth observation methods (such as remote sensing and satellite-derived products) have grown to be an important supplemental source of information, with these methods particularly useful for areas with sparse local monitoring stations. For instance, Garcia et al. (2016) provide further details on the use of remote sensing data for water management.

Outcome: At the end of this step, the project team should have acquired a high-level understanding of the climate hazards the project is exposed to as well as the analytical requirements to adequately conduct a climate impact assessment of the project. Depending on the identified tier, an appropriate modeling approach should be established in consultation with modeling experts. Where a project is composed of separate investment components that are exposed to a different set of hazards, all the activities in Step 1 should be completed for each individual project component in turn.

Case Study Demonstration of Step 1: Climate Resilient Investment Opportunities in the Cubango-Okavango River Basin



The Cubango-Okavango River Basin (Source: King and Chonguiça 2016)

Background: the Cubango-Okavango River Basin is an indispensable basin in southern Africa and of high global environmental importance. It is a transboundary waterbody with river systems that span across Angola, Botswana and Namibia. The headwaters start in the highlands of Angola and flow into the Okavango Delta. The river supports a large variety of plant and animal species as well as people who strongly rely on the river's ecosystem services and natural resources. However, the current development trajectory of the river basin is unsustainable, with the increasing number of people living along the river particularly threatening the basin's fragile ecosystem. Solutions need to be found to satisfy the growing demands for water without compromising the ecosystem's sensitive hydrology.

A more sustainable future can be created through cooperative water infrastructure development. Any infrastructure developments require feasibility, environmental and social impact assessments to ensure sustained benefits for all member states. Developments within the river basin would alter the flow at different times of the year, hence could negatively impact the environment and people's livelihoods, both of which depend on the river. Infrastructure developments also need to consider hydrological changes in light of future climate variability and change. Nine different large-scale basin development strategies were explored in this case study, referred to as BDS1 to BDS9. Each strategy considers a different level of dam construction as well as different levels of agricultural and urban water use.

Within these individual development strategies that focus primarily on different infrastructure interventions, careful management decisions will additionally play a significant role in minimizing downstream impacts, ensuring equitable distribution of the available water to the different users (including the environment) and maintaining the basin's rich biodiversity. There is a particular need to develop sustainable wetland management systems given the vital role of wetlands in the basin. The basin's wetlands are critical in maintaining dry season flows on the river, with these flows supporting the basin's ecosystems and the services which these ecosystems provide. In addition, a Transboundary Diagnostic Analysis completed for the basin in 2011 identified climate change as a major driver of ecosystems change in the basin, indicating that any ecosystems-focused investments will need to consider climate change adaptation measures in order to ensure the resilience of the investments to changing conditions in the basin.

Case Study Demonstration of Step 1 (continued): Climate Resilient Investment Opportunities in the Cubango-Okavango River Basin

1 Assess project exposure and criticality

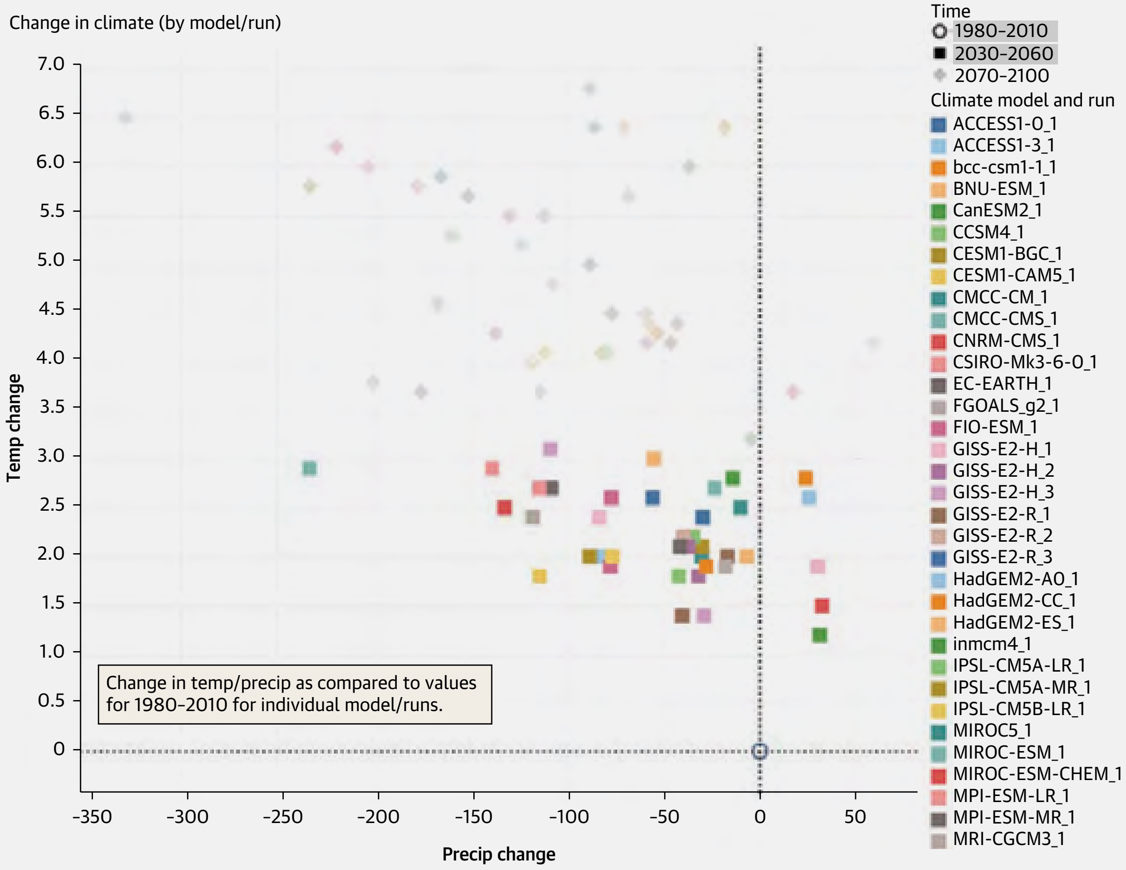
2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

1a. Screen for climate hazards → *1b. Determine project criticality* → *1c. Establish a biophysical modeling approach*

Climate hazards: As shown on the figure below, the Cubango-Okavango River Basin is anticipated to experience higher temperatures and reduced precipitation as a result of climate change. Together, this will result in increased evaporation in the basin, with water supply therefore becoming less reliable. This is coupled with water demands that are expected to increase in the future.



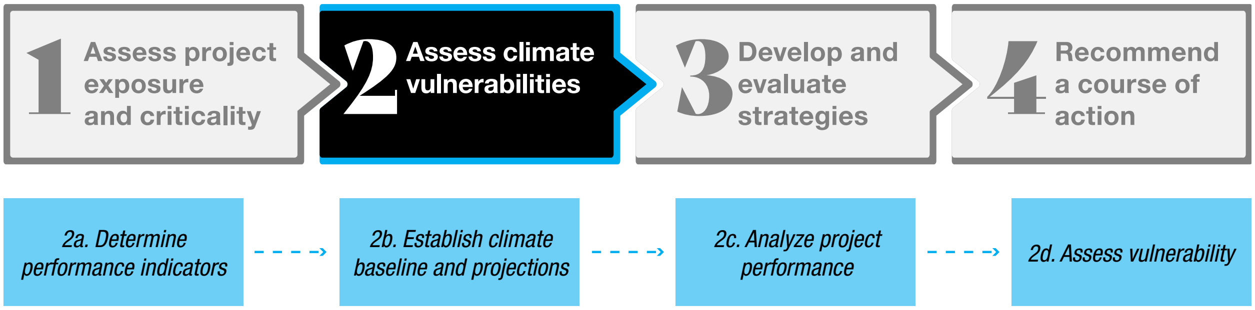
Climate change projections for the Cubango-Okavango Basin in 2050 (Source: World Bank 2019)

Case Study Demonstration of Step 1 (continued): Climate Resilient Investment Opportunities in the Cubango-Okavango River Basin

Project criticality: 1.2 million people currently rely on the river's water for urban and agricultural abstractions. All basin member states are expected to experience high population growth resulting from both natural population growth and migration into the basin. Additionally, some regional centers, including Chitembo, Caiundo, Menongue, Rundu, Maun, Shakawe and Katwitwi, will face increasing urbanization. With the complex nature of the basin's ecosystems, their role supporting critical habitat and several endangered species, as well as the large number of human beneficiaries involved, the project is classified as a high tier project.

Biophysical modelling approach: In order to compare the performance and climate vulnerability of the nine different development alternatives being considered, hydrologic modeling was conducted. The model operates mostly on a monthly time scale and takes into account the natural hydrological processes that are common within southern African drainage systems, as well as human impacts, such as water abstractions from small farm dams, direct abstractions from the river, and the main water reservoirs. Additionally, Delta Inundation Modelling and Dynamic Ecotope Modelling were used as inputs into an Environmental Flows Assessment to describe the ecological consequences of changing conditions and what this means for the different possible investment plans.

7.2.2. Step 2: Assess the Vulnerability of the Project to the Identified Climate Hazards



Objective: After the project screening and assessment of the necessary analytical complexity, the next step is to **assess the project's vulnerability to climate hazards**. This process seeks to identify how a project performs under extreme climate conditions and, incrementally, under a future with climate change (which can further impact the frequency and intensity of extreme events), as compared to current conditions. This same framework will also be used later to assess the performance of possible adaptation options to build climate resilience. The process involves four different activities, each described below.

Textbox 7.3: Suggested Performance Indicators in Ecosystems

- Similarity of species diversity to natural conditions
- Similarly of vegetation cover and biomass to natural conditions
- Similarly of animal biomass to natural conditions
- Percentage of soil covered by vegetation and vegetation residue (both of which offer erosion protection)
- Physical and chemical composition of soils
- Groundwater levels
- Water flow volumes and quality
- Resource stocks and productivity
- Capacity to supply ecosystem services, as measured through e.g. surface area of wetlands, water yield, degree of forest fragmentation or air quality index
- Ecosystem value

Activity 2a. Determine performance indicators and targets to assess the climate vulnerability of the project. On the one hand, these metrics would include the economic return of the project measured as net present value, benefit-cost ratio, or internal rate of return, and minimum acceptable returns or hurdle rates as targets (e.g., a net present value above zero, an economic rate of return above a minimum return). On the other hand, indicators that characterize and assess the success (or failure) of the project and the impact on ecosystem services should be considered, including desired downstream effects or co-benefits such as reduced reservoir sedimentation. Knowing the importance of tipping points when it comes to ecosystem change, indicators could also be selected so as to provide early warning signals that a tipping point threshold is potentially being reached. **Textbox 7.3** provides a sample list of possible indicators for ecosystem-focused investments. Depending on their nature, some may be quantitative outputs from the biophysical or socio-economic models, while others may require additional calculation assumptions. For instance, estimating changes in cultural value requires an estimation of ecosystem contribution to tourism value. When feasible, performance indicators should incorporate metrics established by the broader policy environment and development strategy, particularly when those address climate resilience already.

Whereas typical project evaluation methods consider means and weighted averages as performance metrics, given the large degree of uncertainty associated with future climate conditions, an evaluation of climate resilience should look at a range of expected values across different potential future climate scenarios (for instance, as defined in reports from the Intergovernmental Panel on Climate Change (IPCC)), as well as thresholds that cause a project to fail, in order to identify project designs that perform well across a range of different future conditions.

Activity 2b. Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions. The climate baseline describes the default conditions applicable to the initial design of the project, representing the reference point for the analysis. During later stages in this step, a subset of baseline conditions will be perturbed, and performance between baseline and future conditions will be compared for assessing vulnerability.

Resilience Spotlight: Enhancing Forest Restoration Efforts in Africa Through the Land Accelerator

AFR100 (the African Forest Landscape Restoration Initiative) is a country-led effort to bring 100 million hectares of land in Africa into restoration by 2030. It aims to accelerate restoration to enhance food security, increase climate change resilience and mitigation, and combat rural poverty.

The Land Accelerator is a novel approach to enhance the extent of the restoration efforts underway under AFR100. The Land Accelerator provides land restoration entrepreneurs across Africa with mentorship and networking opportunities, technical training and workshops to build up their storytelling and pitching skills. By furnishing entrepreneurs with these skills and connections, they are empowered to grow their business ideas, scaling their restoration impact accordingly. **Future training sessions under the Land Accelerator could include operating under climate change-altered conditions as a technical module, providing entrepreneurs the necessary knowledge to help ensure the climate resilience of their operations.**

In order to generate a baseline, the project team must first evaluate the availability and quality of historical data (possibly using statistical tools to fill in any data gaps), keeping in mind the expected lifetime of the project. An appropriate time frame for establishing a climate baseline from observed ecosystem data would be 30 years of historic records. In cases with limited data, a baseline of the last 10-20 years could be acceptable, however, the shorter the period used the greater the possibility that the period used is not representative of the long-term climate. Sometimes only older records are available (e.g., hydrological flow data) and these can also provide a useful baseline. Depending on the project, baseline climate data would include historical hydro-meteorological records such as temperature, rainfall, low flows, high flows, and wind speed. The World Bank's Climate Change Knowledge Portal is a good place to start to obtain existing historical data for a particular area. For certain kinds of ecosystem projects, further variables such as humidity, night-time temperatures as well as the seasonality of different climate variables may also need to be examined.

As such, for projects with shorter project horizons and where project objectives are achieved relatively quickly (generally less than 10 years– e.g., replanting of coastal dune vegetation to limit erosion) the range of natural climate variability is the dominant concern, over and above the long-term impacts of changes to mean conditions as caused by climate change. In most cases, however, investments in ecosystem health are designed for long term outcomes and are modeled over long-time horizons. Such projects also typically take several years to reach fruition, especially where they involve passive restoration. Projects with longer time horizons are subject to greater uncertainty and should consider a wide range of future climate conditions.

There is a great deal of uncertainty about future climate conditions, particularly for long time horizons, which makes the question of which climate futures to consider a non-trivial decision point in the evaluation process. Future climate is uncertain not just because of natural stochastic variability in the climate (i.e., one rainy season can be wetter than another), but also because of uncertainty about how future greenhouse gas emissions will grow, and uncertainty about how the climate system will respond to future emissions levels. One way of exploring these various sources of uncertainty is through the use of different future scenarios or pathways. While tempting to focus in on just one or a few individual climate futures, there are compelling reasons to consider a broader range of possible conditions: a single climate future describes only one possible version of the future, with many other possibilities going unexamined, making it difficult to draw well-substantiated conclusions.

Detailed, quantitative simulations of future climate can be obtained from projections modeled through GCMs. Recent World Bank guidance (2022) focuses specifically on the selection of future climate projections and recommends considering **an optimistic and a pessimistic scenario of greenhouse gas concentrations** as driven by global greenhouse gas emissions trajectories and climate mitigation policies, as well as **several scenarios that represent a "dry and hot" and a "wet and warm" future**. The first set of scenarios allows one to assess the impact of uncertain global climate mitigation efforts on project outcomes, whereas the second set helps assess local climate risks and overall uncertainty in climate model outputs on project outcomes. The latter is important because different models simulate different climate outcomes for the same emissions scenario due to their reliance on different modeling approaches. In addition, as a general rule, an analysis should consider different GCMs in order to capture the range of possibilities predicted by climate scientists. Attention should be paid to the range of future conditions described by these model ensembles (by considering confidence intervals, for example) rather than just their averages. **Textbox 7.4** provides guidance on where to obtain climate projections, with further details presented in the technical note on working with climate projections included in the Compendium Volume.

An even more rigorous analysis suitable for high tier projects would include considering the full range of future climate uncertainty (as compared to selecting a number of individual climate scenarios) through stochastic estimations of climate variables from a weather generator. The Decision Tree Framework (Ray and Brown 2015) provides additional guidance on how to use a weather generator in project evaluation.

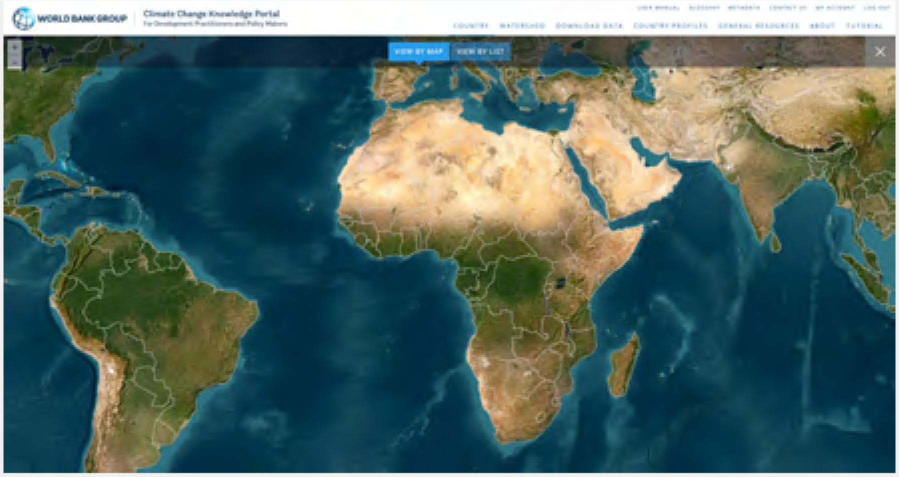
Finally, through stakeholder consultation and expert advice, the project team should assess the degree of uncertainty suggested by the range of climate scenarios considered, as well as to what extent these uncertainties are tolerable and/or should be mitigated.

Activity 2c. Analyze the project's performance under the selected climate scenarios. The output of Activity 2b is then directed into socio-economic models that convert biophysical outputs into costs and benefits, identifying the performance of the project for both baseline and future scenarios. For example, a catchment restoration project may involve the clearing of invasive alien trees at a significant initial cost, followed by ongoing maintenance. The removal of these water-hungry trees will lead to an increase in streamflow, which will translate into higher yields from a downstream reservoir. This avoids having to construct additional water supply infrastructure to meet water demands as a result of decreasing streamflow. Thus, the costs of clearing the invasive plants can be compared with the cost savings, which are the benefits of the project. These results, along with the performance in the metrics established in Activity 2a, serve as the basis for the evaluation.

Textbox 7.4: Where to Obtain Climate Projections

The output of future climate simulations can be obtained from various sources:

The World Bank's Climate Change Knowledge Portal has both historical data and future climate simulations available for every country/sub-national unit/drainage basin in the world. All information contained within the Knowledge Portal is consistently produced and thus directly comparable. As well as being free of charge, it is well-suited to project teams who are not used to working with raw, unprocessed output from climate models and it saves time on data searches and data processing.



National meteorological agencies often also provide localized climate information, which can be accessed through the World Meteorological Organization's website.

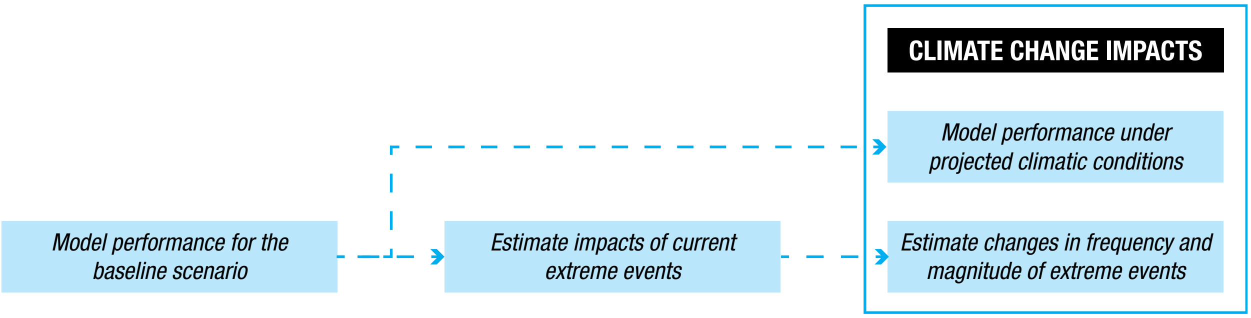
Global observations and computer simulations from the Intergovernmental Panel on Climate Change's various assessment reports, can be obtained from their Data Distribution Centre. Similar information can also be collected from the KNMI/World Meteorological Organization Climate Explorer. These latter two sources provide raw, unprocessed model outputs, which require significant time and expertise to process and bias correct, before they can be utilized in project analyses.

Typically, investment projects are evaluated through Cost-Benefit analysis, which is the primary tool used in economic decision-making. Economic analysis of ecosystems should take into account the direct outputs (costs and benefits) of the investment along with all changes in welfare resulting from positive or negative externalities, such as changes in environmental quality and ecosystem services, and including impacts on future generations. Understanding these impacts requires understanding the ecosystem services supplied, how these are affected by the proposed development, and how to value that change. The technical note on economic modeling included in the Compendium Volume provides a primer on Cost-Benefit analysis, describing how to value the impacts on ecosystems, and approaches to consider additional project externalities (e.g., health benefits or reduced risk).

Of special mention when it comes to ecosystems investments is the question of the project time horizon included in the assessment of costs and benefits. While a hydropower plant, urban transit project or irrigation scheme can begin to accrue benefits as soon as construction is complete and operation is underway, ecosystems typically experience a significant lag between the initial investment and the generation of specific services. When it comes to wetland restoration for instance, it may take several years if not more than a decade for the full flood attenuation, water treatment and biodiversity benefits to be experienced. It is thus crucial for these kinds of "lagged" investments to ensure that the project horizon used for project evaluation is tailored to the specific objectives of the project and the timeline across which these objectives will be met.

Following the analytical approach determined in Step 1, the analysis should model the impacts of climate hazards following the process in **Figure 7.7.** Climate change impacts should be modeled for all the future scenarios considered in the previous activity and compared against the baseline. Hallegatte et al. (2021) and Asian Development Bank (2015) provide further guidance on how to incorporate the effects of climate change and extreme weather events in cost-benefit analysis. For projects with long time horizons, it is recommended to look at the result at multiple timestamps (e.g., midcentury and end of century).

Figure 7.7. **Evaluation Process for Climate Hazards**



When conducting the assessment of a new development, a counterfactual representing a no-investment scenario, would be appropriate to assess whether the investment is better than a no-action scenario, as well as to measure the overall contribution (i.e., benefits minus costs) of the investment.

Activity 2d. Assess the vulnerability of the project in the form of a stress test. The analysis should then explore the performance of the project under the range of possible climate futures selected in Activity 2b to assess whether the project fails under those conditions based on the results from Activity 2c. This stress test will help the project team identify thresholds for failure, as well as failure scenarios (e.g., when the project does not meet the minimum economic returns) and the extent of the failure (i.e., difference between the results and a target measure), as well as any early warning signals that a tipping point may be approaching. The vulnerability of the project is then assessed by looking at all the results generated in the previous activity for each future scenario. The following questions guide the vulnerability assessment:

- **Does the project meet the minimum performance targets**? When looking at economic return metrics, these generally require the project to have a positive Net Present Value and/or meet an Internal Rate of Return hurdle rate (see the technical note on economic modeling included in the Compendium Volume for a primer on economic evaluation). Estimates of the non-market welfare impacts of changes in environmental conditions should also be estimated. Commonly, project analysts would perform a sensitivity analysis and evaluate the project under a range of assumptions and discount rates. A project can also be vulnerable to a climate hazard when minimum performance in other metrics is not met under at least one scenario.

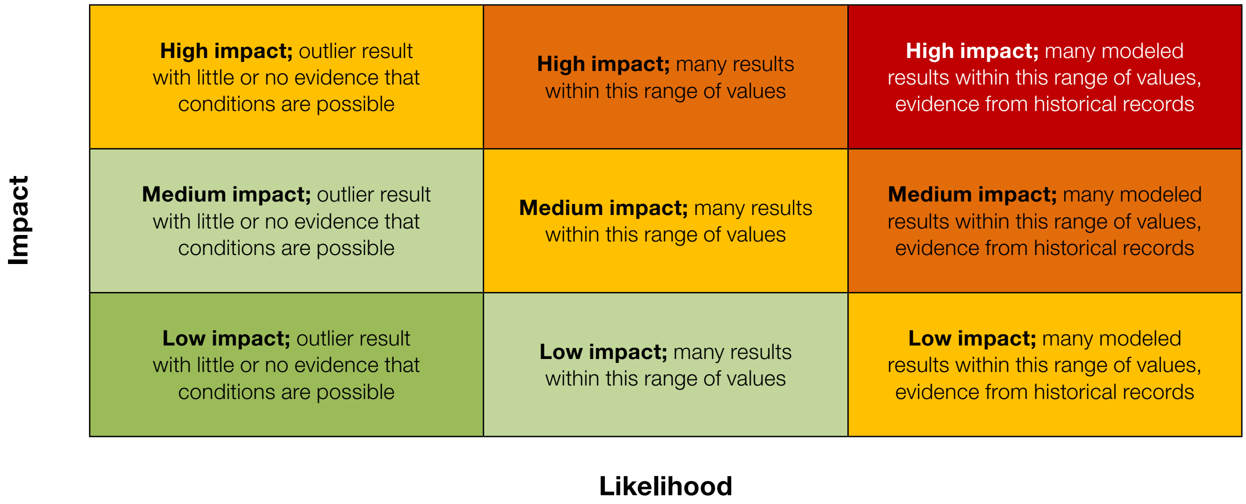
- **To what degree does the project meet the minimum performance targets**? The extent of the failure can be measured through the range of results across different climate futures. This analysis may indicate the presence of scenarios with results below an acceptable threshold, which may render the project vulnerable if consequences can be catastrophic. For example, a storm event that disrupts forest regrowth may have severe and compounding consequences on the ecosystem, aside from the direct damage caused by the storm itself.

On the basis of these questions, a project can be considered vulnerable to climate change impacts if in the future (i) the results for individual climate scenarios are worse than the baseline, (ii) there is a greater number of failure scenarios than in the baseline, (iii) the potential range of results worsens, or (iv) a combination of these situations. For example, a sustainable rangeland management project may fail if ecosystem productivity levels decline below some economically viable threshold, regardless of the performance in other metrics. The analysis may find that for a single GCM scenario, the performance of the investment is sufficient to meet project targets. However, other scenarios show greater changes in future temperatures and precipitation patterns, resulting in the investment no longer meeting its targets. Those scenarios that show a problematic outcome indicate that the project is vulnerable should those futures occur. By using a large number of scenarios, the project team can have more confidence in the level of concern associated with the vulnerability (i.e., large number of problematic scenarios versus few).

A practical framework to summarize the results of the vulnerability analysis, particularly for high tier projects with a large number of results, is to generate a risk matrix that considers impact and likelihood. Impacts refer to the effects of the climate hazard on the project's performance. Likelihood can be thought of as a "weight of evidence" that provides insights as to the level of concern associated with the vulnerabilities. Likelihoods can be assessed in relative terms, based on whether the results of each GCM run fall within the general range of all results or is an outlier, and whether the climatic conditions have been observed in the historical baseline.

Figure 7.8 presents an illustrative example of a risk matrix adapted from Ray and Brown (2015), where higher impacts and higher likelihoods lead to higher levels of risk. All projects found to be vulnerable, particularly those at higher levels of risk, should advance to the next step of the framework to examine whether the project's resilience can be improved.

Figure 7.8. Sample Risk Matrix



High impact; outlier result with little or no evidence that conditions are possible	**High impact;** many results within this range of values	**High impact;** many modeled results within this range of values, evidence from historical records
Medium impact; outlier result with little or no evidence that conditions are possible	**Medium impact;** many results within this range of values	**Medium impact;** many modeled results within this range of values, evidence from historical records
Low impact; outlier result with little or no evidence that conditions are possible	**Low impact;** many results within this range of values	**Low impact;** many modeled results within this range of values, evidence from historical records

Outcome: The result of this step is an understanding of the climate vulnerability of the project as currently designed. Comparison between the performance of the project under a historical baseline and under various climate futures provides an estimate of the degree of vulnerability of the project to climate change. It is possible that some project designs may be found to already be climate resilient in their performance given climate uncertainty and these projects can exit the framework here.

Case Study Demonstration of Step 2: Climate Resilient Investment Opportunities in the Cubango-Okavango River Basin

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

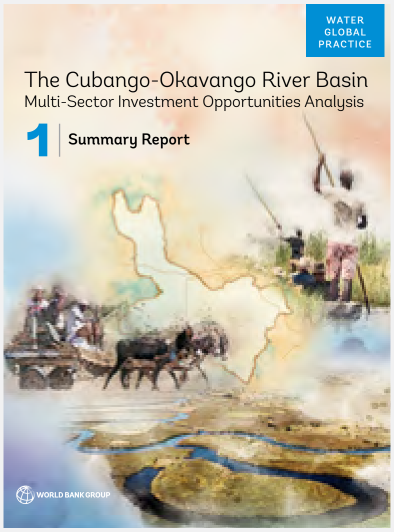
3 Develop and evaluate strategies

4 Recommend a course of action

2a. Determine performance indicators → *2b. Establish climate baseline and projections* → *2c. Analyze project performance* → *2d. Assess vulnerability*

Performance indicators: The main indicators used to compare the different infrastructure development options included simulated streamflow volume per sub-basin and ecological impacts, measured through ecological integrity at each site and across the basin. The chosen infrastructure development plan will ideally go hand-in-hand with a tailored ecosystem management strategy, and many of these same indicators could be used to evaluate different possible ecosystem management strategies, with the addition of a number of more detailed ecosystem-focused indicators, as needed.

Climate baseline and projections: Uncertainty as a concept was introduced into the rainfall-runoff model by combining historical conditions with estimated uncertainties in future rainfall and potential evaporation as well as scenarios of likely future water use. The ranges of change in rainfall and evaporation were based on the published literature which indicates that there is likely to be a decrease in rainfall, increase in temperature and increase in evaporation. The climate change model was run with 62,500 streamflow time-series outputs representing future uncertainties in the flow regime. These 62,500 outputs were derived by combining 250 samples of feasible parameter values with 250 samples of likely future rainfall patterns.



WATER GLOBAL PRACTICE

The Cubango-Okavango River Basin
Multi-Sector Investment Opportunities Analysis

1 | Summary Report

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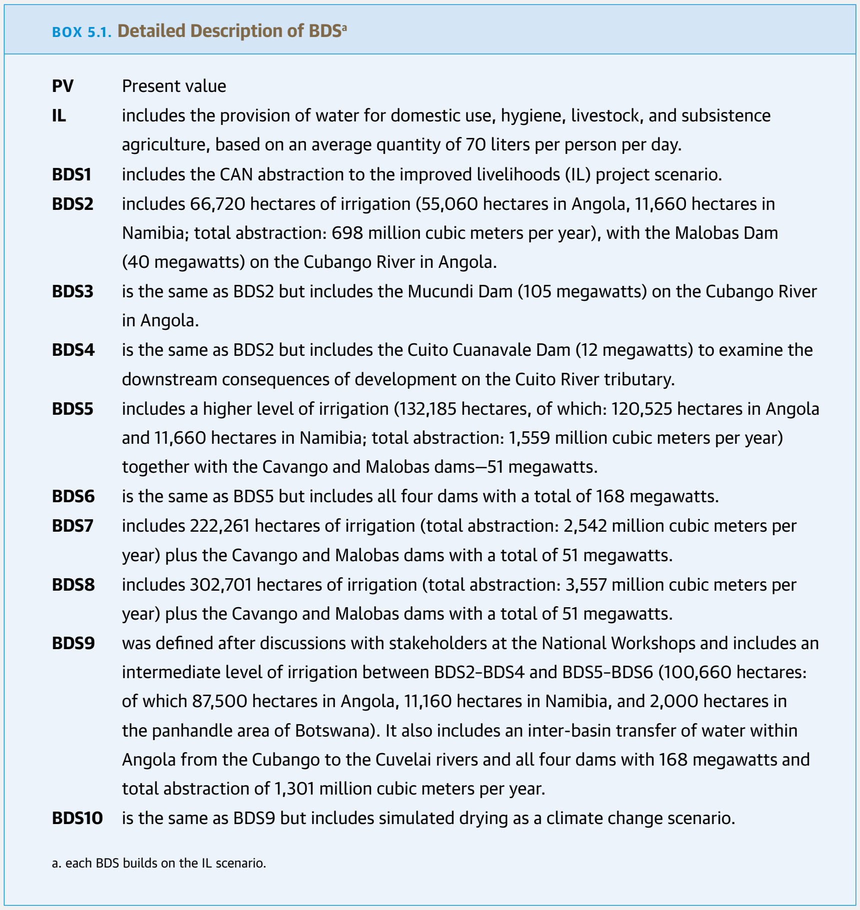
Analyze project performance: Details of the nine different development options (BDS1 through BDS9) are shown on the next page. The performance of each of these development options was assessed using the model chain described in Step 1. The status quo option assumed business-as-usual in terms of baseline hydrology and existing abstractions. The various development options considered the construction of one dam, two dams, and four dams – with different levels of abstractions for irrigation and urban water use. Each development option was configured in the Pitman Rainfall-Runoff Model to assess the relative impact on water availability and environmental integrity.

Case Study Demonstration of Step 2 (continued): Climate Resilient Investment Opportunities in the Cubango-Okavango River Basin



BOX 5.1. Detailed Description of BDS[a]

PV	Present value
IL	includes the provision of water for domestic use, hygiene, livestock, and subsistence agriculture, based on an average quantity of 70 liters per person per day.
BDS1	includes the CAN abstraction to the improved livelihoods (IL) project scenario.
BDS2	includes 66,720 hectares of irrigation (55,060 hectares in Angola, 11,660 hectares in Namibia; total abstraction: 698 million cubic meters per year), with the Malobas Dam (40 megawatts) on the Cubango River in Angola.
BDS3	is the same as BDS2 but includes the Mucundi Dam (105 megawatts) on the Cubango River in Angola.
BDS4	is the same as BDS2 but includes the Cuito Cuanavale Dam (12 megawatts) to examine the downstream consequences of development on the Cuito River tributary.
BDS5	includes a higher level of irrigation (132,185 hectares, of which: 120,525 hectares in Angola and 11,660 hectares in Namibia; total abstraction: 1,559 million cubic meters per year) together with the Cavango and Malobas dams—51 megawatts.
BDS6	is the same as BDS5 but includes all four dams with a total of 168 megawatts.
BDS7	includes 222,261 hectares of irrigation (total abstraction: 2,542 million cubic meters per year) plus the Cavango and Malobas dams with a total of 51 megawatts.
BDS8	includes 302,701 hectares of irrigation (total abstraction: 3,557 million cubic meters per year) plus the Cavango and Malobas dams with a total of 51 megawatts.
BDS9	was defined after discussions with stakeholders at the National Workshops and includes an intermediate level of irrigation between BDS2–BDS4 and BDS5–BDS6 (100,660 hectares: of which 87,500 hectares in Angola, 11,160 hectares in Namibia, and 2,000 hectares in the panhandle area of Botswana). It also includes an inter-basin transfer of water within Angola from the Cubango to the Cuvelai rivers and all four dams with 168 megawatts and total abstraction of 1,301 million cubic meters per year.
BDS10	is the same as BDS9 but includes simulated drying as a climate change scenario.

a. each BDS builds on the IL scenario.

Detailed description of basin development scenarios (Source: World Bank 2019)

Assess vulnerability: The results of the analysis suggest that increases in water use will reduce streamflow volumes and increase future environmental impacts. Irrigation developments have the strongest impact on water availability and the largest negative environmental impact. Hydropower dam developments will increase flow in drier months and have a regulatory effect on the river. Based on these results, BDS9 was selected as the proposed development option.

The impact of future climate change was subsequently evaluated for the different development options by assessing the ecological integrity at each site and across the basin as a whole for a number of different climate futures. Several of the development options were shown to be vulnerable to climate change. Climate change is expected to result in significant decreases in flood peaks and volumes, which is an important part of the natural flow variation within the basin system, particularly in the Delta. Environmental impacts due to climate change were shown to be severe under the suggested development option (i.e. BDS9), indicating that this option is vulnerable to climate change.

7.2.3. Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience

Objective: This next step in the framework develops a set of possible strategies by which to adapt the project to climate hazards to improve its resilience. The analysis seeks to provide insights about the performance of the project given climate change as compared to the adapted project given climate change, and considers three activities.

Activity 3a: Identify individual interventions to enhance the climate resilience of the project. Building resilience involves strengthening the capacity of the ecosystem to cope with climate hazards. As such, the assessment should start from the results of the analysis in Step 2, and search for interventions that can mitigate the project's vulnerabilities by decreasing the magnitude and recurrence of failure scenarios, as well as the likelihood of a tipping point occurring.

All of the types of interventions described in this note involve applying general principles of biodiversity and ecosystem conservation. The key principles for enhancing resilience of ecosystems under climate change are to

- reduce existing stressors,
- protect large and connected systems,
- protect potential refugia,
- implement proactive management to assist species where justified, and
- sustain or restore ecosystem health and functioning outside as well as inside protected and conservation areas.

Changes in climate cannot be eliminated by management, except at very localized scales and with high costs. Climate-smart conservation strategies, therefore, involve determining where and how the broad types of measures listed above should be emphasized in light of current understanding of future species and habitat shifts. Within this, the choice of conservation model (the actions to be taken, by whom and with what support) should be selected based on factors such as likely success and cost-effectiveness. This process helps to determine spatial priorities for conservation, restoration and landscape management efforts under climate change. Subsequent interventions should be biodiversity oriented, financially feasible, and have a high probability of success regardless of the eventual climate outcome. Given limited resources and the significant uncertainties involved, a strategic approach will need to balance spatially targeted priorities and broad-scale, cost-effective measures.

A climate-smart conservation and restoration strategy will be one that meets the spatial configuration and connectivity requirements of shifting biota and one where there is room for the adaptive management of change in the areas that are expected to change. Overall, reducing vulnerability to climate change can be achieved by improving levels of protection combined with restoring and maintaining the health of contiguous ecosystem areas outside protected areas. Increasing biome resilience under climate change requires (1) formal protection, by strengthening the system of protected and conservation areas; (2) off-reserve conservation, by strengthening and targeting measures outside protected areas; (3) increasing efficiency and using incentive measures to get more done for less; and (4) ensuring that a range of enabling factors regarding institutions, policy and legislation, data, and capacities are in place to achieve the above. Additionally, when considering measures to increase the resilience of ecosystem projects, it is important to match the scale of the intervention to the desired outcome. For instance, while restoration of degraded land could offer local benefits such as attenuating extreme precipitation, decreasing erosion and improving crop yields, other benefits such as changes to local weather patterns would require restoration at a much greater scale.

> Given limited resources and the significant uncertainties involved, a strategic approach will need to balance spatially targeted priorities and broad-scale, cost-effective measures.

Table 7.2 summarizes some adaptation measures that can be used to enhance ecosystem resilience in Sub-Saharan Africa. Unlike the other sectoral guidance notes in this Compendium, when it comes to enhancing the climate resilience of ecosystems investments, the vast majority of possible adaptation measures are centered on changes to how the ecosystem is managed rather than structural interventions. More detail on some of the practices shown in **Table 7.2** can be found in the Greater Cape Town Water Fund case study (Stafford et al., 2019) that shows the cost competitiveness of catchment restoration by invasive alien plants removal and a World Bank report that documents the value of natural capital and its role in green urban development in Durban, South Africa (Turpie et al., 2017).

Table 7.2. Biodiversity and Ecosystem Practices to Enhance Climate Resilience

Strategic Element	Priority Management Actions
Formal Protection	• Significantly expanding the conservation estate. • Elevating the current targets for strict protection. • Prioritizing formal protection in relatively stable areas in terms of climate change impacts. • Strengthening protected area management. • Adjusting protected area management objectives and strategies in areas of change.
Off-Reserve Conservation	• Agricultural extension programs that support sustainable rangeland management and address land degradation, fire management, and bush encroachment, as well as promote conservation farming practices. • National certification system(s) to promote biodiversity-friendly practices in livestock and wildlife ranching. • Spatial prioritization of costly management and restoration interventions, for example in areas important for ecological connectivity. • Detailed fire management plans. • Re-evaluating surface and groundwater management in light of changing ecosystem sensitivity to water abstraction and modification of flow patterns. • Ecosystem restoration and landscape management.
Efficiency and Incentives	• Maintaining a strong conservation focus. • Applying best practices for ecological restoration activities. • Incentivizing private and community conservation through biodiversity stewardship. • Finding smart ways to induce large-scale changes by landowners and users. • Obtaining public and political buy-in.
Creating Enabling Conditions	• Finding novel ways to raise conservation finance. • Adjusting policy and legal instruments to incentivize private conservation action. • Filling information and knowledge gaps through research and monitoring. • Capacity building. • Strengthening governance frameworks in which the responsibilities for conservation actions are unambiguous.

Source: Adapted from Turpie et al. (2021)

Thematically, resilience-enhancing interventions may consider investments in four types of ecosystem services:

1) **Regulating services:** This includes measures to restore or secure catchment vegetation and soil cover in order to provide services such as infiltration and flow regulation, flood attenuation, sediment retention, and water quality amelioration. Such measures can include active restoration such as planting and stabilization, sustainable management of rangelands and harvested natural resources, protection of landscapes in conservancies or protected areas, and development setbacks along riparian areas. Interventions could also include agronomy practices designed to minimize soil erosion and loss.

2) **Climate regulation and air quality services:** This includes measures to restore or secure vegetation cover in ecosystems that have a high potential for carbon sequestration and storage,

particularly forests, grasslands, peat wetlands, and seagrass beds, or to maintain local or regional rainfall, such as the conservation of tropical rainforest or cloud forest. This could also include the establishment or protection of tree cover and wetlands in urban areas in order to take advantage of their significant cooling effects.

3) **Provisioning services:** This includes investments in agriculture, livestock, and fishery projects (see the agriculture note included within the Compendium Volume), and in sustainable management of forest or other upland harvested resources, including non-timber forestry products. This can also include investments in the adjacent ecosystems that support these and agricultural activities, such as fish nursery areas and areas supporting bee pollinators. Projects may also focus on developing new opportunities, for example in bio-prospecting and bio-trade.

4) **Cultural services:** This includes conservation or rewilding initiatives to promote biodiversity, particularly focusing on variety, landscape beauty, and charismatic species, in order to promote recreational use and associated economic opportunities, as well as to contribute to overall landscape functioning and resilience.

Activity 3b: Develop adaptation strategies to enhance resilience. Once a set of promising and feasible adaptation measures has been identified for the project, more comprehensive and integrated strategies to build resilience should be developed by combining individual measures. Strategies should consider different sets of interventions, as well as different degrees of implementation, timing, or locations as appropriate, and should be part of a participatory consultation with stakeholders to identify and validate solutions. For example, enhancing the hydrological services of a catchment area can involve a number of or even all the elements listed in **Table 7.2**. The more these elements are used in combination and the greater the area over which they are implemented, the stronger the overall effect will be on system resilience. For this reason, there is increasingly a focus on landscape-level interventions to enhance ecosystem resilience, with these approaches discussed further in Chapter 2 of the Compendium Volume.

Textbox 7.5: Resilience Attributes for Ecosystems

Key capacities to build climate resilience in investments in Sub-Saharan Africa's ecosystems include (adapted from Ospina and Rigaud 2021):

- **Redundancy:** the availability of additional or spare resources that can be accessed in case of an extreme. For example, if many species perform similar functions, ecosystem functions will be more stable in case of species fluctuation due to drought.
- **Connectedness:** the breadth of resources and structures that an ecosystem can access, at multiple levels, to respond and adapt to shocks or stressors. An ecosystem that is divided into parts will have a lower productivity than an intact system of the same size.
- **Diversity**: the ability of the system to undertake different courses of action and to innovate in response to shocks or stressors. For example, the relative abundance of different species in a protected area.
- **Learning:** the ability to develop knowledge and skills to innovate, adapt, and improve performance, leveraging existing knowledge to develop resilience mechanisms. For example, droughts can be predicted with forecasting models incorporating learnings from past events.
- **Inclusion:** building on diversity and inclusion, ensuring that women and vulnerable groups have the necessary tools and resources, both in normal conditions and during crisis.

It is worth drawing attention here to the World Bank's ongoing **Biodiversity, Ecosystem, and Landscape Assessment initiative,** as the outputs of this initiative can inform the development of an ecosystems adaptation strategy. This initiative works to support landscape assessments of biodiversity and ecosystem services in countries across Sub-Saharan Africa, with the outputs of these assessments providing valuable information in terms of enhancing the resilience of proposed investment projects, promoting integrated land management and nature-based solutions.

Ultimately, which interventions become part of a strategy will depend on what attributes of resilience need to be enhanced to reduce climate vulnerability, as well as how stakeholders and users define resilience for the particular project in question. **Textbox 7.5** presents a list of key attributes for ecosystems, which can guide the development of adaptation strategies to enhance resilience, with these attributes ideally to be tailored to local circumstances. While these attributes are introduced here as guidelines to consider when developing possible adaptation strategies, they are a powerful tool to strengthen project design, especially when integrated as key resilience concepts into the project narrative from the outset and then used to track progress towards achieving greater resilience. Additional guidance can be found in the note for practitioners titled Integrating Resilience Attributes into Operations (Ospina and Rigaud 2021). In the face of climate uncertainty, it is appropriate that strategies consider a portfolio of measures to mitigate the impacts from multiple climate hazards, along with insurance and contingency plans for when conditions exceed the capacity of the adapted system to cope.

Resilience Spotlight: Catchment Management in Rwanda's Sebeya Basin

A four-year program is underway in Rwanda to improve catchment management and increase the resilience of communities and landscapes to the impacts of climate change and other drivers. The program, titled Embedding Integrated Water Resource Management in Rwanda, focuses on the Sebeya catchment, in the Western Province of Rwanda. The program is based on a community participatory approach, relying on participation of local communities in planning and implementation catchment restoration activities. The climate resilience of the program is enhanced by a number of activities **including training on soil conservation measures such as progressive terraces, soil bunds, ditches, and radical terraces**; implementation of **rainwater harvesting systems as a supplemental source of water**; and exploring the possibility of **developing green roads from which runoff can be harvested**.

A climate-smart conservation strategy provides an approach for how to combine solutions that improve the combined level of protection as well as restore and maintain the health of contiguous ecosystem areas outside protected areas. Though this guidance note focuses predominantly on climate adaptation (with adaptation considered the priority at present for Sub-Saharan Africa), it is important that adaptation and climate mitigation goals and activities are not treated in isolation, as the resilience of a project can also be impacted by climate mitigation-related considerations. The focus of this note on adaptation should not detract from the identification and quantification of any co-benefits that may accrue from climate mitigation. For example, conservation of forest areas contributes both to climate change mitigation and adaptation.

Activity 3c: Evaluate the selected strategies' contribution to the resilience of the project. Having identified a feasible portfolio of individual adaptation measures, the next step involves using the same modeling framework established in the vulnerability assessment described in Step 2 to evaluate the performance of the different adaptation strategies being considered.

Depending on the specific interventions, it is possible that new model parameters or assumptions may need to be defined (looping back to Step 2) before being able to estimate the costs and benefits of different interventions, which may require the gathering of additional data. Different kinds of adaptation strategies (for instance changes in ecosystem management strategy versus infrastructural interventions) may necessitate different updates to the modeling approach previously developed in Step 1. Comparing the performance of the strategies to the project as originally designed (in Step 2) in terms of how much they reduce the magnitude and recurrence of project failure provides a sense of the degree of climate resilience that different strategies offer. In other words, an adaptation strategy that increases climate resilience is one that results in fewer cases of failure, a reduced impact in the failure scenarios, or both. For example, maintaining healthy vegetation cover in catchment areas reduces the seasonal variability of flows and helps to reduce the frequency of yield failure. The extent of these improvements can be tracked using the Risk Matrix previously shown in **Figure 7.8**.

Outcome: At the end of Step 3, the project team will have identified promising portfolios of interventions that enhance the climate resilience of the original project design evaluated in Step 2. The output of this step is an updated set of results showing the project's performance for each adaptation strategy and climate scenario. This output will be the input for the following decision-making step.

Case Study Demonstration of Step 3: Climate Resilient Investment Opportunities in the Cubango-Okavango River Basin

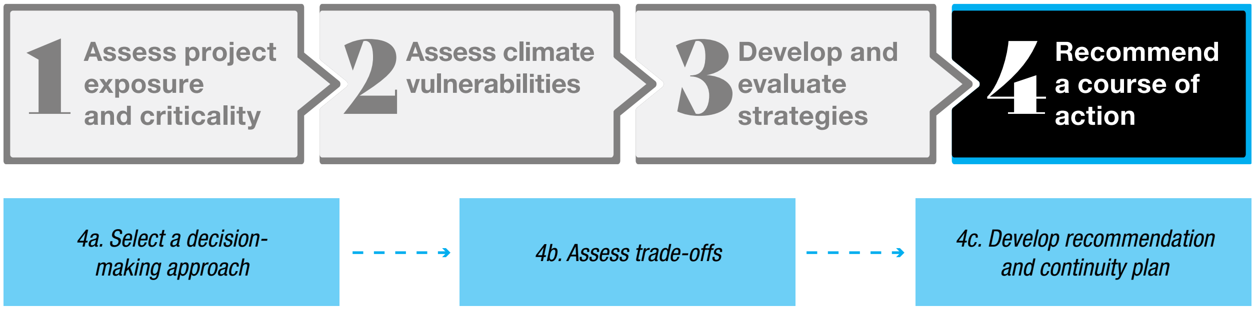
Identify individual interventions and develop adaptation strategies: For future infrastructure development to be sustainable (both for the environment and for the people of the Cubango-Okavango River Basin) given the likely impacts of climate change, lower levels of development (compared to BDS9) would need to be considered. Alternatively, development option BDS9 could also become more resilient through a reduction in water demand for irrigation.

Additionally, several interventions were identified that could improve the resilience of all the different developments options under climate change i.e., short-term, high-impact, no-regret initiatives. Such initiatives included the introduction of a **targeted livelihood enhancement program** and a **tourism investment framework**. Such programs would support development outcomes, decelerate catchment degradation and assure the quality, quantity and timing of water in the basin, even under future conditions altered by climate change.

Each of the resilience building initiatives that address degradation of the catchment are comprised of a number of individual measures. The livelihood improvement program includes initiatives that address the underlying drivers of poverty and thereby reduce the pressures on natural resources. Some individual interventions, for example, focus on food security through sustainable agriculture, including conservation agriculture and improved market linkages. Other suggested programs focus on sustainable energy to move away from environmentally damaging energy sources such as charcoal. Direct employment options could be increased in tourism and related service industries to enhance other income generating activities and reduce the current strong reliance on the river. Specific suggestions were made such as to expand ongoing regional sustainable tourism and conservation initiatives, such as the Kavango-Zambezi Transfrontier Conservation Area.

Evaluate the resilience of the different strategies: Climate change is expected to result in lower river flows. Resilience of the different development strategies was tested by assessing the impact of climate change on different stretches of the river. For example, an assessment was done on the stretch of river around Rundu on the Namibia/Angola border to evaluate the impact of climate change. This analysis indicated that under BDS9 development levels, there would still be sufficient water available to meet the domestic water supply volumes for Windhoek and the Central Area of Namibia as well as irrigation abstractions. However, a more ambitious development scenario or more intense climate change impacts would make certain projects unsustainable from an environmental and economic perspective.

7.2.4. Step 4: Recommend a Course of Action



Objective: Finally, this step will lay out a decision-making approach to identify a course of action from the adaptation strategies considered in Step 3 that considers trade-offs and looks at the full economic lifetime of the project. Three activities are involved.

Activity 4a: Select a decision-making approach that is able to help identify a strategy (from the set developed in Step 3) that is well-suited for a broad range of uncertain conditions. This requires assessing and trading off project performance across a variety of uncertain future conditions, rather than simply maximizing the expected results from averaged future conditions. While the focus in this note is on uncertainty about future climate conditions, resilience analyses in Sub-Saharan Africa are faced with a variety of different uncertainties, including from inadequate historical climate data, the divergence of existing climate projections, as well as changing political and policy environments, external market conditions, or levels of technology adoption. In this context, traditional decision-making methods often fall short because they typically strive to identify an optimal design for an average or most likely set of future conditions. (This group of methods is often described as being founded on **predicting and then acting** – see the technical note on decision making under climate uncertainty included in the Compendium Volume for an overview of these traditional decision analysis methods.)

Given the significant degree of uncertainty associated with future climate conditions, a new group of decision-making methods has been developed that focus on **preparing and adapting,** rather than predicting and acting. This class of methods emphasizes **the identification of flexible decisions that enable ongoing adaptation, or robust decisions that will prove wise across a wide range of future climate conditions.** In general, these methods involve framing the analysis and conducting an exploratory assessment, choosing initial and contingent actions to iterate and perform re-examination, and allowing participation of stakeholders. **Table 7.3** provides a summary of some of these decision-making approaches, grouped based on whether they emphasize the robustness or flexibility of the decision. (See the technical note on decision making under climate uncertainty included in the Compendium Volume for further details.)

Table 7.3. Summary of Approaches for Decision-Making Under Climate Uncertainty

Emphasis of Framework	Description	Examples
Robustness	These approaches focus on achieving acceptable project performance across a wide range of possible future conditions. The emphasis is on the investment decision to be made now and generally follows a conservative approach when incorporating future conditions that are significantly different from the baseline.	• Decision Scaling • Robust Decision Making
Flexibility	These approaches prioritize identifying a design that can adapt in the future given different climate conditions. In general, these value the agility of a design more than its robustness and include consideration of "tipping points" for climate variables that will indicate a change from one set of actions to another.	• Engineering Options Analysis • Adaptation Pathways

The selection of a decision-making framework should be informed by the preference either to account for future uncertainty now through measures that enhance the robustness of the decision or leave options open for future adaptation. This choice should be informed by the available resources today and in the future, the capacity of the project team to control or influence changes in the future, and the optimism that future information will help to clarify the adaptation decision and will arrive in a timely way. For instance, while a critical water catchment restoration project may benefit from a robust approach that ensures it is designed to cope with low-probability but high-impact flooding events, it may be considered acceptable for a local stream to experience increasingly frequent flooding as sea level rises before decisions are made as to whether to restore the riverbed or pursue other more expensive adaptation strategies.

As mentioned before, the framework for enhancing the climate resilience of projects that is presented in this note is circular: it is possible that after selecting a decision-making approach, the activities completed during earlier steps in the framework may need to be revisited and adjusted. For instance, having prioritized the flexibility to make incremental adaptation decisions and delay large investments till later (as compared to prioritizing system robustness now), this decision may necessitate returning to Step 3 and identifying additional adaptation interventions that enable flexibility, as well as returning to Step 2 and selecting a few additional uncertainty scenarios to explore if particular climate futures are concerning to decision makers.

Activity 4b: Assess the trade-offs of each strategy. Generally, there is no perfect adaptation strategy, and more beneficial strategies tend to be more expensive. Strategies that are good for mitigating the impacts of one climate hazard, for instance drought, may also fail at properly addressing others such as floodings. Furthermore, strategies that benefit one sector may cause negative downstream impacts to other stakeholders. In this context, the decision-making process must also look at minimizing trade-offs. The starting point of this activity requires identifying, and if possible, quantifying, the trade-offs of each strategy. In cases when ecosystem investments are linked to another project (e.g., as an adaptation measure for it), trade-offs between the resilience and performance of both the ecosystem and linked project must be assessed. Typical trade-offs between investment decisions include investing in conservation for tourism or for climate regulating ecosystem services versus investing in management for extractive use of resources. These two types of interventions are often incompatible, requiring careful allocation of resources for optimal broadscale strategies.

The quantitative analysis performed during Steps 2 and 3 can produce two kinds of results: a point estimate of an economic performance indicator (e.g., internal rate of return or net present value) and information related to the variability (i.e., distribution of uncertainty) around the point estimate. Under uncertain future conditions, the point estimate may be no more likely to occur than the wide range of other possible outcomes around it. For this reason, when assessing trade-offs, the project team should consider the distribution of uncertainty around point estimates to promote better decision-making.

Resilience Spotlight: Restoring Coastal Dunes in Nouakchott, Mauritania

Mauritania's capital city Nouakchott is at, or below, sea level and suffers from frequent flooding. The city is currently protected by a perilous row of coastal dunes. These natural defenses have weakened due to natural and human-driven erosion, sand mining, and the grazing of livestock on dune vegetation. If the dune defenses were breached, as much as 30 percent of the city would be inundated. Under the West Africa Coastal Areas (WACA) Resilience Investment Project, efforts are underway to protect against further erosion and restore the city's coastal dune system, with **a focus on nature-based solutions.** Strategies include **planting thorny branches in the existing dunes to serve as anchors to fix beach sand in place, which will ultimately contribute to the restoration of protective dunes.** The resilience of these restoration efforts could be further strengthened by **the creation of a dune stewardship program, whereby members of the local community play a leadership role in dune vegetation maintenance and education when it comes to dune restoration efforts.**

In order to weigh the importance of different strategies, the project team should develop a hierarchy of all consequences that result from project failure. These causes of failure correspond to all the reasons why the project does not meet the performance metrics in the face of extreme weather events and climate change, as identified from the vulnerability assessment and addressed through adaptation strategies. For instance, if precipitation events of average magnitude (and therefore frequent occurrence) are found to cause greater disruption in total than occasional, high magnitude floods, a standard flooding plan for a large catchment may be a more worthwhile strategy than reinforcing a small subset of catchment areas to withstand high magnitude flood events. This list will indicate the order of priority and urgency and should be produced in consultation with and validated by stakeholders of the project.

The project team should then carry out the decision-making process, with the benefits of the strategy (i.e., the performance metrics defined in Step 2 and evaluated in Step 3, considering the distribution of uncertainty of estimates), its direct costs and associated trade-offs, and the hierarchy of priorities as inputs. As mentioned, this process may require revising the analysis done in previous steps as new information is obtained and inputs are gathered from stakeholders. Decisions then could fall into three categories, namely:

1. **Investing in climate-proofing the project at the time the project is being designed or implemented**, which can result in low-regret, no-regret and/or win-win options depending on the projected costs and benefits;
2. **Deferring from investing in climate-proofing but designing the project in such a way it can be more easily climate-proofed in the future**, if deemed necessary; Or
3. **Deciding that the project design and monitoring should not take account of climate variables and their impacts at the present time**, and that investment in climate-proofing will be undertaken at a later point, if needed.

The first option sees more substantial investments in climate resilience at the project outset than the latter two options. The second option is commonly referred to as **adaptive management**, where proactive and incremental adaptation investments are introduced over the project's lifetime. The third decision making approach embodies **a wait-and-see mindset** – while this latter approach maximizes flexibility and adaptability, minimizes investments in fixed infrastructure (both natural and built), and may be preferred when funds are limited, and uncertainty is high, it is only suitable for situations where baseline risk is considered acceptably low. For example, in Payments for Ecosystem Services programs, beneficiaries pay ecosystem users for environmentally friendly behaviors, and payments are conditional on service provision.

Resilience Spotlight: Mapping Hotspots of Urban Natural Assets in Lilongwe, Malawi

Urban green spaces and natural assets serve a crucial role in enhancing the climate resilience of urban areas. They can store and attenuate flood waters and lower urban air temperatures, all while improving the quality of life of urban residents. **The continued resilience offered by these natural assets relies on communities being aware of their value and taking steps to maintain and protect them**. In Lilongwe City in Malawi, the Urban Natural Assets: Rivers for Life project saw the completion of a mapping exercise to identify urban natural asset hotspots in the city, with these areas being particularly important to the resilience of the city and therefore in need of protection. Steps have been taken to safeguard the continued functioning of these mapped priority hotspots by implementing a monitoring and enforcement schedule to ensure sound management of these assets as well as compliance with city planning recommendations seeking to preserve these areas.

The recommendation of a preferred course of action should cover all components of the project cycle, starting with project identification, focusing on risk screening and identifying critical stakeholders and their roles and responsibilities. The recommendation should focus on those adaptation solutions that are technically feasible to address projected climate vulnerabilities, taking into account the related costs and benefits. In this context, the trade-offs analysis should also inspect the feasibility of a strategy in terms of technical capacities, policy environment, and financial constraints, with particular attention to the extent to which the environment supports or limits their implementation. Potentially, the analysis may require returning to Step 3 and revising the strategies proposed. Project implementation should identify stakeholders with the capacity to implement the preferred adaptation option(s), and include necessary capacity building at the individual and institutional levels. Lastly, the recommendation works best if it draws and builds upon country-level plans that identify priority areas, such as ecosystem and biodiversity conservation strategies or policies.

Activity 4c: The development of a recommendation and continuity plan should provide a narrative that justifies the selection of a course of action from the process in the previous activity. Moreover, the continuity plan should describe how project evaluation will be conducted, along with a clear schedule of activities and stakeholder responsibilities into the future, both during and after the implementation phase, including how resources for maintenance and/or continued adaptation will be mobilized, to ensure the investment continues to perform over the course of its life.

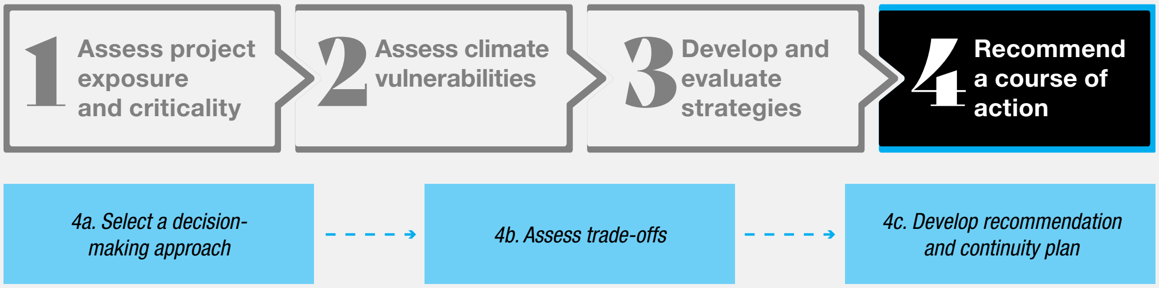
Both the narrative and continuity plan should discuss residual climate risks not addressed in the proposed project design that are still material to the project. Since it is not always economical or preferred to address all risks under all potential future conditions, there will generally be a residual risk. However, since the future is uncertain, it is possible for residual risk to grow over time in unanticipated ways to a point where it would be appropriate to address and should be the basis for a monitoring and evaluation plan. For example, precipitation-related risks may not be considered relevant today if most climate scenarios point to a drier future but may become significant if the climate evolves differently than predicted. Monitoring and evaluation should focus on assessing how progress toward vulnerability reduction and changes in residual risk will be measured in terms of indicators, tipping points, and thresholds, and how lessons learned can be used to improve current and future projects underpinned by a fit-for-purpose monitoring, evaluation and reporting framework.

This plan should include which actors will be responsible for each action and when, and should cover the full economic life of the project. Developing such a plan is fundamental when selecting a wait-and-see type of strategy that requires future actions. Even when interventions are prioritized in the near-term, as (climate and non-climate) uncertainties resolve over time, the continuity plan provides critical milestones for revising the resilience of the project.

Outcome: After completing these four steps, the project team should be capable of providing an assessment of the vulnerability of the project as initially proposed, and developing a narrative on how much a particular strategy (or set of alternative strategies) can enhance its resilience and, therefore, reduce its vulnerability. The assessment, moreover, should enable the team to understand whether the improvements (and corresponding trade-offs) are acceptable, as well as the costs of following each course of action.

Case Study Demonstration of Step 4: Climate Resilient Investment Opportunities in the Cubango-Okavango River Basin

Okavango Delta (Source: Gertrude M. Matswiri)

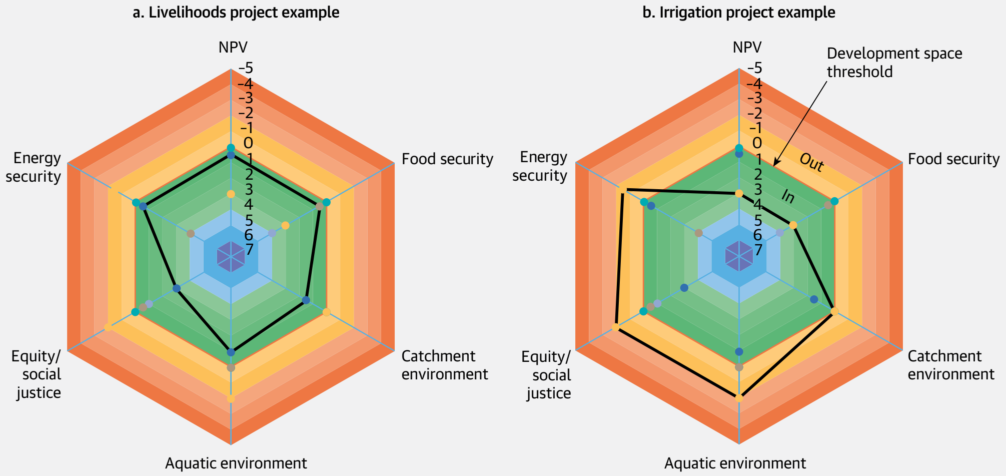


Select a decision-making approach: The hydrological modelling that was performed in this case study provided insights about the economic and environmental impacts of a number of different development alternatives. This included estimating the employment that would be created as a result of the different development alternatives.

Case Study Demonstration of Step 4 (continued): Climate Resilient Investment Opportunities in the Cubango-Okavango River Basin

The consideration of short-term, high-impact, resilience improving initiatives indicate that a flexible approach to long-term resilience was implicitly prioritized in project decision-making. A flexible approach is typically characterized by the ability to make no-regret investments in the present day, followed by further incremental investments in the future as climate impacts become clearer. In contrast, a decision-making approach that instead prioritized robustness could have focused on more significant investments in the near-term that helped assure acceptable project performance across a wide range of possible future conditions.

Trade-offs: A number of development options were analyzed in order to ascertain the benefits against the associated environmental impacts of each. There are direct trade-offs between increased economic development and increased environmental impacts in the basin. Furthermore, tradeoffs between different water-using sectors (e.g., domestic, agricultural and multi-purpose hydropower developments) may also have to be confronted. Ultimately, when selecting a development option to pursue, a balance must be achieved between social justice (livelihood improvements including employment opportunities), economic prosperity (net present value of the investment project), and environmental integrity (based on an evaluation of environmental flows), among other considerations, as shown in the figure below.



Tradeoffs within the multi-dimensional development space (Source: World Bank 2019)

Develop recommendation: A “drier” future climate change scenario showed the most significant impact on water resource availability in the river basin under the proposed development level. The case study hence demonstrates the importance of including uncertainty in hydrological modelling as it provides a better understanding of the risks associated with each specific development. Hydrological models need to be updated regularly to ensure that future developments are feasible under changing climate conditions. Ongoing monitoring and re-evaluation of the project is crucial. Ultimately, the case study recommended that cooperative infrastructure development was pursued by the basin countries, incorporating resilience-building measures such as the livelihood enhancement and tourism investment measures described above. This should be underpinned by management strategies that protect the ecosystem health and biodiversity of the basin’s wetlands.

7.3. Concluding Remarks

This guidance note presents a practical framework for enhancing the climate resilience of development projects in Sub-Saharan Africa's ecosystem sector. The framework includes four steps: (1) assessing the exposure to climate hazards and determining the criticality of the project; (2) assessing the vulnerability of the project to the identified climate hazards; (3) developing and evaluating strategies to enhance the project's resilience; and (4) recommending a course of action. For each step, the note provides illustrative examples, along with references to additional technical notes for issues that expand beyond the scope of the guidance note and are common to the other sectors covered in the Compendium Volume.

There is no single approach for assessing climate hazards in project evaluation, and this guidance note is based on the authors' understanding of the most appropriate methods available for ecosystem investments in Sub-Saharan Africa. Future climate conditions are uncertain in nature, and the proposed framework was designed for incorporating the vast and evolving field of study in climate science by way of a practical and flexible approach that can adapt to new emerging knowledge.

Investments in ecosystem integrity are inherently designed to increase resilience to climate change but can in themselves also prove vulnerable to climate change, both directly and indirectly. While the direct impacts of climate change on biodiversity should be incorporated into project design, the impacts of climate change on stakeholders involved in the projects pose an even greater threat and are more difficult to predict. Conservation projects typically involve finding ways to induce people to engage in sustainable practices or to obey rules designed to protect sensitive biodiversity or ecosystems. However, the increasing pressures on these societies make this increasingly difficult to achieve. Ecosystem conservation projects, therefore, have to be very carefully designed in order to be robust in this respect.

This note is of an incremental nature: it seeks to inform how to incorporate climate-related uncertainties and the assessment of resilience over existing project evaluation methodologies. Only the fundamentals of economic, climate, and biophysical modeling, as well as of decision-making under uncertainty are covered in this note, and extensive references to external resources are provided to those seeking further detail. The note does not address other uncertainties in project performance such as demographic changes, political and policy environment, or macroeconomic factors. However, although the principles presented in this note can be extended to other uncertainties, specific guidance on these is preferable.

The framework presented in this note will always benefit from further refinement through widespread application in Sub-Saharan Africa, for a wide range of geographies, socio-economic, and climatic conditions. As conditions in the region change, and climate knowledge advances become more accessible, periodic updating of this note will ensure that users continue to be provided with the best guidance possible for enhancing the climate resilience of much-needed infrastructure investments in the region.

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GUIDANCE NOTE:

Enhancing the Climate Resilience of Urban Infrastructure Projects in Sub-Saharan Africa

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Acronym List

AFRI-RES	Africa Climate Resilient Investment Facility
GCM	General Circulation Model (or Global Climate Model)
IPCC	Intergovernmental Panel on Climate Change

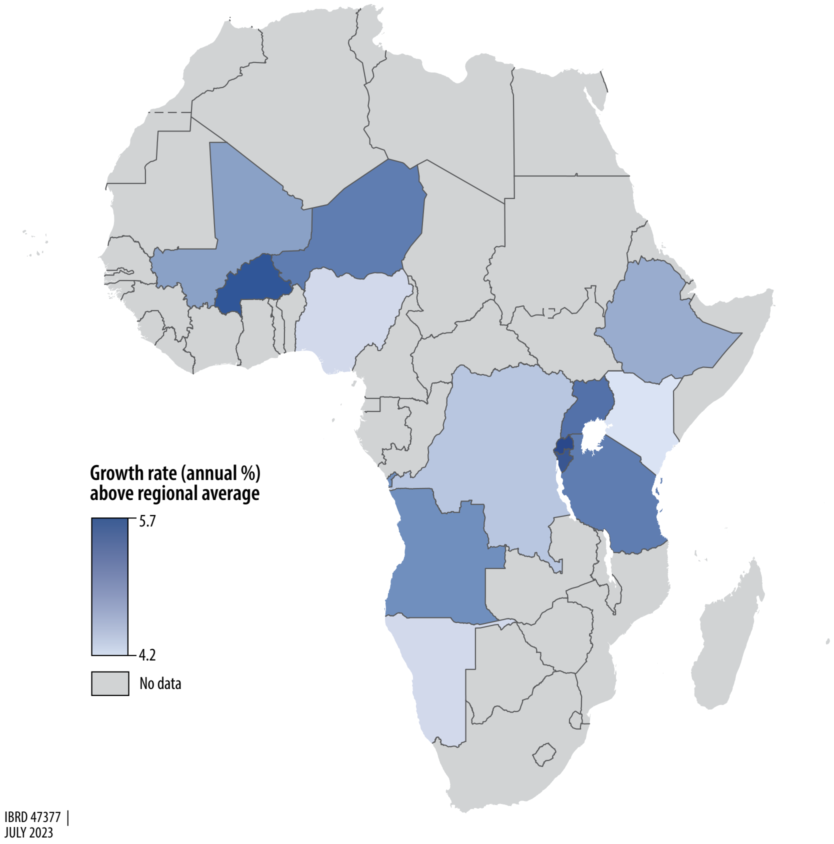
8.1. Introduction and Background

8.1.1. Problem Statement

Urban areas are the economic heart and home of the majority of the world's population. Gross domestic product is typically concentrated in and reliant on the productivity of a country's urban centers, with the transformative transition from a low- to a middle-income country dependent on the success of urbanization. Urban areas require significant energy, water, and other resources to function effectively, while simultaneously having a substantial impact on both environmental and human health (Burdett et al. 2011).

While remaining mostly rural (42 percent of the total population lives in urban areas), **Sub-Saharan Africa is one of the world's fastest urbanizing regions**, with urban population growth rates averaging 4.1 percent per year, as compared to the global average of 2 percent. The number of urban dwellers in Sub-Saharan Africa is expected to double by 2050 (Saghir and Santoro 2018). **Figure 8.1** shows the urban population growth rate for countries in Sub-Saharan Africa, as compared to the regional average. Cities like Lagos and Kinshasa already constitute urban agglomerations of over 10 million residents, while Dar-es-Salaam, Johannesburg, and Luanda are projected to reach that size by 2030 (United Nations 2019). These high rates of urban population growth are driven by migration from rural areas, endogenous growth, as well as the expansion of urban boundaries which translates into larger contiguous areas of urban settlement. Consequently, the land area used for urban activities is projected to increase by nearly 600 percent by 2030 (Güneralp et al. 2017).

Figure 8.1. Urban Population Growth Rate (Percent Per Year) Above Regional Average



Source: World Bank, (2017).

Presently, most urban areas in Sub-Saharan Africa are ill-prepared to cope with the impending risks associated with rapid urbanization. Rapidly increasing urban populations will add strain on already inadequate infrastructure systems and bring new governance challenges as urban development efforts continue to be hampered by inadequate transport, network communication, water, and power infrastructure. Increasing urban population densities result in increasing reliance on external sources of food, energy, and water and the waste streams produced by urban areas are associated with detrimental environmental effects (Thompson et al. 2021), such as air and water pollution. The high building densities of urban areas, coupled with the fewer social connections of the inhabitants can have negative impacts on the health of urban residents (Harpham 2009). These environmental and health risks are particularly acute in Sub-Saharan Africa where rapid urbanization has growing numbers of people living in slums and other unhealthy environments: 62 percent of Sub-Saharan Africa's urban population resides in slums as compared to 35 percent in Southern Asia, 24 percent in Latin America and the Caribbean, and 13 percent in North Africa (Amegah 2021). Cities such as Accra, Ghana; Lagos, Nigeria; Nairobi, Kenya; Addis Ababa, Ethiopia; and Johannesburg, Cape Town and Durban, South Africa are home to some of the world's largest slums, driven largely by the rapid growth of these urban centers over the past two decades.

Furthermore, **these risks will intensify as climate change exacerbates the vulnerabilities of urban residents.** Climate change impacts in Sub-Saharan Africa may drive further migration from rural areas to African urban centers. However, many of the rapidly expanding urban areas are coastal and are expected to be particularly negatively affected by severe climatic events over the next thirty to fifty years (Parnell and Walawege 2011). The range of expected threats to urban areas includes heat waves, vector-borne diseases, flooding, decreasing water supply reliability, and sea-level rise, many of which are expected to intensify due to climate change. Together, these can set in motion cascading interdependent effects on people, infrastructure, and urban systems with the potential to override system thresholds leading to catastrophic consequences. Informal settlements and slums are particularly vulnerable due to their typically improvised and unregulated infrastructure, dense population, and prevalent poverty.

Sub-Saharan Africa's macroeconomic outcome continues to improve and countries in the region are increasingly becoming integrated into the global economy leading to a surge in inward foreign direct investment, and therefore, the transfer of capital, technology, and skills. Henceforth, **the stability of economic growth and shared prosperity will be increasingly undermined if vulnerabilities to climate change are not addressed,** particularly in countries where a large share of the economy is concentrated in a handful of urban areas.

While there is general consensus on the broad range of impacts that climate change is already causing and can be expected in the near-term, there remains significant uncertainty about future climate impacts due to the varied output from existing climate models, the absence of model outputs suitable for use at the scale of urban areas, and data limitations, not to mention other non-climate uncertainties such as demographic changes, the political and policy environment, and macroeconomic factors. Furthermore, there is a need to improve the capacities of scientific institutions, local governments, stakeholders, and civil society in the region to help them understand the implications of climate change on droughts and water scarcity, flooding, food scarcity, and health. This should be complemented by the development of appropriate tools to support adaptation and damage mitigation (including advanced early warning systems), integrated management strategies and cross-sectoral cooperation, as well as sharing of experiences and policies. Against this backdrop, this document presents a guidance note that offers practical suggestions for developing climate-resilient investment projects within Sub-Saharan Africa's urban areas, where resilience is understood to mean the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner (Intergovernmental Panel on Climate Change 2012).

8.1.2. Objectives and Scope of This Guidance Note

Funded through the Africa Climate Resilient Investment Facility (AFRI-RES), this document provides guidance on enhancing the climate resilience of infrastructure investment projects in Sub-Saharan Africa's urban areas.[8] It is pedagogically oriented and draws on extensive experience and robust research and analytical methods. This guidance note provides **a framework for evaluating infrastructure project assets to ensure they meet project objectives in spite of possible future climate impacts**. As a result, this note is primarily relevant for climate adaptation, with climate mitigation benefits only considered if they are an explicit objective of the project being considered. The focus of this note is on guidance, serving neither as a comprehensive technical text nor an exhaustive policy handbook, but as brief direction on the most important principles to take into account when seeking to enhance the climate resilience of infrastructure projects in the face of future climate uncertainty. (While the note focuses on uncertainty as it relates to future climate conditions, the principles presented here could be extended to include other sources of uncertainty.) In addition, this note focuses on enhancing the resilience of projects that have been at least roughly scoped in terms of their location and the type of investment to be made, being less relevant for very early-stage projects where the location and type of project are as of yet unknown.

These notes build on a range of existing resources produced by the World Bank and others, notably including the Resilience Rating System (World Bank Group 2021) and the disaster and climate risk stress test methodology (Hallegatte et al. 2021). Furthermore, the framework presented in these notes also complements new guidance developed by the World Bank to ensure that future Bank investment projects are in alignment with both the climate mitigation targets set out in the Paris Agreement (United Nations 2015) as well as the country's adaptation goals.

The Resilience Rating System mentioned above distinguishes between two dimensions of resilience, namely **resilience of** the project and **through** the project (World Bank 2021):

- **Resilience of** the project is the extent to which a project's assets have considered climate and disaster risk in their design e.g., a power plant with improved cooling to account for increasing temperatures in the future.
- **Resilience through** project outcomes reflects whether a project's objective is to enhance the target sector and beneficiaries' climate resilience through its interventions (e.g., a community solar project aimed at improving energy security for a town).

The scope of this note is focused on the **resilience of** projects, including the resilience of direct project outputs. While many investments in urban areas can enhance both the resilience of and through projects, **the framework presented in this note focuses on the resilience of particular investment projects** and not on how those investments enhance the resilience of a community that benefits from it.

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[8] A partnership with the African Union, United Nations Economic Commission of Africa, Nordic Development Fund, African Development Bank, and the World Bank. This note is part of a series of guidance and technical notes funded by AFRI-RES that focus on climate resilient investment in Sub-Saharan Africa.

Textbox 8.1: The Three Elements of Urban Resilience

When studying urban resilience, it is key to identify and understand the interaction of the three elements of urban resilience:

Systems: Urban areas require infrastructure to support and deliver essential services. These networks of systems are intertwined with other systems at various scales. For instance, regional food production relies on ecosystems to deliver provisioning services.

Agents: Physical infrastructure systems require the actions of social agents to operate. The adaptive capacity of these agents is a key consideration when it comes to building urban resilience.

Institutions: Institutions are the social rules that structure human behavior and exchange in social and economic interactions in metropolitan areas. Institutions are dynamic and respond to climate pressures such as alterations to land and resource management, social organization, infrastructure, and design.

While **the focus of this note is on the project design level, it remains crucial to understand the particular policy, regulatory, and institutional context in which the project is situated.** In the study of urban climate resilience, three elements are seen as important namely **systems, agents,** and **institutions** (see **Textbox 8.1**). While the focus in this guidance note is on project design decisions taken as they relate to projects within urban systems, "agents" and "institutions" must be kept in mind as they act as either enablers or barriers for implementation. This note is part of a larger Compendium Volume, with these cross-cutting issues discussed in Chapter 2 of the Compendium Volume. Chapter 1 of the Compendium provides a general introduction, with the remainder of the Compendium broken down into two parts: Part 1 houses sector-specific guidance notes (including this one), while Part 2 provides a series of more detailed technical notes.

> While the focus in this guidance note is on project design decisions taken as they relate to projects within urban systems, "agents" and "institutions" must be kept in mind as they act as either enablers or barriers for implementation.

The urban built environment is made up of both **hard** and **soft infrastructure**. For example, we can describe the 'healthcare system' as not only the hospital buildings (hard infrastructure) but also the expertise of medical staff, money to pay for it, the legal system which allows it to happen and the political will to make adequate decisions about healthcare provision (soft infrastructure). The scope of this note focuses on the development of hard infrastructure in urban areas, which is comprised of the following sub-systems, all of which interact with and depend on each other:

- **Buildings**, including housing, public buildings (such as schools, hospitals, or recreation facilities), and informal settlements.
- **Solid waste management systems**, including collection, treatment, and disposal facilities, as well as other processes such as recycling or energy recovery.
- **Systems that manage water resources in urban areas**, including municipal water supply and wastewater collection facilities, stormwater management and urban drainage, as well as flood protection infrastructure. These are covered in the accompanying water guidance note included in the Compendium Volume.
- **Electrical utilities and telecommunications systems.** More detail on this sub-system is provided in the accompanying energy guidance note included in the Compendium Volume.
- **Transportation systems,** including roads and highways, railway networks, and other forms of public transit. These are covered in the accompanying transport guidance note included in the Compendium Volume.
- **Green and open spaces,** which require consideration of vegetation and water, accessibility, as well as amenities (such as toilets, seating, playgrounds, and lighting).

These systems represent a pragmatic categorization of key physical elements of the urban landscape, and are all interdependent. **The note is not specific nor prescriptive regarding development in the urban sector, but rather presents principles that can be applied to the evaluation of infrastructure investment projects of any kind.** Improved adaption to climate change will depend on comprehensive and inclusive policies and strategies that are inter-sectoral, underpinned by a unified framework such as the one presented in this note that allows meaningful coordination and provides adequate climate information services.

8.1.3. Target Audience

There are three primary audiences for this guidance note:

- **Practitioners**. The note will help practitioners develop their staff and internal expertise to perform the necessary climate vulnerability and adaptation analyses.
- **Government Staff, including City Officials**. The note will give staff from all levels of government (national, provincial and municipal) an understanding of the steps involved in evaluating and enhancing the resilience of a proposed project, how to be prepared for creative and alternative investment packages, and how to draft Terms of Reference for practitioners to develop climate resilient projects.
- **Donors and Development Banks**. The note will help donors and development banks provide clear direction and guidance to consultants for how to make project designs more resilient to climate change.
- Each of these three target audiences differ considerably in their technical focus, operational roles, and objectives. Typical investment projects will see this note used both as high-level guidance by donors and banks, as well as more detailed technical guidance for use within client countries. This note was developed to be accessible to these different audiences, with the general framework presented here supplemented by further detail in the technical notes included in Part 2 of the Compendium Volume.

8.1.4. When to Use this Note

While each of these target audiences will use the note in slightly different ways, within the overall project development process, this guidance note is intended to be used anywhere from the project's **conception** and **planning** stages, as well as during post-project completion **monitoring** (see the orange components of **Figure 8.2**). It is anticipated that in most cases, project teams will utilize this guidance note during the scoping, early design, and final design stages of the project planning process. That said, the earlier in the project lifecycle that climate resilience considerations (as described in this guidance note) are incorporated, the greater the scope and opportunity to improve the performance of the project given climate uncertainty. Furthermore, while not the focus of this note, attention should be paid throughout the project planning process to the policy and institutional landscape, as well as the role of policy shifts and improved local capacity in building resilience.

Figure 8.2. Applicability of this Guidance Note During a Typical Project Life Cycle

8.1.5. Structure of and Roadmap to Using This Note

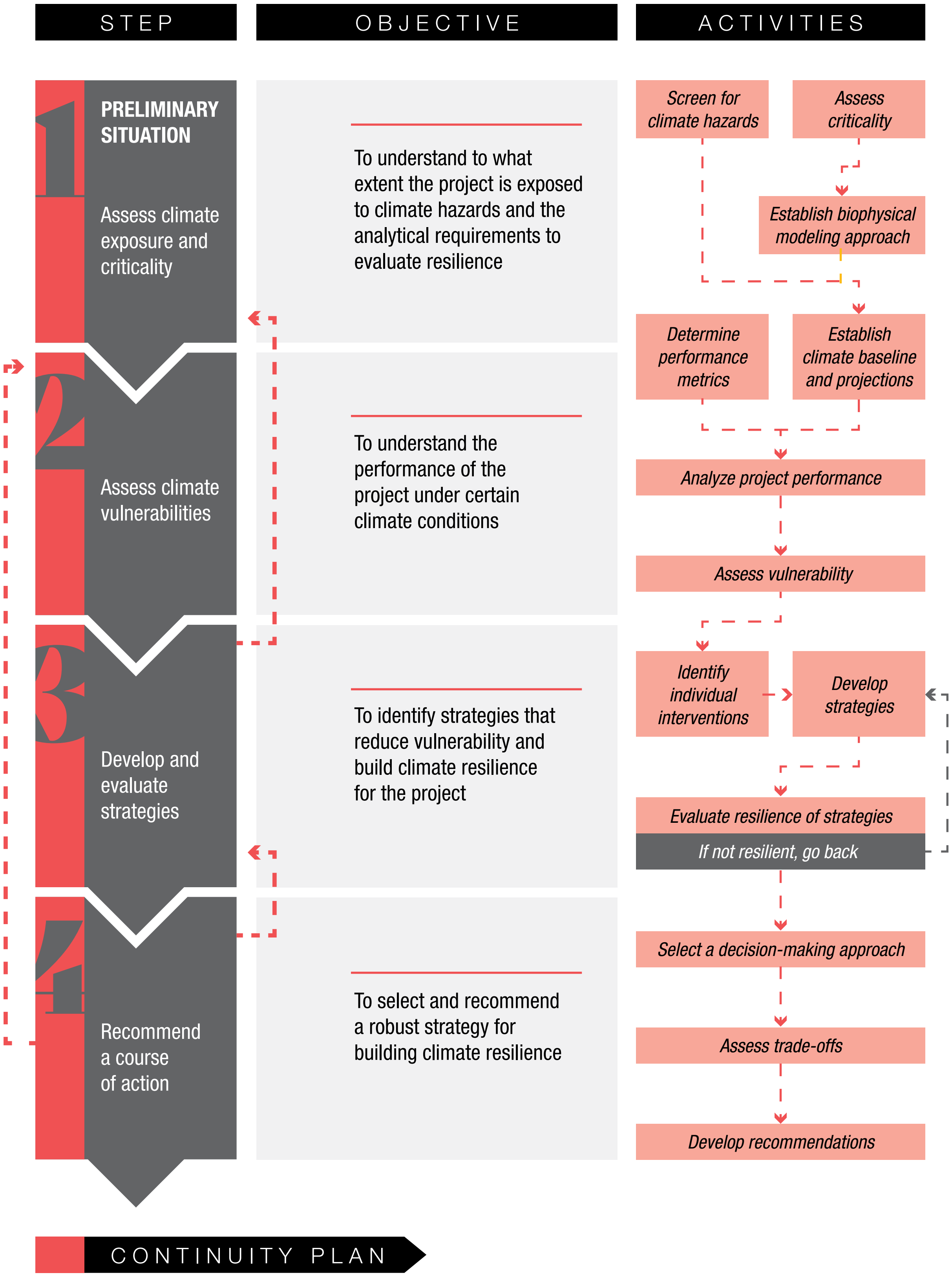
The remainder of this document is structured as follows: Section 8.2 describes a step-by-step framework used to enhance the resilience of urban projects to climate hazards. This section is subdivided into four steps, each containing different activities to carry out the analysis. Rigorously completing each activity requires a non-trivial amount of resources in terms of time, data and analytical know-how. Where these resources are not available, completion of a more rapid qualitative assessment is still useful to undertake in order to provide a high-level understanding of the situation, but such high-level insights alone should not form the basis for recommendations. A case study is provided to illustrate the framework and is intended to be consulted by all users of the note. Lastly, Section 8.3 offers brief concluding remarks.

Finally, urban areas are unique in that they bring together a multitude of diverse cross-sectoral components. Depending on the different investment components included in a project, several of the individual guidance notes beyond this one may need to be consulted. When using this note, **project leads should look beyond their particular project to consider both the broader system as well as any possible inter-system effects in their evaluation process**. For instance, those involved in a proposed urban green space project would benefit from also consulting the water and ecosystems notes; and a team working on an electricity project should additionally review the energy note, with all these notes included in the Compendium Volume.

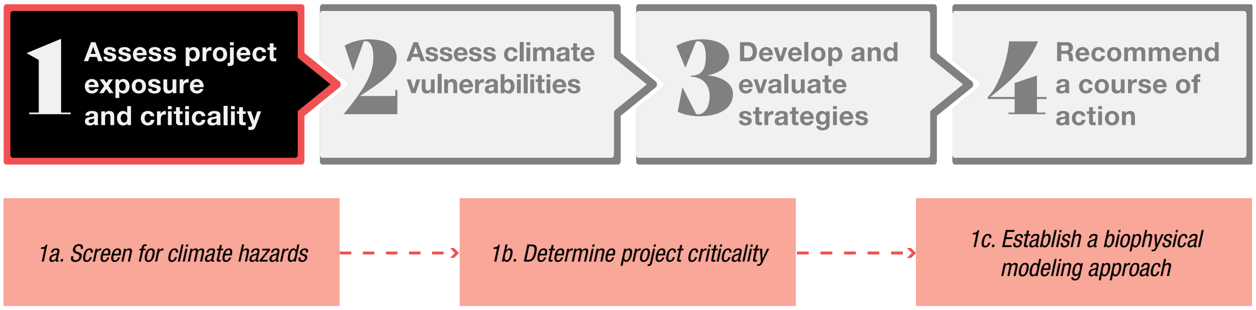
8.2. A Framework for Enhancing the Climate Resilience of Infrastructure Projects in Sub-Saharan Africa's Urban Areas

The guidance for developing climate-resilient investments presented in this note builds on a broadly applicable, multi-step framework, summarized in **Figure 8.3**. The framework consists of a series of four steps, each explained in further detail below, with many of the steps linked through important feedback loops. As noted in Chapter 2 of the Compendium Volume, the framework is founded on an initial assessment of the preliminary situation, which examines the **institutional and project context** (including the existence of country-level development plans, support from relevant ministries and the state of weather and climate change monitoring capabilities) as well as identifies **relevant stakeholders** (including community groups, beneficiaries, technical experts, policymakers, and non-governmental organizations).

Figure 8.3. **Framework for Enhancing the Climate Resilience of Investment Projects**



8.2.1. Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality



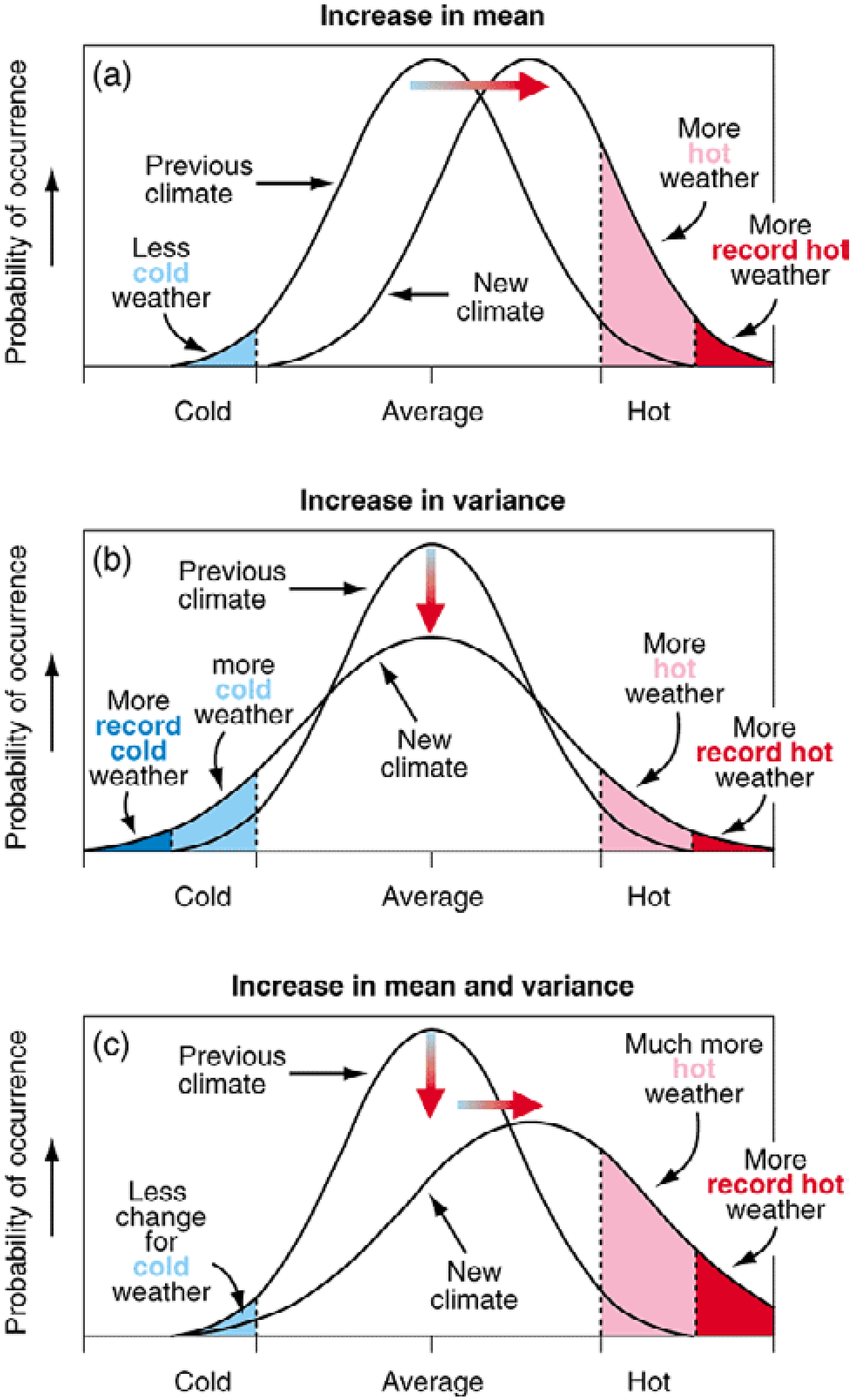
Objective: The purpose of the first step is twofold. One, the process evaluates whether the project is exposed to any climate hazards, both now and over the course of the project's expected lifespan. And two, the process seeks to determine the level of complexity required for the analysis based on the project criticality.

Activity 1a. Screening for climate hazards. In the context of Sub-Saharan Africa's urban areas, a hazard is the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. When focusing on urban infrastructure projects, a climate hazard is any climate-driven event that may result in damage and loss to the project. These can be a product of:

- **Extreme weather events:** low-probability but high-impact climatic phenomena such as floods, droughts, or heat waves (while more frequent, lower-intensity events can also cause significant impacts, typical urban design standards offer some degree of protection against events of medium magnitudes that are more routinely experienced)
- **Long-term changes to normal climate conditions:** changes relative to the historic baseline

As **Figure 8.4** shows, taken together, climate change can impact both the mean conditions to which a project will be exposed (e.g., higher temperature on average in the future), as well as the frequency and intensity of extreme weather events (e.g., more record hot weather). Exposure to climate hazards refers to whether the hazard is present at the project's location, either because of natural conditions or the absence of protective systems. **As such, the choice of a project's location is a critical first step in minimizing its exposure to climate hazards.** For instance, it may be best to avoid landslide-prone areas, if possible, regardless of whether more intense future precipitation will worsen the landslide risk or not. When considering future exposure over the course of the project's useful lifespan, understanding the uncertain nature of future climate hazards is essential for evaluating the climate resilience of a project.

Figure 8.4. Illustration of Climate Change Impacts



Source: Intergovernmental Panel on Climate Change (2001).

Screening for climate hazards will help the project team identify the types of hazards that threaten the performance of the project, given the project's location and expected useful lifespan. Climate hazards can impact virtually every part of urban systems, from destruction of infrastructure and property damage, to human health effects and the loss of livelihoods. Typical climate hazards to consider for urban areas are extreme temperature, drought, flooding and storms, strong winds, and sea level rise. These constitute a hazard when their magnitude and/or duration affect the performance of the project. Implicit in this is an understanding of the design standards used to develop the project design e.g. increasing future precipitation intensity will pose more of a concern for a project designed to cope with a one-in-five-year rain event versus a project designed for a one-in-fifty-year event. **Textbox 8.2** summarizes key climate hazards for urban areas in Sub-Saharan Africa.

Textbox 8.2: Key Climate Hazards that Impact Urban Areas in Sub-Saharan Africa

Temperature: more frequent and extreme temperatures and humidity can exacerbate the urban heat island effect, increase cooling costs, decrease utility reliability, damage buildings, and increase the risk of heat-related ailments, food- and water-borne diseases. Changes in temperature and humidity can expand the habitat of vectors (e.g., mosquitos or rats) carrying diseases (e.g., malaria) into new locations, which can easily spread in areas of high population density. Municipal waste and urban waters may become breeding grounds and facilitate transmission.

Flooding and storms: more intense precipitation events can result in more frequent flooding of low-lying indoor and outdoor areas, harming buildings and homes, and damaging infrastructure providing critical services (e.g., electricity grids, hospitals, etc.). Strong winds from storms can further exacerbate damage to infrastructure systems.

Drought and water supply: changes in precipitation can lead to more frequent and intense droughts, as well as seasonal shifts in the water cycle, which can result in reduced water availability, higher water costs, saltwater intrusion and changing groundwater levels, all placing strain on water supply and sanitation services. Drought can also impact electricity production from hydropower resources.

Sea-level rise: can increase the frequency of flooding and impacts of storm surge, thereby reducing land availability for development, damaging coastal ecosystems, and creating flood risk for existing infrastructure.

To screen the various climate hazards for the project's chosen location (- ideally the selection of this location would already have taken into account any significant hazards known to affect the area), the frequency and severity of historic events are first analyzed. However, it is important to consider the future exposure over the course of the project's useful lifespan. Generally, projects with a short useful lifespan may only need to focus on the impact of extreme weather events consistent with those experienced historically. In contrast, projects with longer lifespans should carefully inspect whether the project is exposed to new hazards and the increased frequency and severity of existing ones. Given the significant degree of uncertainty about future climate conditions, it is recommended to consider the broadest possible range of climate hazards, including those considered less likely, rating the severity of each threat to identify those most relevant for the project.

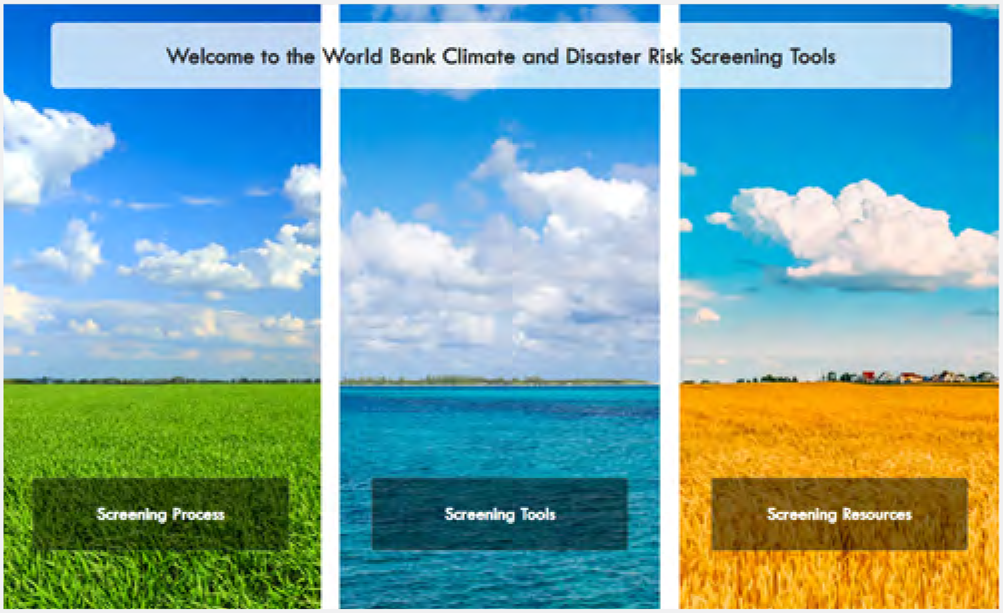
Various tools exist that can be used to screen a project's exposure to climate hazards; **Textbox 8.3** shows a selection of tools that could be used. Note that the individual outputs from these different tools may not be directly comparable to each other due to differences in the design of the tool and the assumptions it makes. In addition, these tools are not designed for detailed asset-level risk analysis but rather offer broad insights about the hazards present at the location of a proposed project. Subject-matter experts and local stakeholders should further supplement the climate risk screening results from these tools, as a mechanism to both validate the identified threats and reduce the risk of omitting relevant hazards.

Activity 1b: Determine the project criticality to establish the appropriate level of effort required to assess project resilience. Evaluating the impacts of the climate hazards identified to be relevant to the project can be complex, data-intensive, and expensive. However, not every project requires the same level of analytical complexity, and to ensure the framework is practical and accessible, projects are classified into two tiers. A low tier method is less data-intensive and simpler than a high tier method, which is generally treated as being able to more accurately model the project's response to climate hazards. For example, the construction of new residential streets will likely be considered a low tier investment, whereas a new multi-modal transit hub is likely a high tier investment. Distinct components within a large project that require separate analysis or modeling could be analyzed separately and may be classified into different tiers. **While the focus of this guidance note is on the project design level, it is crucial to understand the development setting in which the project is situated.** All project design decisions should be mindful of local conditions, including the policy landscape, as well as technical and institutional capacity (see Compendium Volume Chapter 2 for a discussion of these kinds of cross-cutting factors that can enable or hinder a project).

The tier of a project can be determined using the sample process shown in **Figure 8.5**, which assesses criticality based on the useful lifespan, essential functions, and beneficiaries of the project. **Note that this framework is qualitative and flexible in nature, with Figure 8.5 providing guiding principles** and suggested cutoffs to determine short/long lifespan, assessment of essential services, and small/large number of beneficiaries to judge the project under evaluation. However, **project teams and stakeholders should consider a more flexible set of criteria, carefully assessing which guiding principles and cutoff values are appropriate for their particular project and inspecting whether using the selected criteria results in an appropriate level of criticality**. For example, when looking at urban transportation investments, high tier projects could also include those that offer significant improvement in terms of transport access for under-privileged portions of the community. These examples highlight that context is required to appropriately determine the criticality of a project.

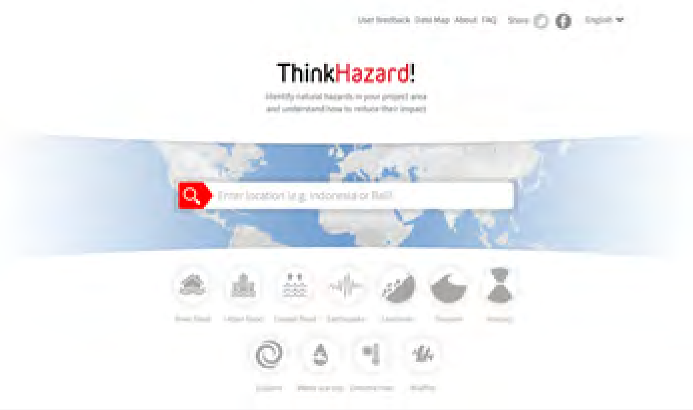
Textbox 8.3: Climate Hazard Exposure Screening Tools

Climate and Disaster Risk Screening Tool **(World Bank).** This tool provides a guided method to identify climate hazards and levels of risk to project evaluators at an early stage in the project design process. It focuses on physical and non-physical components of the project, and ranks the threat between low to high, including a no risk and insufficient understanding category. It has a “rapid” (about 30 min) and “in-depth” (about 2 hours) version for multiple sectors, the latter being highly recommended unless the evaluator is familiar with climate science and the project context. The tool relies on the World Bank’s Climate Change Knowledge Portal, which is a web tool that provides processed and synthetized historical and projected climate information from the Intergovernmental Panel on Climate Change. The tool considers extreme temperatures, extreme precipitation, flooding, drought, winds, sea level rise, and storm surge. Users would ideally be in possession of a project concept or design, as well as subject matter expertise for the country and project context. In terms of strengths, the tool guides the user on how to perform the screening and how to use data from other tools. It provides an assessment that includes the hazards at the project location as well as the potential impacts on the project’s infrastructure and service delivery, as well as how institutional and contextual factors interact with hazards and the project’s physical components.

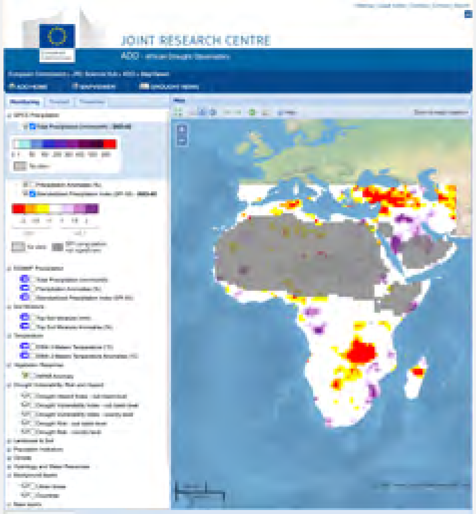


Textbox 8.3 (continued): Climate Hazard Exposure Screening Tools

ThinkHazard! **(Global Facility for Disaster Reduction and Recovery)**. A web tool that provides a general assessment of climate hazards at a sub-national scale. The tool covers 12 different hazards including flooding (river, urban, and coastal), extreme heat, water scarcity, and cyclones. The tool presents a qualitative assessment of the level of a particular threat (i.e., low to high) both now and in the future given potential impacts of climate change, describing general impacts of the hazard along with generic recommendations for planning and evaluation. The tool also includes additional local and/or regional online resources when available. All that is required to run the tool is a general project location. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining a list of the relevant hazards to consider in a particular area, without requiring project specific information. It can help place climate hazards in context with other non-climate threats.

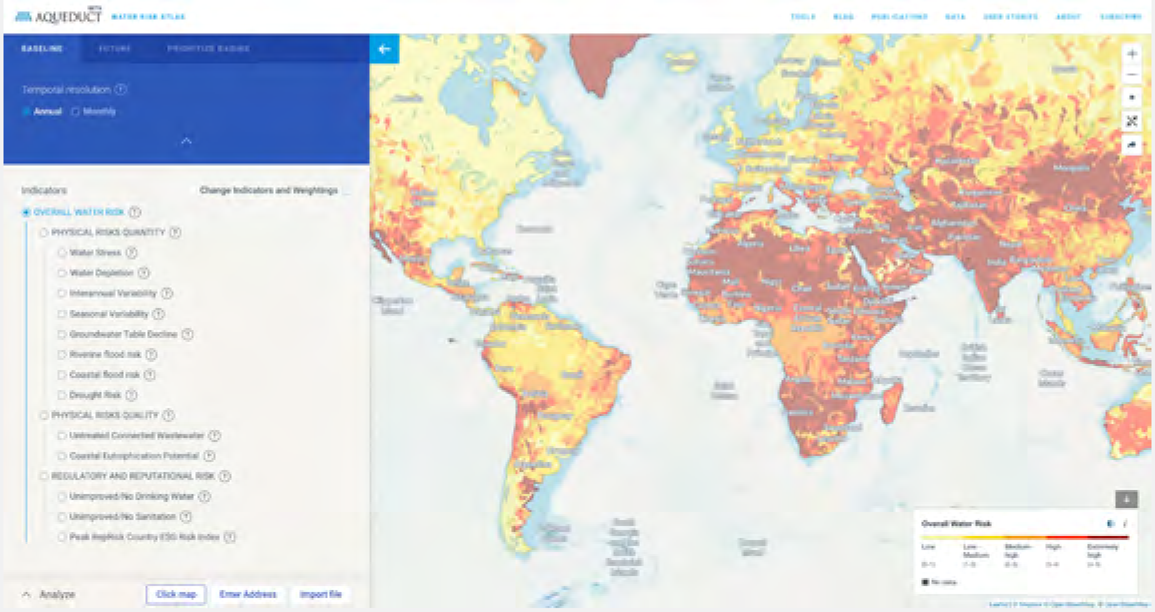


African Drought Observatory **(European Commission Joint Research Centre)**. A web map service to identify potential drought hazard and risk levels in Africa. It offers access to recent drought monitoring data, as well as probabilistic forecasts for near term precipitation. A general project location is required to run the tool. In terms of strengths, the tool is very quick and simple to use. It is useful for obtaining an overview of historic climate hazards to consider in a particular area, without requiring project specific information.



Textbox 8.3 (continued): Climate Hazard Exposure Screening Tools

Aqueduct Water Risk Atlas **(World Resources Institute)**. A global web map service that provides an assessment of coastal and riverine flood risks. The tool allows the customization of water hazards by time horizon, climate scenario and projection model, and return period. A general project location is required to run the tool. In terms of strengths, it easily allows users to explore how water risks change under different future climate scenarios.

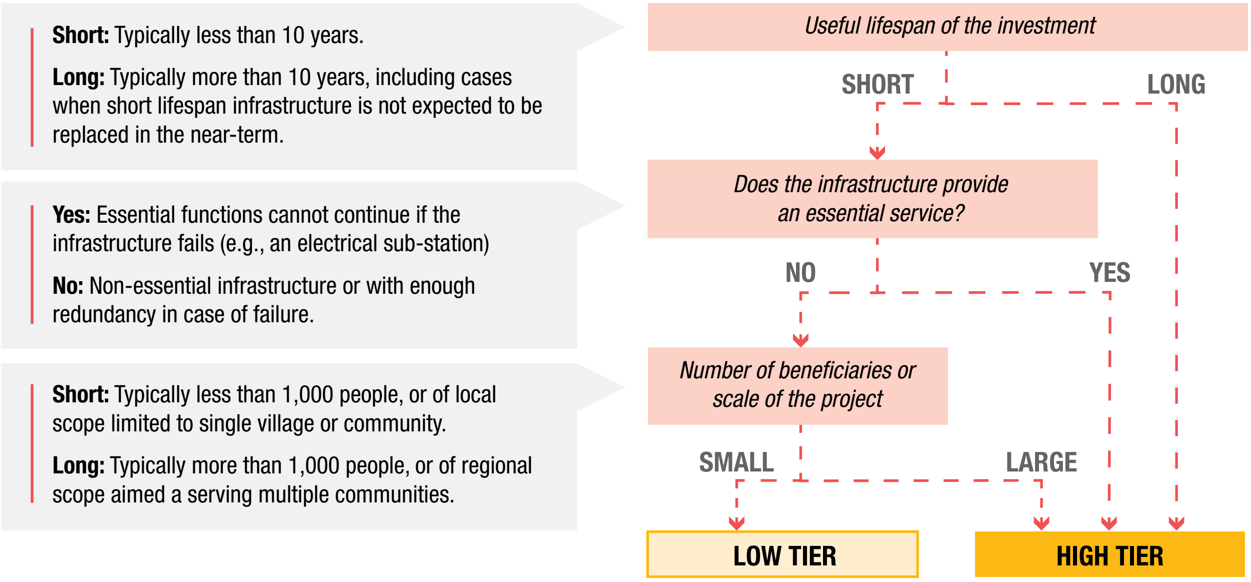


ClimateLinks **Screening and Management Tools (United States Agency for International Development)**. The screening and management tool provides a sectoral toolkit for self-screening and rating of climate risks in the early stages of project design. The risk profiles consist of short briefs for countries and regions that assess the potential impacts of climate change on key economic sectors, including an overview of historical and future climate trends, the policy context, and existing adaptation projects.

Additional non-web-based tools that could be consulted include:

The CRiSTAL **(International Institute for Sustainable Development)**. A project planning tool for identifying climate risks and design components to enhance resilience. It incorporates stakeholder consultation and expert interviews, as well as guidance notes for internal evaluation developed by the African and Asian Development Banks. The tool includes an initial screening step that can be used to understand the potential impacts of climate hazards on the project and local livelihoods in the area. It expands beyond a cursory screening tool, offering guidance for project design and evaluation through a participatory process. A project concept or design is necessary in order to run the tool. In terms of strengths, it guides the user to perform a screening following a questionnaire and provides a community-based perspective of the project, as opposed to the perspective of funders only. It additionally puts climate hazards in context with social, political, and cultural conditions and provides a framework for incorporating local and expert knowledge through consultation.

Figure 8.5. Sample Tier Determination Process



Short: Typically less than 10 years.

Long: Typically more than 10 years, including cases when short lifespan infrastructure is not expected to be replaced in the near-term.

Yes: Essential functions cannot continue if the infrastructure fails (e.g., an electrical sub-station)

No: Non-essential infrastructure or with enough redundancy in case of failure.

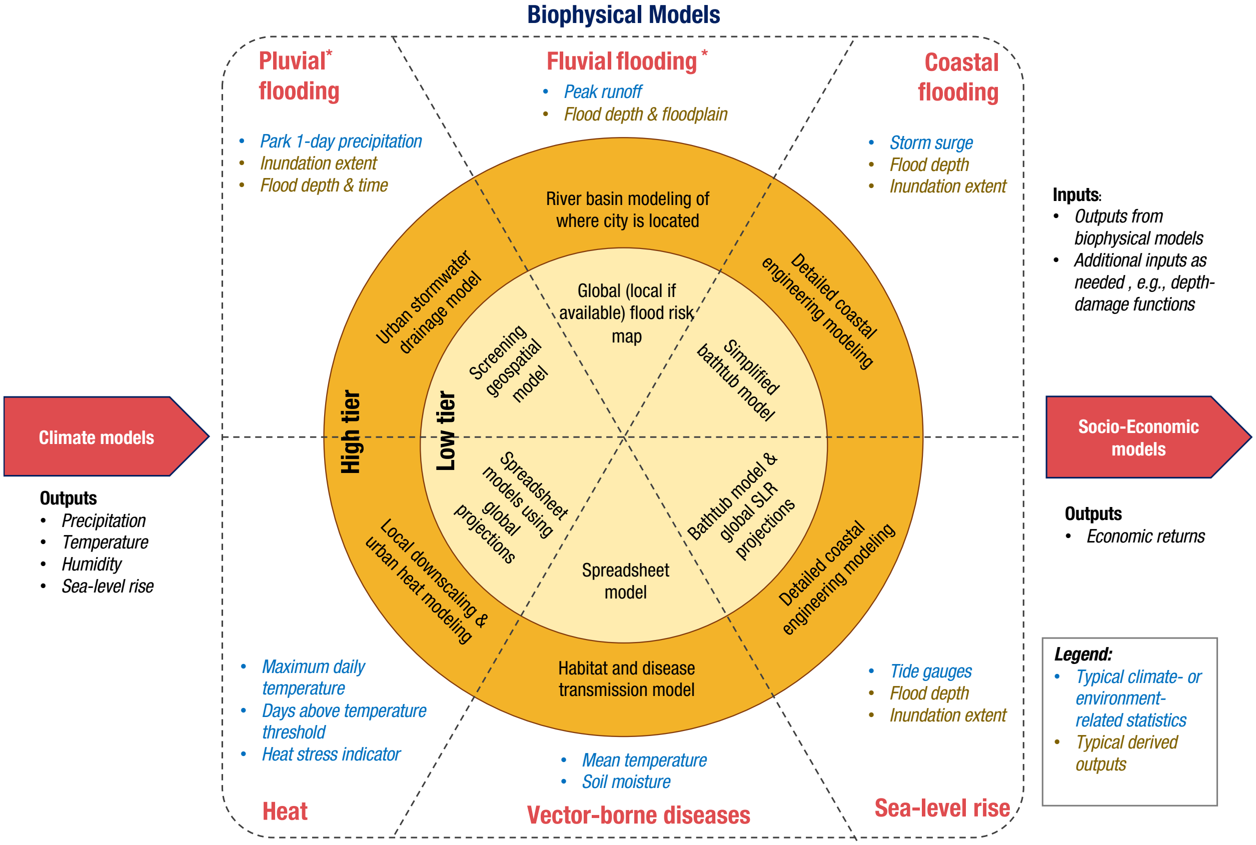
Short: Typically less than 1,000 people, or of local scope limited to single village or community.

Long: Typically more than 1,000 people, or of regional scope aimed a serving multiple communities.

Activity 1c. Establish a biophysical modeling approach based on the project tier. The results of the tier determination process serve as the basis for establishing a biophysical modeling approach that simulates the physical behavior of the project under different climatic conditions (e.g., translating changes in future temperature to urban health impacts). These models (i.e., simplified, conceptual, mathematical representations of a system) require climate variables as inputs and ultimately produce outputs of interest that are later used for the socio-economic evaluation. The kind of climate and other input variables required will vary based on the biophysical modeling approach selected.

Selecting a model for a particular analysis always depends on the specifics of the project. Models should be determined based on their capacity to inform and improve the design of the project, particularly from changes in climate inputs. In the urban sector, modeling approaches can be classified based on the climate hazard they model. There is a myriad of models that could be used for each hazard, particularly for flooding events. **Figure 8.6** presents an overview of the typical modeling approaches for each hazard, while **Table 8.1** presents further detail on these models as they relate to low and high tier urban investment projects.

Figure 8.6. Possible Modeling Approaches by Tier



* A **pluvial flood** occurs when an extreme rainfall event creates a flood independent of an overflowing water body. For example, torrential rain can overwhelm the urban drainage system leading to pluvial flooding. A **fluvial, or river flood**, occurs when the water level in a river, lake or stream rises and overflows onto the neighboring land. The water level rise could be due to excessive rain or snowmelt. A **coastal flood** is the inundation of land areas along the coast by seawater. This can be due to storm surge or tsunamis.

Table 8.1. Description of Modeling Approaches

Hazard	Low tier	High tier
Pluvial & fluvial flooding	Geospatial screening and flood risk maps are used to identify the exposed assets, on which generic damage functions can be used to estimate impacts (e.g., Aqueduct Water Risk Atlas by the World Resources Institute).	Stormwater drainage and river basin models simulate runoff, drainage, and inundations over time and space, taking into account soil and infrastructure conditions (e.g., the United States Environmental Protection Agency's Storm Water Management Model).
Coastal flooding & sea level rise	Bathtub models simulate the coastal area at risk of inundation, based on topography and elevation.	Engineering studies consider in-depth assessment of coastal conditions and infrastructure and are typically site-specific.
Heat- & vector-borne diseases	Spreadsheet models take the projection of a key climate variable (e.g., temperature or humidity) and apply a damage factor or impact parameter to estimate the shock on human health.	High-resolution models that consider the simulation of local environmental conditions, exposure of population, and subsequent health effects (e.g., Patz et al. 1998).

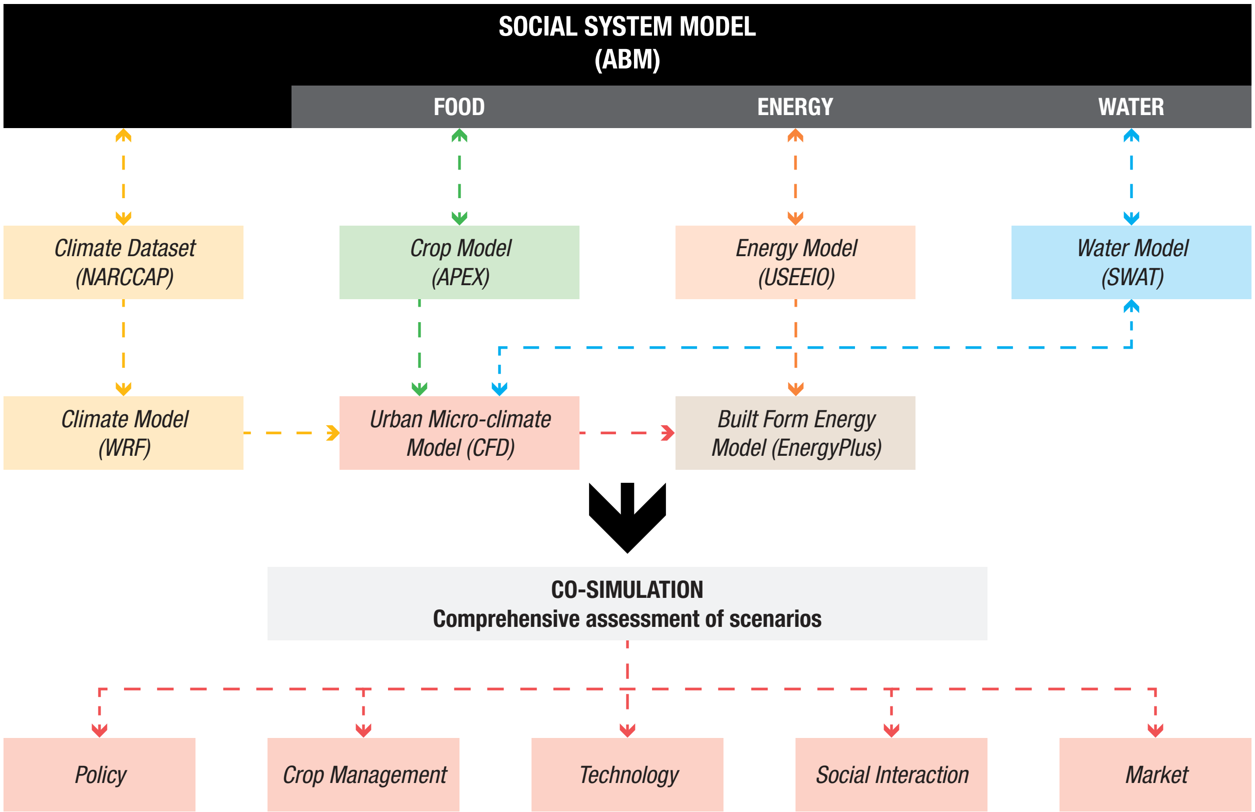
Resilience Spotlight: Bringing Green and Grey Together in the City of Beira, Mozambique

Mozambique is the third-most climate-hazard exposed country in Africa. It is at high risk of impacts from not just floods and droughts, but also cyclones. The coastal city of Beira is plagued by recurrent flooding due to coastal storms, made worse by poorly planned settlements and inadequate housing. Over the course of the last decade, the city has implemented a number of different measures to improve the flood resilience of the area, as documented by the city's resilience master plan. Through the Cities and Climate Change Project, the World Bank and its development partners have financed a number of these investments including **improvements to grey infrastructure such as drainage systems, as well as green nature-based solutions focused on restoring the Chiveve River's capacity to mitigate floods.** Restoration of the Chiveve has seen the formerly polluted river and riverbanks transformed into a green urban park that provides recreational spaces in addition to retaining and absorbing floodwaters. **The climate resilience of these investments in the Chiveve were safeguarded by conducting ongoing community rehabilitation of its degraded mangroves and native flora.** By investing in green and grey interventions together, the objective was to enhance climate resilience while simultaneously improving the quality of life for the inhabitants of Beira.

Urban areas typically bring together infrastructure from multiple sectors. Therefore, in addition to modeling individual climate hazards and estimating their direct impacts on assets, analytical approaches may also require sector-specific models commonly used when evaluating water, energy, transport, agriculture and ecosystems-focused projects (see the notes for these sectors included in the Compendium Volume), as well as their subsequent consequences on urban dwellers beyond the impacts on the physical infrastructure and sectoral system itself. As a result, when developing a modeling approach for urban areas, a so-called "system-of-systems" analytical framework is usually needed, which incorporates both social and biophysical elements. **Figure 8.7** below provides a sample framework for an urban project that integrates social and biophysical models for urban food, energy, and water systems.

These models are interconnected, with some outputs becoming inputs for another model. **Ultimately, model selection should be conducted considering the scope, functionality, availability, and processing capacity of a particular model, experience utilizing it, knowledge of its caveats and limitations, and data availability**, drawing on the more detailed guidance provided in the other notes included in this Compendium Volume. That said, where existing models and analytical tools already exist for a project that are more analytically rigorous and detailed than the identified tier level, these existing tools should be preferentially used.

Figure 8.7. Sample "System-of-Systems" Modeling Approach that Integrates Social and Biophysical Models for the Urban Food, Energy, and Water Systems



Source: Thompson et al. (2021)

Outcome: At the end of this step, the project team should have acquired a high-level understanding of the climate hazards the project is exposed to as well as the analytical requirements to adequately conduct a climate impact assessment of the project. Depending on the identified tier, an appropriate modeling approach should be established in consultation with modeling experts. Where a project is composed of separate investment components that are exposed to a different set of hazards, all the activities in Step 1 should be completed for each individual project component in turn.

Case Study Demonstration of Step 1: Climate-Resilient Expansion of Urban Health Care Systems in Mali

Healthcare workers in Mali (Source: United States Embassy in Mali 2021)

Background: The World Bank and the United States Agency for International Development are both involved in Mali to improve the quality and coverage of urban health care systems. The primary objectives of these investments are to enhance health facilities and health care training to improve health outcomes and access to care. The project considered climate vulnerabilities in the country, including flooding, drought and high temperatures, to make project infrastructure more resilient to identified climate threats. The potential adverse impacts of rising temperature and rainfall variations in Mali are significant and include enhanced stress on food systems, and increased occurrence of malaria and diarrheal disease. By strengthening the primary care system and supporting the performance of community health workers, the project will help mitigate the adverse impact of climate change on health in targeted areas.

Case Study Demonstration of Step 1 (continued): Climate-Resilient Expansion of Urban Health Care Systems in Mali

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

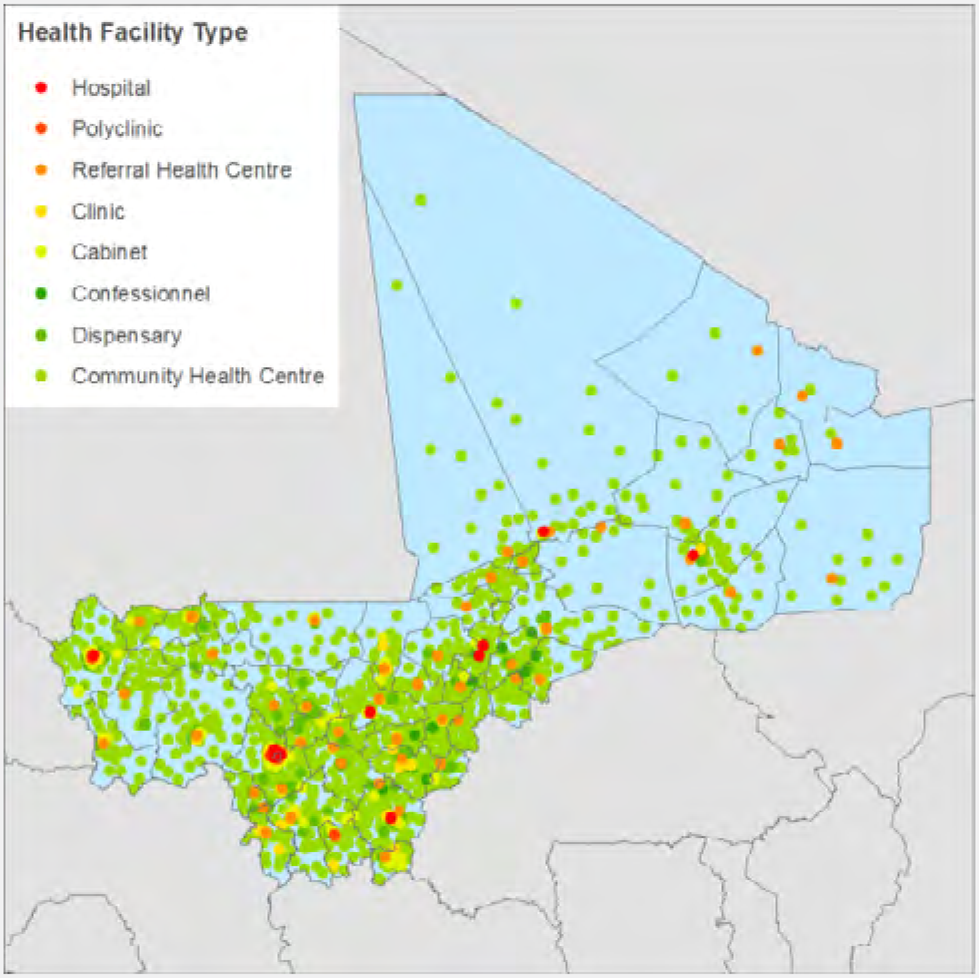
1a. Screen for climate hazards → *1b. Determine project criticality* → *1c. Establish a biophysical modeling approach*

Climate hazards: Mali is exposed to a number of climate hazards, including floods, droughts, and high temperatures. Droughts are especially prevalent in the northern regions of the country, specifically in Tombouctou and Kidal. However, most of the population impacted by droughts reside in the southern regions of Mopti, Segou, Sikasso, and in the capital city, Bamako. The country experienced significant periods of drought in 2004 and 2011, and more recently a drought event in 2017 damaged crop production, leaving 3.5 million people impacted (Global Facility for Disaster Reduction and Recovery 2019). Mali is also at risk of flooding, specifically in areas along the Niger River Basin in Mopti, Segou, and Koulikoro. Yearly, approximately 500,000 individuals are impacted by floods in the country, and flooding events impact a combined 300 education and health care facilities (Global Facility for Disaster Reduction and Recovery 2019).

Project criticality: The World Bank's involvement in Mali will see infrastructure improvements made at 515 primary care facilities and 22 hospitals, having far-reaching impacts on those in need of health services. Beneficiaries of the projects will primarily include children, adolescents, and women of reproductive age, which includes over 700,000 children and 1 million women of reproductive age. A total of 4.5 million Malians are expected to benefit from the project. Given the high number of beneficiaries and the long lifespan of most hospital systems, these investments could be classified as high tier.

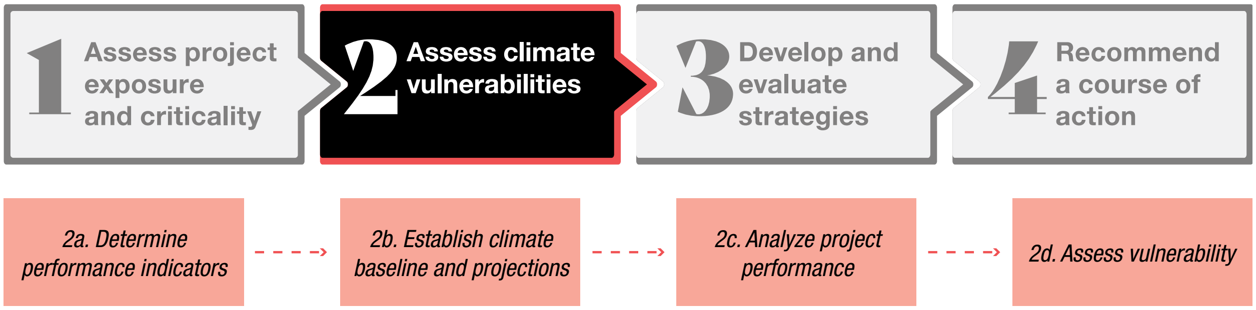
Case Study Demonstration of Step 1 (continued): Climate-Resilient Expansion of Urban Health Care Systems in Mali

Biophysical modelling approach: Currently, health facilities are concentrated in the southern regions of the country as shown in the figure below. These regions, specifically, Mopti, Segou, and Koulikoro, are exposed to a combination of drought and flood risks. As a high tier project, a detailed assessment of the impact of climate hazards on health outcomes should be conducted to quantify the expected impacts of project investments and the influence of an altered climate on those impacts. Such a biophysical modelling approach would likely map each anticipated climatic change onto the various pathways by which this would cause impacts to the health system. For instance, a change in the number of hot days due to climate change, could result in more hospital visits for heat-related ailments, greater incidence of certain water-and vector-borne diseases, as well as potential losses or damages to vaccines and critical medicines due to the increased need for cooling which may not currently be available. The modeling conducted should allow an assessment of how different proposed infrastructure interventions will enable facilities to continue to meet health objectives even under altered operating conditions.



Distribution of health facilities in Mali (United States Agency for International Development 2014)

8.2.2. Step 2: Assess the Vulnerability of the Project to the Identified Climate Hazards



Objective: After the project screening and assessment of the necessary analytical complexity, the next step is to **assess the project's vulnerability to climate hazards**, where vulnerability is taken to mean the susceptibility of project components to physical harm from climate hazards. This assessment of vulnerability is mostly critical in informal parts of Sub-Saharan Africa's urban areas, particularly slums, where the conditions of informal settlements are drivers and multipliers of risk (Dodman, et al. 2018; Gannon, et al. 2018) – see **Textbox 8.4**. This process seeks to identify how a project performs under extreme climate conditions and, incrementally, under a future with climate change (which can further impact the frequency and intensity of extreme events), as compared to current conditions. This same framework will also be used later to assess the performance of possible adaptation options to build climate resilience. The process involves four different activities, each described below.

Textbox 8.4: How Climate Change Impacts are Magnified in Sub-Saharan Africa's Urban Areas

According to United Nations-Habitat, a slum is an urban area that lacks access to clean water and improved sanitation services, a durable housing structure, sufficient living spaces (i.e., there is overcrowding), and secure tenure (United Nations-Habitat 2003). In Sub-Saharan Africa, slums are typically exposed to a variety of climate hazards, including flooding, heatwaves, fires, and storms. The inadequate provision of services, precarious infrastructure, and unregulated planning that many times results in slum dwellers settling in hazard-prone locations (e.g., riverbanks), make slums particularly vulnerable to climate hazards. Furthermore, the lack of climate information and communication, particularly during emergencies, the resident's inability to improve their housing conditions, and their limited social capital result in heightened levels of vulnerability (Owusu and Nursey-Bray 2019).

With about 62 percent of the urban population in Sub-Saharan Africa living in slums (Amegah 2021), cities can become threat multipliers for state and human security (i.e., places that exacerbate existing socioeconomic stress factors in societies with high exposure and poverty levels, particularly in fragile states with limited institutional capacity) not only due to their intersectoral nature, but also because of the interactions with conflict, violence, corruption, and migration that typically take place in urban spaces (Huntjens and Nachbar 2015).

Activity 2a. Determine performance indicators and targets to assess the climate vulnerability of the project. On the one hand, these metrics would include the economic return of the project (i.e. benefits generated by the project, in the form of revenues or other economic gains) measured as net present value, benefit-cost ratio, or internal rate of return, and minimum acceptable returns or hurdle rates as targets (e.g., a net present value above zero, an economic rate of return above a minimum return). On the other hand, indicators that characterize and assess the success (or failure) of the project and the contribution to sustainable development should be considered. **Textbox 8.5** provides a sample list of possible indicators for urban-focused investments. Depending on their nature, some may be quantitative outputs from the biophysical or socio-economic models, while others may require additional calculation assumptions. For instance, estimating future urban energy needs requires an assumption on population growth rates. When feasible, performance indicators should incorporate metrics established by the broader policy environment and development strategy, particularly when those address climate resilience already.

Textbox 8.5: Performance Indicators in Cities

- Percentage of households with a reliable water supply
- Water supply cuts during summer/hot months
- Share of drinking and sanitation water from sources less affected by drought
- Share of residents living in flood prone areas
- Percentage of rehabilitated and new pipes in water and wastewater distribution system
- Percent of residents near open/green space
- Number of jobs accessible from new developments
- Number of upgraded informal settlements
- Share of waste safely disposed or collected

Whereas typical project evaluation methods consider means and weighted averages as performance metrics, given the large degree of uncertainty associated with future climate conditions, an evaluation of climate resilience should look at a range of expected values across different potential future climate scenarios (for instance, as defined in reports from the Intergovernmental Panel on Climate Change (IPCC)), as well as thresholds that cause a project to fail, in order to identify project designs that perform well across a range of different future conditions.

Activity 2b. Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions. The climate baseline describes the default conditions applicable to the initial design of the project, representing the reference point for the analysis. During later stages in this step, a subset of baseline conditions will be perturbed, and performance between baseline and future conditions will be compared for assessing vulnerability.

In order to generate a baseline, the project team must first evaluate the availability and quality of historical data (possibly using statistical tools to fill in any data gaps), keeping in mind the expected lifetime of the project. An appropriate time frame for establishing a climate baseline from observed data in urban areas would be 30 years of historic records. In cases with limited data, a baseline of the last 10-20 years could be acceptable, however, the shorter the period used the greater the possibility that the period used is not representative of the long-term climate. Depending on the project, baseline climate data would include historical hydro-meteorological records such as temperature, rainfall, storm surge level and wind speed. The World Bank's Climate Change Knowledge Portal is a good place to start to obtain existing historical data for a particular area.

As such, for projects with short lifetimes (generally less than 10 years), the range of natural climate variability is the dominant concern, over and above the long-term impacts of changes to mean conditions as caused by climate change. For example, investments to extend the life of an existing landfill may have a short enough lifetime that it is sufficient to take climate variability into account at the outset, while managing any emerging impacts from climate change adaptively over the course of the project's life. Projects with longer time horizons are subject to greater uncertainty and should consider a wide range of future climate conditions. For instance, the roll-out of information and communication technologies to cope with climate risks typically requires widespread transformation of an urban area's connectivity and production capabilities, a long-term project that would require the mobilization of public and private investments, with a lifespan of well over 10 years.

Resilience Spotlight: The Second Lagos Urban Transport Project in Lagos, Nigeria

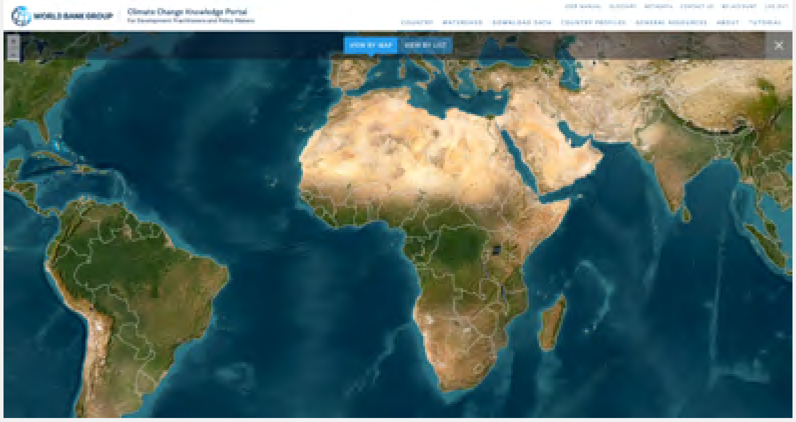
The Second Lagos Urban Transport Project, supported jointly by the World Bank and the French Development Agency, built on the successes of Lagos' Bus Rapid Transit corridor, expanding the corridor by 13 kilometers. The original corridor was so successful that the operator was able to recoup its capital investment in the bus fleet within only 18 months. This second phase of the project included the rehabilitation and widening of the road from four to six lanes, the construction of pedestrian overpasses, a bus depot, terminals, a road bridge, as well as improved interchange and transfer facilities. **To ensure the resilience of these investments to the frequent floods experienced by the city of Lagos, measures to enhance flood resilience were also included in the project. These flood resilience measures included upgrading of pavement in sections of the road that experience submersion during the rainy season, as well as implementing portions of Lagos State's drainage master plan.**

There is a great deal of uncertainty about future climate conditions, particularly for long time horizons and at local scales such as those required for urban investments, which makes the question of which climate futures to consider a non-trivial decision point in the evaluation process. Future climate is uncertain not just because of natural stochastic variability in the climate (i.e., one rainy season can be wetter than another), but also because of uncertainty about how future greenhouse gas emissions will grow, and uncertainty about how the climate system will respond to future emissions levels. One way of exploring these various sources of uncertainty is through the use of different future scenarios or pathways. While tempting to focus in on just one or a few individual climate futures, there are compelling reasons to consider a broader range of possible conditions: a single climate future describes only one possible version of the future, with many other possibilities going unexamined, making it difficult to draw well-substantiated conclusions.

Textbox 8.6: Where to Obtain Historical Climate Data and Future Projections Suitable for Use in Urban Projects

Historical climate data as well as the output of future climate simulations can be obtained from various sources:

The World Bank's Climate Change Knowledge Portal has both historical data and future climate simulations available for every country/sub-national unit/drainage basin in the world. All information contained within the Knowledge Portal is consistently produced and thus directly comparable. As well as being free of charge, it is well-suited to project teams who are not used to working with raw, unprocessed output from climate models and it saves time on data searches and data processing.



National meteorological agencies often also provide localized climate information, which can be accessed through the World Meteorological Organization's website. Climate information services, for instance Eastern Africa's Intergovernmental Authority on Development Climate Prediction and Applications Centre, are also being developed under the United Nations Economic Commission for Africa's African Climate Policy Centre. Africa-oriented climate and weather data, along with training material, is also available from University of Cape Town's Climate Systems Research Group.

Global observations and computer simulations from the Intergovernmental Panel on Climate Change's various assessment reports, can be obtained from their Data Distribution Centre. Similar information can also be collected from the KNMI/World Meteorological Organization Climate Explorer. These latter two sources provide raw, unprocessed global climate model outputs, which require significant time and expertise to process and bias correct, before they can be utilized in project analyses.

Regional sea-level observations and projections can be obtained from the National Aeronautics and Space Administration's Sea-Level Change Tools.

Detailed, quantitative simulations of future climate can be obtained from projections modeled through GCMs. Recent World Bank guidance (2022) focuses specifically on the selection of future climate projections and recommends considering **an optimistic and a pessimistic scenario of greenhouse gas concentrations** as driven by global greenhouse gas emissions trajectories and climate mitigation policies, as well as **several scenarios that represent a "dry and hot" and a "wet and warm" future**. The first set of scenarios allows one to assess the impact of uncertain global climate mitigation efforts on project outcomes, whereas the second set helps assess local climate risks and overall uncertainty in climate model outputs on project outcomes. The latter is important because different models simulate different climate outcomes for the same emissions scenario due to their reliance on different modeling approaches. In addition, as a general rule, an analysis should consider different GCMs in order to capture the range of possibilities predicted by climate scientists. Attention should be paid to the range of future conditions described by these model ensembles (by considering confidence intervals, for example) rather than just their averages. **Textbox 8.6** provides guidance on where to obtain climate projections that are suitable for analyzing urban projects, with further details presented in the technical note on working with climate projections included in the Compendium Volume. The local scale of urban infrastructure projects poses additional challenges given that additional sources of uncertainty are introduced during the process of downscaling global climate simulations to regional and local scales.

> Attention should be paid to the range of future conditions described by these model ensembles (by considering confidence intervals, for example) rather than just their averages.

An even more rigorous analysis suitable for high tier projects would include considering the full range of future climate uncertainty (as compared to selecting a number of individual climate scenarios) through stochastic estimations of climate variables from a weather generator. The Decision Tree Framework (Ray and Brown 2015) provides additional guidance on how to use a weather generator in project evaluation.

Scale is a particularly important consideration when selecting scenarios for an urban climate resilience assessment. For instance, temperatures can be much higher in urban areas due to the presence of asphalt and generally high impervious land cover, which results in a heat island effect. However, weather stations are typically located at airports or rural areas, measuring temperatures that could be 1 to 2.5 degrees lower than actual city temperatures. While a low tier analysis may recognize this difference as a limitation, a high tier assessment should investigate - and if feasible, model - these differences, particularly when temperatures are near maximum tolerance thresholds.

Projects in urban areas should also be wary of the multiplicative effects of combined hazards and extreme conditions, for example flooding and heat associated with tropical storms. Such events may cause simultaneous disruption or failure of services, generating compound threats that can impact multiple sectors, and indirectly affect the project's performance. For instance, while a medical facility may not be directly exposed to flooding, a storm may result in a spike in the demand for emergency services, damage to above-ground electricity distribution lines, increased demand for climate-controlled environments due to heat and humidity, and expanded breeding ground for vector-borne diseases. All of these changes may negatively impact the ability of the facility to operate and to respond to the emergency, hence negatively impacting its climate resilience.

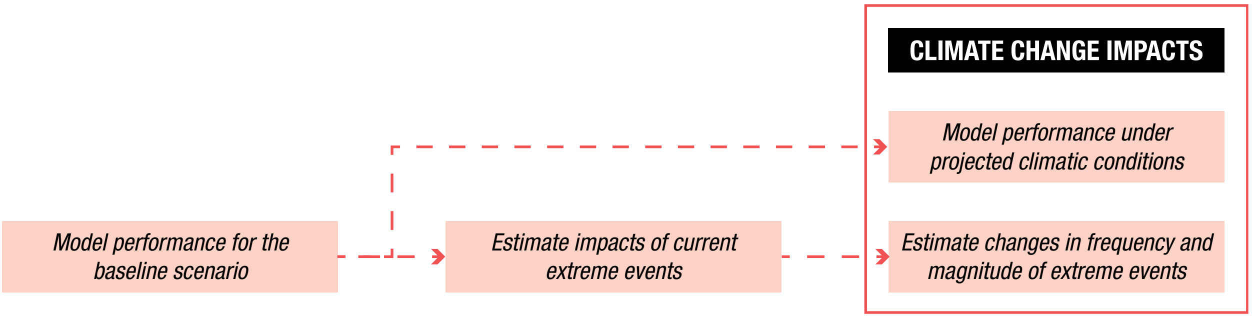
Finally, through stakeholder consultation and expert advice, the project team should assess the degree of uncertainty suggested by the range of climate scenarios considered, as well as to what extent these uncertainties are tolerable and/or should be mitigated.

Activity 2c. Analyze the project's performance under the selected climate scenarios. The output of Activity 2b is then directed into socio-economic models that convert biophysical outputs into costs and benefits, identifying the performance of the project for both baseline and future scenarios. For instance, biophysical outputs such as projected future flood depths would be coupled with the design standards of the proposed project infrastructure and with depth-damage curves to provide an estimate of the costs associated with future flood damages. In this example, the design standard will determine how much reduction of disaster and climate risks can be expected from the project. As another example, a project to expand a city's transit system could see positive impacts in terms of reduced travel times and fewer emissions from single occupancy modes of travel. These anticipated positive impacts could be offset by delays caused by more frequent flooding of roads in the future due to higher intensity precipitation events. These results, along with the performance in the metrics established in Activity 2a, serve as the basis for the evaluation.

Following the analytical approach determined in Step 1, the analysis should model the impacts of climate hazards following the process in **Figure 8.8**. Climate change impacts should be modeled for all the future scenarios considered in the previous activity and compared against the baseline. Hallegatte et al. (2021) and Asian Development Bank (2015) provide further guidance on how to incorporate the effects of climate change and extreme weather events in cost-benefit analysis. For projects with long time horizons, it is recommended to look at the result at multiple timestamps (e.g., midcentury and end of century).

When conducting the assessment of a new development, a counterfactual representing a no-investment scenario, would be appropriate to assess whether the investment is better than a no-action scenario, as well as to measure the overall contribution (i.e., benefits minus costs) of the investment.

Figure 8.8. Evaluation Process for Climate Hazards



Activity 2d. Assess the vulnerability of the project in the form of a stress test. The analysis should then explore the performance of the project under the range of possible climate futures selected in Activity 2b to assess whether the project fails under those conditions based on the results from Activity 2c. This stress test will help the project team identify thresholds for failure, as well as failure scenarios (e.g., when the project does not meet the minimum economic returns) and the extent of the failure (i.e., difference between the results and a target measure). The vulnerability of the project is then assessed by looking at all the results generated in the previous activity for each future scenario. The following questions guide the vulnerability assessment:

- **Does the project meet the minimum performance targets?** When looking at economic return metrics, these generally require the project to have a positive Net Present Value and/or meet an Internal Rate of Return hurdle rate (see the technical note on economic modeling included in the Compendium Volume for a primer on economic evaluation). A project can also be vulnerable to a climate hazard when minimum performance in other metrics is not met under at least one scenario. For example, a green space project might fail if it does not meet water drainage requirements.

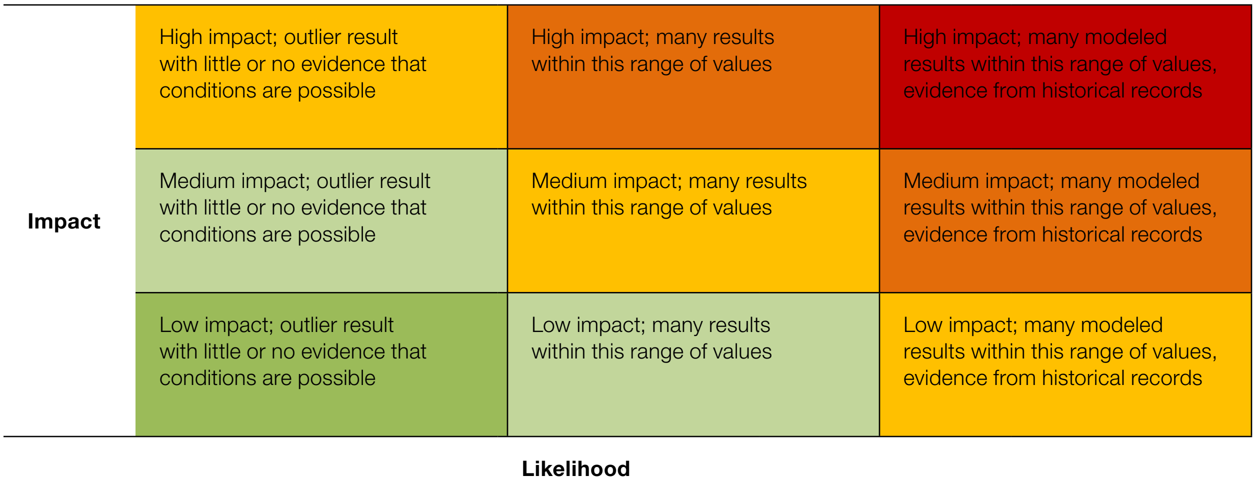
- **To what degree does the project meet the minimum performance targets?** The extent of the failure can be measured through the range of results across different climate futures. This analysis may indicate the presence of scenarios with results below an acceptable threshold, which may render the project vulnerable if consequences can be catastrophic.

On the basis of these questions, a project can be considered vulnerable to climate change impacts if in the future (i) the results for individual climate scenarios are worse than the baseline, (ii) there is a greater number of failure scenarios than in the baseline, (iii) the potential range of results worsens, or (iv) a combination of these situations. For example, an urban stormwater management project may fail if the percentage of water treated during precipitation events declines sufficiently to result in unacceptable water quality readings. The analysis may find that for a single future scenario, the performance of the investment is sufficient to meet project targets. However, other scenarios show greater changes in future precipitation intensity, resulting in the investment no longer meeting its targets. Those scenarios that show a problematic outcome indicate that the project is vulnerable should those futures occur. By using a large number of scenarios, the project team can have more confidence in the level of concern associated with the vulnerability (i.e., large number of problematic scenarios versus few).

A practical framework to summarize the results of the vulnerability analysis, particularly for high tier projects with a large number of results, is to generate a risk matrix that considers impact and likelihood. Impacts refer to the effects of the climate hazard on the project's performance. Likelihood can be thought of as a "weight of evidence" that provides insights as to the level of concern associated with the vulnerabilities. Likelihoods can be assessed in relative terms, based on whether the results of each GCM run fall within the general range of all results or is an outlier, and whether the climatic conditions have been observed in the historical baseline.

Figure 8.9 presents an illustrative example of a risk matrix adapted from Ray and Brown (2015), where higher impacts and higher likelihoods lead to higher levels of risk. All projects found to be vulnerable, particularly those at higher levels of risk, should advance to the next step of the framework to examine whether the project's resilience can be improved.

Figure 8.9. Sample Risk Matrix

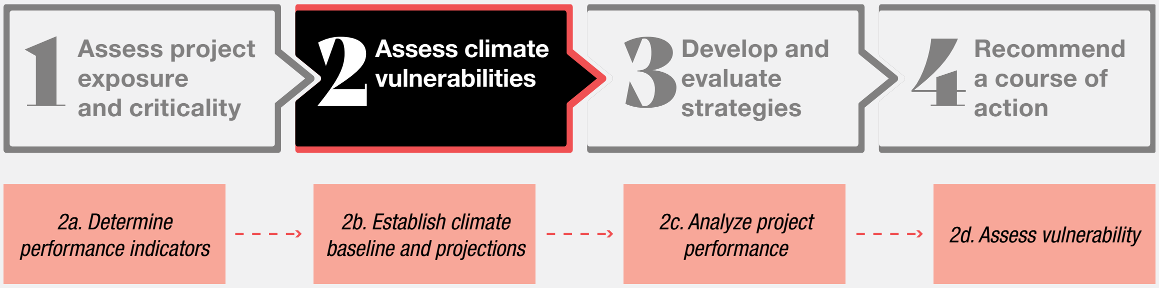


Impact	High impact; outlier result with little or no evidence that conditions are possible	High impact; many results within this range of values	High impact; many modeled results within this range of values, evidence from historical records
	Medium impact; outlier result with little or no evidence that conditions are possible	Medium impact; many results within this range of values	Medium impact; many modeled results within this range of values, evidence from historical records
	Low impact; outlier result with little or no evidence that conditions are possible	Low impact; many results within this range of values	Low impact; many modeled results within this range of values, evidence from historical records

Likelihood

Outcome: The result of this step is an understanding of the climate vulnerability of the project as currently designed. Comparison between the performance of the project under a historical baseline and under various climate futures provides an estimate of the degree of vulnerability of the project to climate change. It is possible that some project designs may be found to already be climate resilient in their performance given climate uncertainty and these projects can exit the framework here.

Case Study Demonstration of Step 2: Climate-Resilient Expansion of Urban Health Care Systems in Mali



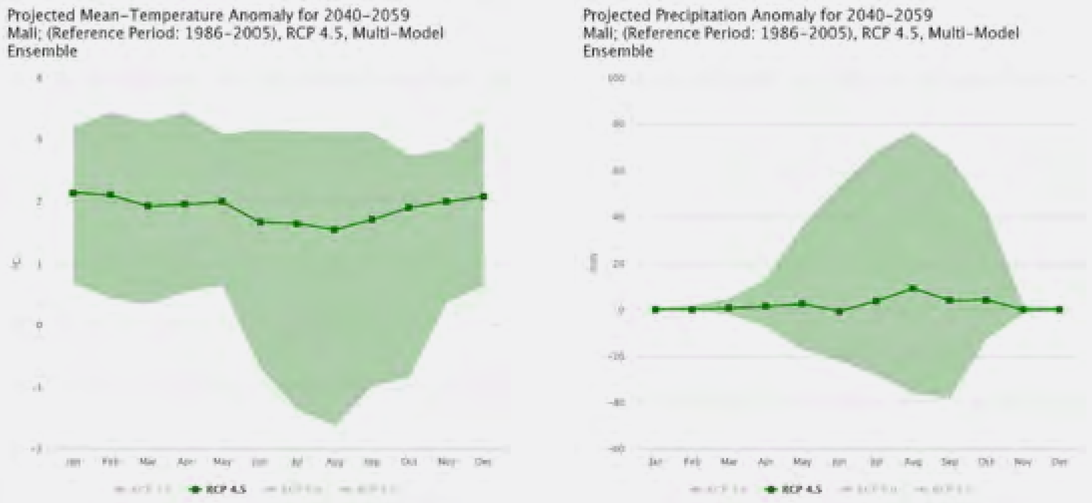
Performance indicators: The project's investments are focused primarily on increasing the access of health care services to beneficiaries, and the success of these projects will be measured through various health performance indicators, including the number of children immunized, the percentage of adolescent girls using contraception and the number of people receiving health, nutrition and population services.

To assess the ability of health care facilities to continue to provide such services when faced with climate hazards will require consideration of additional indicators such as the percentage of facilities that meet a minimum standard of quality, satisfaction rates of clients with the quality of health services and distance traveled and time waited to receive care.

Climate baseline and projections: While the project was screened for climate change and the overall assessment of potential risks was deemed "high", few details were available as to the climate baseline and projections that were utilized. However, short and long-term climate risks in the project area could be determined by using the World Bank's Climate and Disaster Risk Screening Tool. Looking at an intermediate scenario for future greenhouse gas emissions (i.e., Representative Concentration Pathway 4.5), the country is expected to face:

- An increase in monthly temperature ranging from 1.5°C-2.1°C above the monthly mean by 2040-2059
- An additional 33 hot days per year (defined as days with temperatures above 35°C) in the period from 2040-2059

Case Study Demonstration of Step 2 (continued): Climate-Resilient Expansion of Urban Health Care Systems in Mali

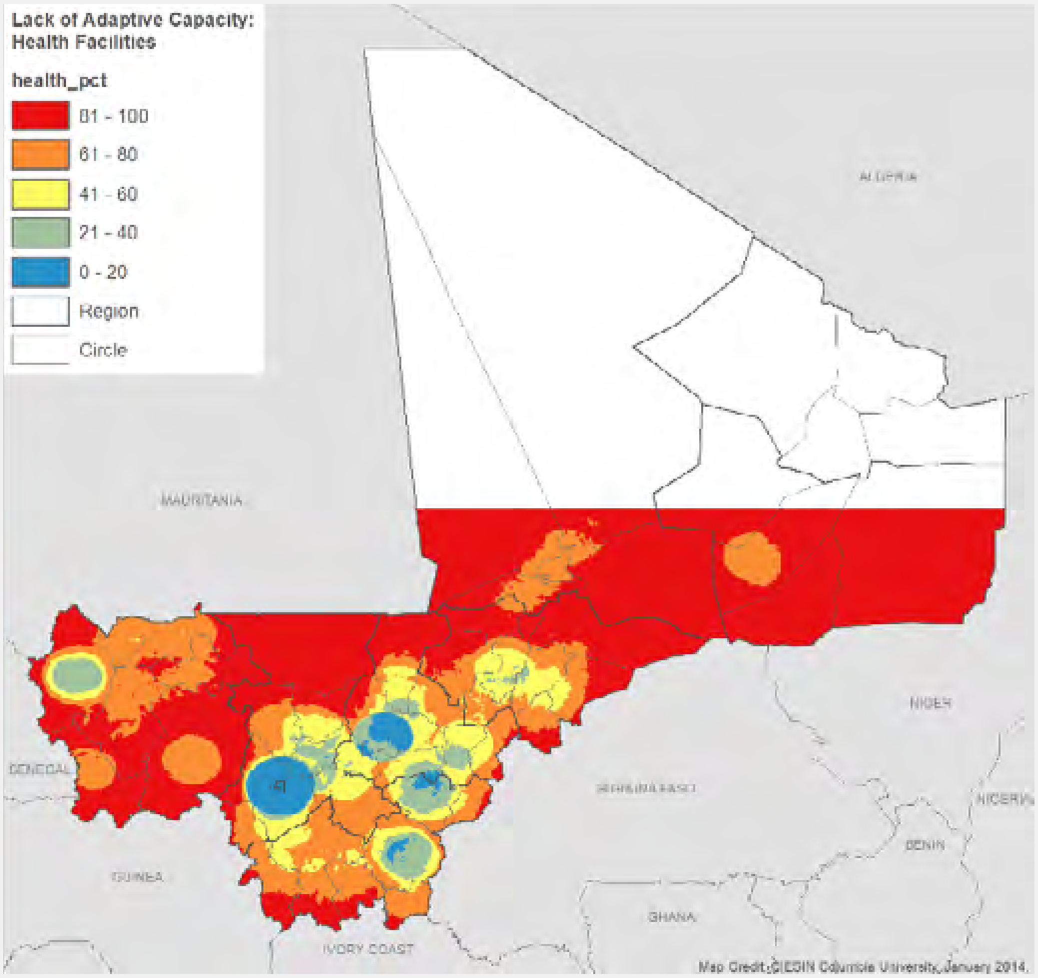


Projected mean-temperature and precipitation anomalies for Mali for 2040-2059 (Source: World Bank 2021)

Analyze project performance and assess vulnerability: An analysis of project performance given possible future climate impacts would ideally be based on a quantitative assessment that converts the biophysical impacts of investing in the project into costs and health benefits, for both baseline and future climate conditions. For investments in Mali's healthcare infrastructure, previous work conducted by the United States Agency for International Development (2014) can provide a general picture of the climate vulnerability of Mali's healthcare system. This previous climate vulnerability mapping exercise utilized a spatial vulnerability index comprised of 18 indicators grouped into three vulnerability components: climate exposure, sensitivity, and adaptive capacity.

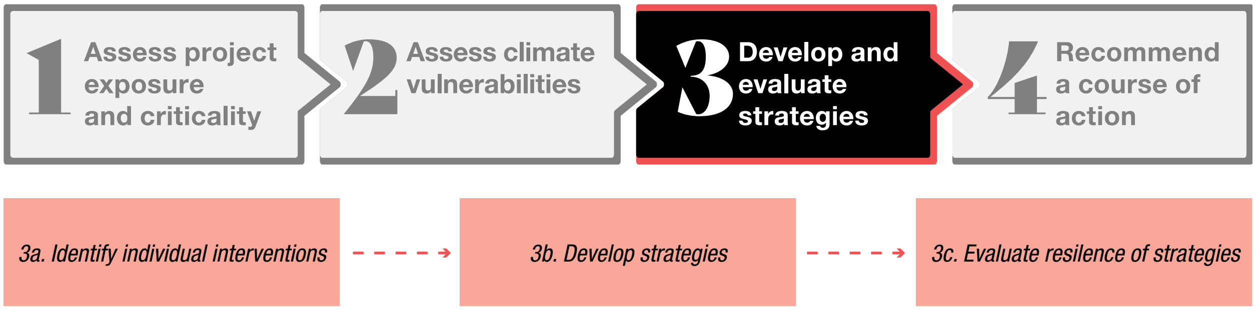
Case Study Demonstration of Step 2 (continued): Climate-Resilient Expansion of Urban Health Care Systems in Mali

The results of this vulnerability mapping are shown in the figure below, displayed as the (lack of) adaptive capacity of the healthcare system in different parts of the country. The capital city, Bamako, is found to have low vulnerability (i.e., a low lack of adaptive capacity, shown in blue), as does the region around Sikasso. The most densely settled agricultural region in southeastern Mali has medium to medium-high vulnerability (shown in yellow/orange), with the large rural areas in the north generally very vulnerable (i.e., a high lack of adaptive capacity, shown in red). While these results are not tailored to the specific investments being considered in the current World Bank project, they offer a valuable snapshot of current vulnerability of health facilities and demonstrate a modeling framework that could be adapted to assess the impact and climate resilience of specific proposed investments in the project in question.



Lack of adaptive capacity of health facilities in Mali (United States Agency for International Development 2014)

8.2.3. Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience



Objective: This next step in the framework develops a set of possible strategies by which to adapt the project to climate hazards to improve its resilience. The analysis seeks to provide insights about the performance of the project given climate change as compared to the adapted project given climate change, and considers three activities:

Activity 3a: Identify individual interventions to enhance the climate resilience of the project. Building resilience involves strengthening the capacity of the urban system to cope with climate hazards. As such, the assessment should start from the results of the analysis in Step 2, and search for interventions that can mitigate the project's vulnerabilities by decreasing the magnitude and recurrence of failure scenarios. In general, these practices to enhance resilience fall into four different categories (adapted from the Food and Agriculture Organization 2010):

- **Structural:** structural modifications to the project in terms of its capacity, dimensions, materials used, etc. and the inclusion of protective infrastructure. For example, the use of different building materials and green infrastructure for improved cooling in buildings.
- **Technology:** use of emerging technologies to improve the resilience of a project. For example, Information and Communication Technologies for disaster resilience in urban areas, which can include operation centers that display real-time integrated data from various agencies to improve coordination and reaction times and wireless early warning systems that connect civil protection and environmental institutions with cameras that monitor river channels crossing the urban area and share online real-time hazard information with citizens.
- **Management and planning:** water, land use and maintenance planning. For example, consideration of the impacts of a new housing development on the occurrence of local floods, landslides, soil degradation etc. can help ensure urban resilience is not eroded.
- **Knowledge:** education (e.g. through schools, universities, other education service providers); training (e.g. courses, seminars, webinars, e-learning); networking (e.g. conferences, workshops, sharing platforms, communities of practice, networks of excellence); specific coaching; and technical assistance (e.g. expert missions, twinning of cities) (Swart and Singh 2013).

Table 8.2 lists some measures that could be used in Sub-Saharan Africa to enhance resilience. Finally, it is important to highlight the role of **nature-based solutions**, which harness biodiversity and ecosystems services to reduce vulnerability and build resilience to climate change. For instance, the restoration of a forest outside of an urban area can help reduce flood peaks, thereby acting as an adaptation measure for a flood-prone neighborhood. The ecosystems note included in this Compendium Volume provides additional guidance on incorporating such measures into a project.

Table 8.2. Urban Adaptation Practices to Enhance Climate Resilience

System	Frequent / prioritized practices
Buildings	• Review, adopt, and enforce updated building codes that protect buildings from hazards (e.g., flooding, wind, etc.) • Adopt the International Building Code and International Residential Code • Buildings should be designed and adequately anchored to prevent collapse or other destruction during flood or storm events • Require building foundation design, braced elevated platforms, and protection against lateral forces from wind and waves • Incorporate passive ventilation in building and site design • Encourage wind-resistant roof shapes and materials • Adopt coastal zone management regulations, beach management plans, and shoreline setback regulations • Limit or prohibit development in areas along the coast susceptible to flooding
Solid Waste managemeny systems	• Technological and institutional improvements in solid waste collection, transfer, and disposal • Build or upgrade waste sorting and treatment facilities • Close dumps, construct or refurbish landfills, and provide bins, dumpsters, trucks, and transfer stations.
Systems that manage water resources in urban areas	• Regularly check for leaks to minimize water supply losses • Develop ordinances to restrict public water resources for non-essential use • Use flexible pipes when extending water or sewer service • Replace brittle pipe material with pipe made of more flexible, ductile materials (e.g., steel, ductile iron, copper) • Install structures to protect facilities from flooding (e.g., physical barriers, green infrastructure, floodwater pumping systems) • Develop the capability to temporarily remove and safely store vulnerable infrastructure components before a flood • Install saltwater-resistant equipment and storage tanks • Develop process guidelines or models to understand potential water quality changes that may be required to attain drinking water standards • Relocate or elevate pump house and distribution system accessories that are susceptible to flooding • Separate combined sewers to reduce flows to treatment works in a flood • Anchor critical infrastructure (e.g., storage sheds) to protect from severe winds

System	Frequent / prioritized practices
Electrical utilities and telecommunications systems	• Establish standards for all utilities regarding tree pruning around lines • Inspect utility poles to ensure they meet specifications and are wind resistant • Bury power lines to safeguard power transmission during severe wind events • Upgrade utility infrastructure (pole size, span widths, line strength) • Avoid aerial extensions to water, sewer, and gas lines • Install redundancies and loop feeds
Transportation systems	• Routinely inspect transport infrastructure and identify if any repairs or retrofits are needed to prevent failure • Place facilities at higher elevations to protect from sea-level rise and storm surge • Use heat-resistant materials • Enhance drainage for extreme precipitation events • Enhance surface infrastructure to ensure resilience against storm surge
Green and Open Spaces	• Increase tree planting around buildings to shade public areas • Encourage the installation of green roofs to provide shade and remove heat from roofs and surrounding areas • Use cool roofing products that reflect sunlight and heat from buildings • Discourage the use of dark colors and asphalt in outdoor spaces to reduce urban heat • Create cool centers for the public
Cross-cutting	• Establish regular schedules to monitor and report extreme weather conditions • Use natural features such as wind buffers in site design • Use GIS to map hazard areas, at-risk structures, and associated hazards • Sites for new critical facilities should be outside flood-prone areas • Update/develop climate resilient urban design standards and regulations

Activity 3b: Develop adaptation strategies to enhance resilience. Once a set of promising and feasible adaptation measures has been identified for the project, more comprehensive and integrated strategies to build resilience should be developed by combining individual measures. Strategies should consider different sets of interventions, as well as different degrees of implementation, timing, or locations as appropriate, and should be part of a participatory consultation with stakeholders to identify and validate solutions. Moreover, project evaluators should also pay attention to possible interactions between measures.

Ultimately, which interventions become part of a strategy will depend on what attributes of resilience need to be enhanced to reduce climate vulnerability, as well as how stakeholders and users define resilience for the particular project in question. **Textbox 8.7** presents a list of key attributes for an urban system, which can guide the development of adaptation strategies to enhance resilience, with these attributes ideally to be tailored to local circumstances. While these attributes are introduced here as guidelines to consider when developing possible adaptation strategies, they are fact a powerful tool to strengthen project design, especially when integrated as key resilience concepts into the project narrative from the outset and then used to track progress towards achieving greater resilience. In the face of climate uncertainty, it is appropriate that strategies consider a portfolio of measures to mitigate the impacts from multiple climate hazards, along with insurance and contingency plans for when conditions exceed the capacity of the adapted system to cope.

Additional guidance on the development of adaptation strategies can be found in the note for practitioners titled Integrating Resilience Attributes into Operations (Ospina and Rigaud 2021) and the United Nations Development Programme's Urban Risk Management and Resilience Strategy (2021). The latter provides insights on how small and medium-sized cities can combine solutions for addressing the interlinked challenges of development and climate change through a risk-based approach.

Though this guidance note focuses predominantly on climate adaptation (with adaptation considered the priority at present for Sub-Saharan Africa), it is important that adaptation and climate mitigation goals and activities are not treated in isolation, as the resilience of a project can also be impacted by climate mitigation-related considerations. For example, conservation of urban forests contributes both to climate change mitigation and adaptation. The focus of this note on adaptation should not detract from the identification and quantification of any co-benefits that may accrue from climate mitigation.

Textbox 8.7: Resilience Attributes for Cities

Key capacities to build climate resilience in infrastructure investments in Sub-Saharan Africa's urban areas include (adapted from Ospina and Rigaud 2021):

- **Robustness:** the ability to withstand the impacts of climate extremes and variability, maintaining functioning of the city, its supporting processes and infrastructure, while minimizing variability in performance.
- **Redundancy:** the availability of additional or spare resources that can be accessed in case of an extreme, for instance multiple pipes that provide water to one location.
- **Learning:** the ability to develop knowledge and skills to innovate, adapt, and improve performance, leveraging existing knowledge to develop resilience mechanisms.
- **Flexibility:** the ability of the system to be nimble and utilize opportunities in responding to uncertainty or other challenges. For instance, adapting infrastructure development plans after a disruptive extreme event.
- **Inclusion:** building on diversity and inclusion, ensuring that women and vulnerable groups have the necessary tools and resources, both in normal conditions and during crisis.
- **Self-organization:** the ability to locally lead adaptation efforts by independently rearrange functions and processes in the face of shocks or stressors, diagnose problems, assess priorities, and/or mobilize resources.

These resilience attributes are mirrored by the qualities of resilience systems defined by the Resilient Cities Network: resilient systems are those that are **reflective, robust, redundant, flexible, resourceful, inclusive,** and **integrated** (Rockefeller Foundation and Arup 2014).

Resilience Spotlight: Championing Climate Resilience Through Solid Waste Management in Lusaka, Zambia

Lusaka, the capital city of Zambia experiences periodic droughts and severe flooding. The effects of extreme weather are exacerbated due to the city's rapid population growth, with a large peri-urban population living in informal settlements. These informal settlements experience diverse vulnerabilities, many of which are magnified by climate change. For instance, with 70 percent of Lusaka's population living in informal settlements, waste management in these areas is a growing concern. The accumulation of urban waste from informal settlements often results in blocked drains, which worsens flood risk. This in turn can result in standing water, which increases the risk of water-borne disease outbreaks, such as cholera.

Through the *Cities Race to Resilience* initiative, Lusaka has implemented a number of solid waste management programs. **The resilience of these programs in the face of more frequent intense urban precipitation events is enhanced through actions such as monthly clean-ups in the city which sees the mayor's office work directly with ward councilors as well as communities to clean out drainage systems to minimize flood risk.**

Activity 3c: Evaluate the selected strategies' contribution to the resilience of the project. Having identified a feasible portfolio of individual adaptation measures, the next step involves using the same modeling framework established in the vulnerability assessment described in Step 2 to evaluate the performance of the different adaptation strategies being considered.

Depending on the specific interventions, it is possible that new model parameters or assumptions may need to be defined (looping back to Step 2) before being able to estimate the costs and benefits of different interventions, which may require the gathering of additional data. Comparing the performance of the strategies to the project as originally designed (in Step 2) in terms of how much they reduce the magnitude and recurrence of project failure provides a sense of the degree of climate resilience that different strategies offer. In other words, an adaptation strategy that increases climate resilience is one that results in fewer cases of failure, a reduced impact in the failure scenarios, or both. For example, the inclusion of a multi-purpose green space in an urban development can offer greater resilience for the area's inhabitants by providing cooling during hot days and encouraging infiltration of intense precipitation, thereby reducing urban flooding. The extent of these improvements can be tracked using the Risk Matrix previously shown in **Figure 8.9**.

Outcome: At the end of Step 3, the project team will have identified promising portfolios of interventions that enhance the climate resilience of the original project design evaluated in Step 2. The output of this step is an updated set of results showing the project's performance for each adaptation strategy and climate scenario. This output will be the input for the following decision-making step.

Case Study Demonstration of Step 3: Climate-Resilient Expansion of Urban Health Care Systems in Mali

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

3a. Identify individual interventions → *3b. Develop strategies* → *3c. Evaluate resilence of strategies*

Identify individual interventions to improve project resilience and develop adaptation strategies: Within the $50 million budget for the project, a portion will be dedicated to enhancements that improve the climate resilience of health service providers, and by extension of beneficiaries. The project aims to incentivize investments in climate smart equipment at the primary care facility level and at the district level. Potential such climate smart interventions include:

- Energy efficient appliances
- Cooling technologies (i.e., refrigeration, tree planting to increase shade around facilities)
- Water efficient fixtures to decrease water loss
- Solar photovoltaic energy systems
- Rainwater harvesting
- Grey water capture infrastructure and water recycling systems
- Advanced autoclaving of infectious health care waste
- On-site wastewater pretreatment and sanitation improvements
- Onsite water treatment and safe water storage
- Better procurement and management of pharmaceuticals, medical devices, business products and services (reducing energy footprint in production and transport of unused pharmaceuticals and products)

Case Study Demonstration of Step 3 (continued): Climate-Resilient Expansion of Urban Health Care Systems in Mali

Solar energy for health centers in Mali (EKOEnergy 2021)

Evaluate the resilience of the different strategies: Having identified a number of possible resilience-building measures above, and given this project's classification as a high tier project, a detailed quantitative assessment would ideally be conducted to evaluate how different possible strategies influence the resilience of an individual facility or the healthcare network as a whole. Depending on the specifics of the analysis conducted, the project team would be able to identify which resilience-building measures result in the greatest improvements to climate resilience and health outcomes, and at what cost.

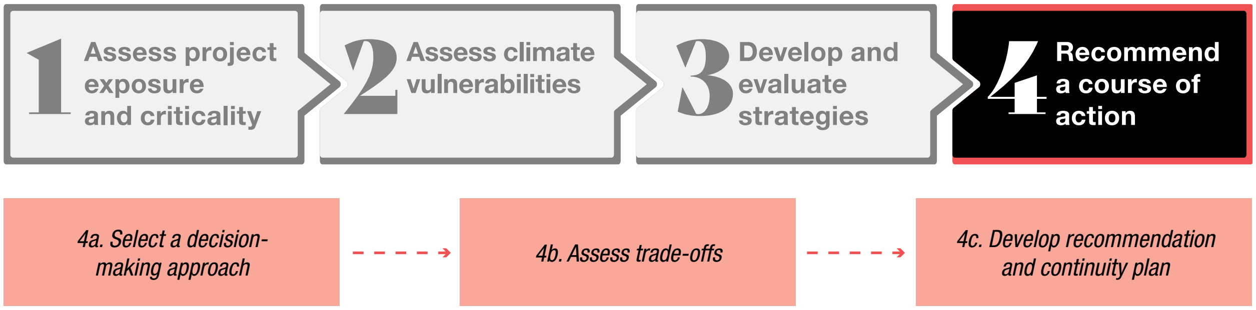
For instance, looking at the various water-focused measures listed above, do water efficient fixtures (to decrease demand) or rainwater harvesting (to increase supply) result in equal improvements to a facility's climate resilience under future drought conditions and at what relative cost-effectiveness?

Case Study Demonstration of Step 3 (continued): Climate-Resilient Expansion of Urban Health Care Systems in Mali

Rainwater harvesting in cisterns (Food and Agriculture Organization 2018)

In the case of this project, resilience-enhancing measures were evaluated pragmatically and qualitatively looking at available budget, infrastructure needs, and climate hazards experienced by the different facilities, all underpinned by the findings of a cost effectiveness analysis, a cost benefit analysis and a financial analysis.

8.2.4. Step 4: Recommend a Course of Action



Objective: Finally, this step will lay out a decision-making approach to identify a course of action from the adaptation strategies considered in Step 3 that considers trade-offs and looks at the full economic lifetime of the project. Three activities are involved.

Activity 4a: Select a decision-making approach that is able to help identify a strategy (from the set developed in Step 3) that is well-suited for a broad range of uncertain conditions. This requires assessing and trading off project performance across a variety of uncertain future conditions, rather than simply maximizing the expected results from averaged future conditions. While the focus in this note is on uncertainty about future climate conditions, resilience analyses in Sub-Saharan Africa are faced with a variety of different uncertainties, including from inadequate historical climate data, the divergence of existing climate projections, as well as changing political and policy environments, external market conditions, or levels of technology adoption. In this context, traditional decision-making methods often fall short because they typically strive to identify an optimal design for an average or most likely set of future conditions. (This group of methods is often described as being founded on **predicting and then acting** – see the technical note on decision-making under climate uncertainty included in the Compendium Volume for an overview of these traditional decision analysis methods.)

Given the significant degree of uncertainty associated with future climate conditions, a new group of decision-making methods has been developed that focus on **preparing and adapting**, rather than predicting and acting. This class of methods emphasizes **the identification of flexible decisions that enable ongoing adaptation, or robust decisions that will prove wise across a wide range of future climate conditions**. In general, these methods involve framing the analysis and conducting an exploratory assessment, choosing initial and contingent actions to iterate and perform re-examination, and allowing participation of stakeholders. **Table 8.3** provides a summary of some of these decision-making approaches, grouped based on whether they emphasize the robustness or flexibility of the decision. (See the technical note on decision-making under climate uncertainty included in the Compendium Volume for further details.)

Table 8.3. Summary of Approaches for Decision-Making Under Climate Uncertainty

Emphasis of Framework	Description	Examples
Robustness	These approaches focus on achieving acceptable project performance across a wide range of possible future conditions. The emphasis is on the investment decision to be made now and generally follows a conservative approach when incorporating future conditions that are significantly different from the baseline.	• Decision Scaling • Robust Decision Making
Flexibility	These approaches prioritize identifying a design that can adapt in the future given different climate conditions. In general, these value the agility of a design more than its robustness and include consideration of "tipping points" for climate variables that will indicate a change from one set of actions to another.	• Engineering Options Analysis • Adaptation Pathways

The selection of a decision-making framework should be informed by the preference either to account for future uncertainty now through measures that enhance the robustness of the decision or leave options open for future adaptation. This choice should be informed by the available resources today and in the future, the capacity of the project team to control or influence changes in the future, and the optimism that future information will help to clarify the adaptation decision and will arrive in a timely way. For instance, while development of a new hospital complex may benefit more from a robust approach that ensures the infrastructure is designed to withstand low-probability but high-impact climate events, projects that can more easily be conducted in an incremental way, such as extension of a transit network, may take a more flexible approach that waits to make further investments until it is clear they will be required.

As mentioned before, the framework for enhancing the climate resilience of projects that is presented in this note is circular: it is possible that after selecting a decision-making approach, the activities completed during earlier steps in the framework may need to be revisited and adjusted. For instance, having prioritized the flexibility to make incremental adaptation decisions and delay large investments till later (as compared to prioritizing system robustness now), this decision may necessitate returning to Step 3 and identifying additional adaptation interventions that enable flexibility, as well as returning to Step 2 and selecting a few additional uncertainty scenarios to explore if particular climate futures are concerning to decision makers.

Activity 4b: Assess the trade-offs of each strategy. Generally, there is no perfect adaptation strategy, and more beneficial strategies tend to be more expensive. Strategies that are good for mitigating the impacts of one climate hazard, for instance using different more heat-resistant materials on roadways, may influence urban runoff and change the drainage profile of the city. Within urban areas, there may also be trade-offs between decisions that offer resilience against climate hazards versus resilience against other non-climate hazards such as earthquakes or fire safety. Furthermore, strategies that benefit one sector may cause negative downstream impacts to other stakeholders. In this context, the decision-making process must also look at minimizing trade-offs. The starting point of this activity requires identifying, and if possible, quantifying, the trade-offs of each strategy. As an example of a typical trade-off between investment decisions in urban areas, Xu et al. (2019) found that unilateral investments for climate mitigation or adaptation can in fact cause contradicting consequences with respect to reducing emissions and climate stresses, while integrating both climate mitigation and adaptation strategies into broader land use measures can help minimize this tradeoff.

The quantitative analysis performed during Steps 2 and 3 can produce two kinds of results: a point estimate of an economic performance indicator (e.g., internal rate of return or net present value) and information related to the variability (i.e., distribution of uncertainty) around the point estimate. Under uncertain future conditions, the point estimate may be no more likely to occur than the wide range of other possible outcomes around it. For this reason, when assessing trade-offs, the project team should consider the distribution of uncertainty around point estimates to promote better decision-making.

Resilience Spotlight: Mapping Hotspots of Urban Natural Assets in Lilongwe, Malawi

Urban green spaces and natural assets serve a crucial role in enhancing the climate resilience of urban areas. They can store and attenuate flood waters and lower urban air temperatures, all while improving the quality of life of urban residents. **The continued resilience offered by these natural assets relies on communities being aware of their value and taking steps to maintain and protect them.** In Lilongwe City in Malawi, the Urban Natural Assets: Rivers for Life project saw the completion of a mapping exercise to identify urban natural asset hotspots in the city, with these areas being particularly important to the resilience of the city and therefore in need of protection. Steps have been taken to safeguard the continued functioning of these mapped priority hotspots by implementing a monitoring and enforcement schedule to ensure sound management of these assets as well as compliance with city planning recommendations seeking to preserve these areas.

In order to weigh the importance of different strategies, the project team should develop a hierarchy of all consequences that result from project failure. These causes of failure correspond to all the reasons why the project does not meet the performance metrics in the face of extreme weather events and climate change, as identified from the vulnerability assessment and addressed through adaptation strategies. For instance, if increases in long-term average urban air temperatures are found to cause greater cumulative negative effects than the more severe urban heat waves predicted for the future, a plan that prioritizes improving building design for more efficient cooling may be a more worthwhile strategy than providing a small number of public cooling facilities that are operated during heat waves only. This list will indicate the order of priority and urgency and should be produced in consultation with and validated by stakeholders of the project.

The project team should then carry out the decision-making process, with the benefits of the strategy (i.e., the performance metrics defined in Step 2 and evaluated in Step 3, considering the distribution of uncertainty of estimates), its direct costs and associated trade-offs, and the hierarchy of priorities as inputs. As mentioned, this process may require revising the analysis done in previous steps as new information is obtained and inputs are gathered from stakeholders. Decisions then could fall into three categories, namely:

1) **Investing in climate-proofing the project at the time the project is being designed or implemented,** which can result in low-regret, no-regret and/or win-win options depending on the projected costs and benefits;

2) **Deferring from investing in climate-proofing but designing the project in such a way it can be more easily climate proofed in the future,** if deemed necessary; Or

3) **Deciding that the project design and monitoring should not take account of climate variables and their impacts at the present time,** and that investment in climate-proofing will be undertaken at a later point, if needed.

> Project implementation should identify stakeholders with the capacity to implement the preferred adaptation option(s) and include necessary capacity building at the individual and institutional levels.

The first option sees more substantial investments in climate resilience at the project outset than the latter two options. The second option is commonly referred to as **adaptive management**, where proactive and incremental adaptation investments are introduced over the project's lifetime. The third decision making approach embodies **a wait-and-see mindset** – while this latter approach maximizes flexibility and adaptability, minimizes the hardening of infrastructure today, and may be preferred when funds are limited, and uncertainty is high, it is only suitable for situations where baseline risk is considered acceptably low. As an example of adaptive management, land could be set aside for future storage of urban runoff during extreme precipitation events, but the actual construction of ponds or other retention infrastructure could be deferred until higher runoff volumes are actually experienced.

The recommendation of a preferred course of action should cover all components of the project cycle, starting with project identification, focusing on risk screening and identifying critical stakeholders and their roles and responsibilities. The recommendation should focus on those adaptation solutions that are technically feasible to address projected climate vulnerabilities, taking into account the related costs and benefits. In this context, the trade-offs analysis should also inspect the feasibility of a strategy in terms of technical capacities, policy environment, and financial constraints, with particular attention to the extent to which the environment supports or limits their implementation. Potentially, the analysis may require returning to Step 3 and revising the strategies proposed. Project implementation should identify stakeholders with the capacity to implement the preferred adaptation option(s) and include necessary capacity building at the individual and institutional levels. Lastly, the recommendation works best if it draws and builds upon existing urban development plans and strategies, which have likely already identified priority areas for action.

Activity 4c: The development of a recommendation and continuity plan should provide a narrative that justifies the selection of a course of action from the process in the previous activity. Moreover, the continuity plan should describe how project evaluation will be conducted, along with a clear schedule of activities and stakeholder responsibilities into the future, both during and after the implementation phase, including how resources for maintenance and/or continued adaptation will be mobilized, to ensure the investment continues to perform over the course of its life.

Both the narrative and continuity plan should discuss residual climate risks not addressed in the proposed project design that are still material to the project. Since it is not always economical or preferred to address all risks under all potential future conditions, there will generally be a residual risk. However, since the future is uncertain, it is possible for residual risk to grow over time in unanticipated ways to a point where it would be appropriate to address and should be the basis for a monitoring and evaluation plan. For example, precipitation-related risks may not be considered relevant today if most climate scenarios point to a drier future but may become significant if the climate evolves differently than predicted. Monitoring and evaluation should focus on assessing how progress toward vulnerability reduction and changes in residual risk will be measured in terms of indicators, tipping points, and thresholds, and how lessons learned can be used to improve current and future projects underpinned by a fit-for-purpose monitoring, evaluation and reporting framework.

This plan should include which actors will be responsible for each action and when, and should cover the full economic life of the project. Developing such a plan is fundamental when selecting a wait-and-see type of strategy that requires future actions. Even when interventions are prioritized in the near-term, as (climate and non-climate) uncertainties resolve over time, the continuity plan provides critical milestones for revising the resilience of the project.

Outcome: After completing these four steps, the project team should be capable of providing an assessment of the vulnerability of the project as initially proposed, and developing a narrative on how much a particular strategy (or set of alternative strategies) can enhance its resilience and, therefore, reduce its vulnerability. The assessment, moreover, should enable the team to understand whether the improvements (and corresponding trade-offs) are acceptable, as well as the costs of following each course of action.

Case Study Demonstration of Step 4: Climate-Resilient Expansion of Urban Health Care Systems in Mali

1 Assess project exposure and criticality

2 Assess climate vulnerabilities

3 Develop and evaluate strategies

4 Recommend a course of action

4a. Select a decision-making approach → *4b. Assess trade-offs* → *4c. Develop recommendation and continuity plan*

Select a decision-making approach: Having identified a number of different adaptation strategies (in Step 3 above) that could be pursued to improve the climate resilience of health facilities in Mali, investment decisions were ultimately made on the basis of a cost effectiveness analysis, a cost benefit analysis and a financial analysis. With anywhere from 5-30% of a facility's funding ultimately dedicated to infrastructure projects (including the implementation of climate resilient infrastructure), stakeholders assessed the relative climate risks, the relative benefits and costs of different interventions, and the ability of different interventions to respond to identified climate hazards to identify those interventions that would yield the highest expected returns.

Project records suggest that there was an implicit focus on the implementation of "no regret" measures to improve project resilience, with such measures providing health benefits regardless of how the climate evolves in the future. For instance, investment in energy efficient appliances and water efficient fixtures will reduce operating costs of health facilities no matter how the future climate is different to that of the present day; and the implementation of cooling technologies will be advantageous for reducing spoilage of pharmaceuticals even under the present climate. Such a focus on no regret investments offers significant flexibility to make further incremental investments in the future (e.g., adding further cooling technologies if temperatures become hotter than the current cooling interventions are able to cope with). In contrast, a decision-making approach that prioritized robustness would have seen more emphasis on maintaining health outcomes across a wide range of possible future conditions, paying particular attention to worst case future conditions (e.g., investing in cooling technologies now that are able to cope with possible but uncertain significant temperature increases in the future).

Assess trade-offs: When considering projects that enhance urban resilience such as those in Mali's healthcare sector, the tradeoffs are typically in the form of competing objectives. For instance, while investment in cooling technologies is expected to have positive health outcomes due to reduced spoilage of perishable medical products (among other mechanisms), operating costs and facility greenhouse gas emissions will almost certainly increase as a result of these measures. This tradeoff between climate adaptation and mitigation is a particularly important one to be mindful of when evaluating and selecting resilience interventions, with the perfect solution offering both climate adaptation and mitigation benefits.

Develop recommendation: Ultimately, individual facilities will be equipped with a portfolio of climate smart measures that are found to balance improvements in climate resilience with cost effectiveness and improvements to health outcomes. It will be important that these physical interventions are coupled with training and capacity building to ensure that infrastructure is operated in such a way as to offer the greatest degree of resilience.

8.3. Concluding Remarks

Urban areas are the economic heart of the majority of the world's population, with Sub-Saharan Africa being one of the world's fastest urbanizing regions. However, most urban areas in Sub-Saharan Africa are ill-prepared to cope with the impending risks associated with rapid urbanization. Furthermore, the risks to urban areas will only intensify as climate change exacerbates the vulnerabilities of urban residents. The stability of urban economic growth and shared prosperity will be increasingly undermined if vulnerabilities to climate change are not addressed. Hence there is a vital urgency to develop and implement climate-smart strategies in Sub-Saharan Africa's urban areas, such that resilience to climate extremes, whether floods, droughts, or extreme heat, be built into urban projects at all scales.

This guidance note presents a practical framework for enhancing the climate resilience of infrastructure development projects in Sub-Saharan Africa's urban areas. The framework includes four steps: (1) assessing the exposure to climate hazards and determining the criticality of the project; (2) assessing the vulnerability of the project to the identified climate hazards; (3) developing and evaluating strategies to enhance the project's resilience; and (4) recommending a course of action. For each step, the note provides illustrative examples, along with references to additional technical notes for issues that expand beyond the scope of the guidance note and are common to the other sectors covered in the Compendium Volume.

There is no single approach for assessing climate hazards in project evaluation, and this guidance note is based on the authors' understanding of the most appropriate methods available for urban areas in Sub-Saharan Africa. Future climate conditions are uncertain in nature, and the proposed framework was designed for incorporating the vast and evolving field of study in climate science by way of a practical and flexible approach that can adapt to new emerging knowledge.

This note is of an incremental nature: it seeks to inform how to incorporate climate-related uncertainties and the assessment of resilience over existing project evaluation methodologies. Only the fundamentals of economic, climate, and biophysical modeling, as well as of decision-making under uncertainty are covered in this note, and extensive references to external resources are provided to those seeking further detail. The note does not address other uncertainties in project performance such as demographic changes, political and policy environment, or macroeconomic factors. However, although the principles presented in this note can be extended to other uncertainties, specific guidance on these is preferable.

The framework presented in this note will always benefit from further refinement through widespread application in Sub-Saharan Africa, for a wide range of geographies, socio-economic, and climatic conditions. As conditions in the region change, and climate knowledge advances become more accessible, periodic updating of this note will ensure that users continue to be provided with the best guidance possible for enhancing the climate resilience of much-needed infrastructure investments in the region.

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PART 2: Technical Notes

09 **Technical Note:** A Primer on Working With Climate Projections

10 **Technical Note:** A Primer on Economic Modeling

11 **Technical Note:** Decision-making Under Climate Uncertainty

12 **Technical Note:** Overview of the Africa Climate Resilient Investment Facility's Training Program That Builds on These Notes

13 **Technical Note:** Working With Consultants on Project Level Resilience and Vulnerability Assessments

TECHNICAL NOTE:

A Primer on Working with Climate Projections

The attached Compendium Volume and six individual guidance notes are all built on a step-by-step framework for evaluating and enhancing the climate resilience of development projects in Sub-Saharan Africa. The second and third steps of this framework involve assessing the performance of a particular investment project and various adaptation strategies under different possible future climate conditions. This primer provides an introduction to working with climate projections. It starts with a brief discussion of why we need climate projections (Section 9.1). It then presents an introduction to climate models (Section 9.2) and discusses key characteristics of climate projections such as uncertainty (Section 9.3). Section 9.5 discusses different approaches to using climate projections in project evaluation, paying particular attention to the deeply uncertain nature of climate change. Finally, Section 9.5 presents details on where to obtain climate information and Section 9.6 provides guidance on how to select climate information for use in project evaluation.

9.1. Why Do We Need Climate Projections?

Climate change is altering future climate conditions beyond those that have experienced in the past. This means that investments may be exposed to conditions different than those they were designed for. Knowing how to adapt investment projects, particularly infrastructure projects, to improve their climate resilience is difficult because of the high degree of uncertainty about future climate conditions. If one knew with certainty that the future would be significantly wetter or drier than the present day (i.e., if we had "perfect foresight"), then decision-makers could simply select whichever project design is best adapted to the anticipated future conditions. However, future climate conditions are highly uncertain, especially for much of Sub-Saharan Africa where there is no scientific consensus on the anticipated direction of change (e.g., wetter versus drier), let alone the magnitude of the change (e.g., 10 percent wetter versus 20 percent wetter), which in turn results in uncertain future impacts from climate change. Furthermore, Sub-Saharan Africa's climate already experiences a high degree of natural variability from year to year due to phenomena like the El Nino Southern Oscillation, among others.

Given this large degree of variability and uncertainty, traditional methods of exploring project performance under one (or a few) likely climate futures increasingly fall short when searching for project designs that continue to perform well even if future conditions are different than expected. This search for a project that performs well over a wide range of futures – **a robust project** – requires consideration of a wide range of plausible climate futures. These can be in the form of qualitative storyline-type scenarios, but for quantitative modeling purposes are usually in the form of climate projections. A **climate projection** is defined as *the simulated response of the climate system to a scenario of future emissions or concentrations of greenhouse gases and aerosols, and changes in land use* (Intergovernmental Panel on Climate Change 2013). Climate projections are generally derived from **climate models** (as detailed in Section 9.2). It is important to emphasize that climate projections are not climate predictions: they are realizations of what the future climate could look like if certain assumptions are made regarding future emissions, socioeconomic and technological developments etc.

9.2. An Introduction to Climate Models

9.2.1. Global Climate Models

Climate projections are often derived from **Global Climate Models** (also called General Circulation Models - GCMs), which simulate global climate patterns. They are made up of a series of equations and parameters that represent the current scientific understanding of the physical relationships of the global climate system. These models capture not just the physics of the atmosphere, but also fluid dynamics, coupled atmosphere-ocean interactions, as well as observational and theoretical knowledge of coupled terrestrial-atmosphere, energy-water, and biogeochemical cycles.

GCMs are built at research institutes all over the world. Although there are many similarities between the models, they differ in their treatment of details (e.g., how they simulate cloud generation), which means different models produce different outputs even when using the same inputs. Output from the various GCMs is provided through the coordinated Coupled Model Intercomparison Project (CMIP). These individual groups coordinate their various updates around the release of assessment reports by the Intergovernmental Panel on Climate Change (IPCC), releasing new model results in the lead-up to each new assessment report. Phase 3 of this project (CMIP3) was released in 2005 and 2006 for the IPCC's 4th Assessment Report; Phase 5 (CMIP5), was released in 2012 for the 5th Assessment Report and CMIP6 has been partly released over the course of 2021 and 2022. CMIP6 includes more than 70 models, run by 33 different modeling groups. Typical outputs from such models are in the form of meteorological variables such as precipitation and temperature.

9.2.2. Emissions Scenarios

In order to simulate the response of the climate system to diverse possible future conditions, GCMs are typically forced by a series of different **emissions scenarios**. An emissions scenario is *a plausible representation of the future development of emissions of substances that are radiatively active* (e.g., greenhouse gases, aerosols). (All terms defined in this section are consistent with definitions contained in the IPCC's glossary of terms (2013)). At present, the scientific community uses emissions scenarios in the form of illustrative **Representative Concentration Pathways** (RCPs). RCPs are *scenarios that include time series of emissions and concentrations of greenhouse gases, aerosols and chemically active gases, as well as land use/land cover.* They represent different intensities in the additional radiative forcing caused by human activities. The word **representative** in "Representative Concentration Pathway" signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term **pathway** in "Representative Concentration Pathway" emphasizes the fact that not only the long-term concentration levels, but also the trajectory taken over time to reach that outcome are of interest.

Scenarios in the CMIP5 model runs are based on the following four RCPs, named for their 2100 greenhouse gas radiative forcing (in W/m^2):

- **RCP2.6:** A low emissions pathway (or a stringent mitigation pathway) where radiative forcing peaks at approximately 3 W/m^2 and then declines to be limited at 2.6 W/m^2 in 2100. This is broadly consistent with a scenario that aims to keep global warming less than 2°C above pre-industrial temperatures.

- **RCP4.5 and RCP6.0:** Two intermediate stabilization pathways in which radiative forcing is limited at approximately 4.5 W/m^2 and 6.0 W/m^2 in 2100.

- **RCP8.5:** A high emissions pathway which leads to >8.5 W/m^2 in 2100, leading to an average warming of almost 5°C by 2100.

Scenarios in the CMIP6 model runs are based on five **Shared Socioeconomic Pathways** (SSPs) combined with assumptions on policies to achieve certain levels of radiative forcing (i.e., RCPs). SSPs represent different possible evolutions of the world in terms of demography, technology, economy, behaviors, and so on, paired with a trajectory of greenhouse gases radiative forcing. The most commonly used CMIP6 scenarios are the following:

- **SSP1-1.9:** Represents reductions in greenhouse gas emissions in line with 1.5°C warming by 2100.

- **SSP1-2.6:** Represents reductions in greenhouse gas emissions in line with the Paris Agreement and average warming of less than 2°C by 2100.

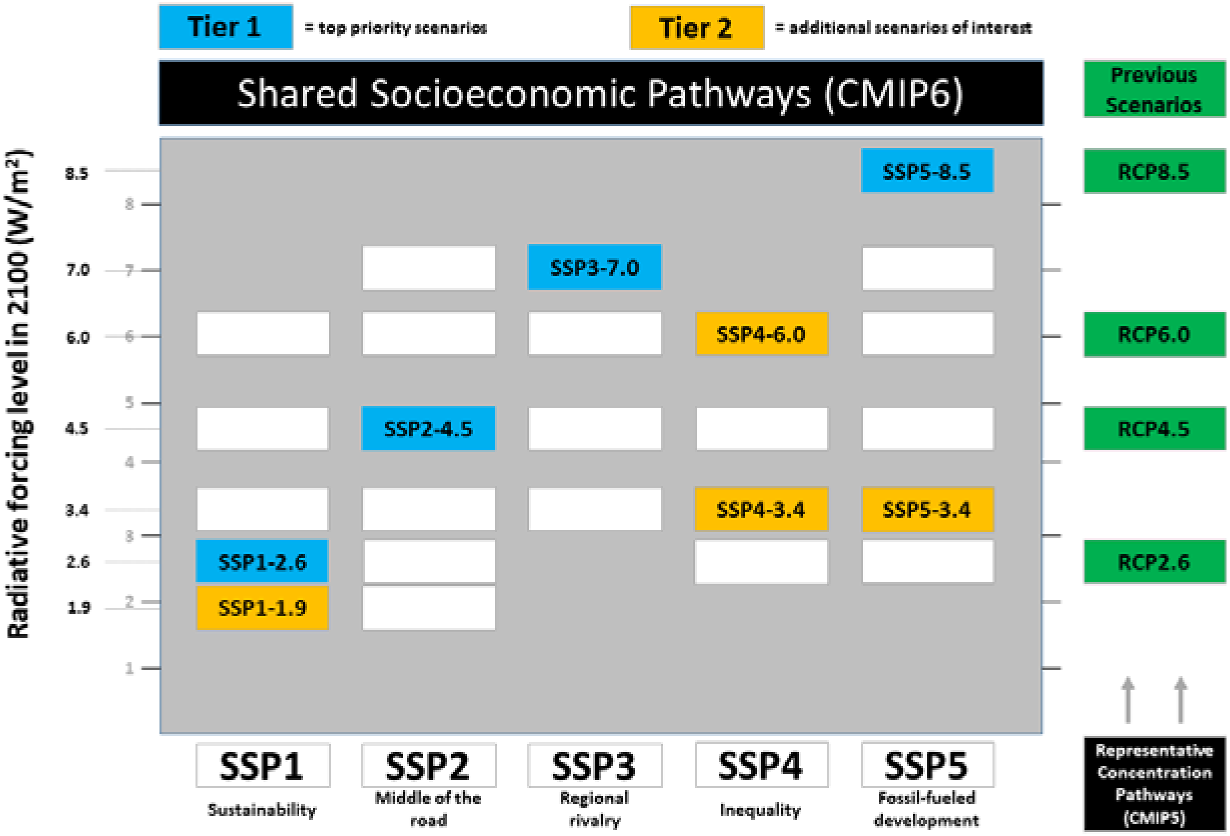
- **SSP2-4.5:** Represents global mitigation consistent with current climate commitments and 2030 targets (as of November 2021).

- **SSP3-7.0:** Represents a scenario in which warming reaches 4°C by 2100, due for example to more lax climate policies in the future or to a reduction of the ability of ecosystems and oceans to capture carbon.

- **SSP5-8.5:** Represents an extreme worst case in which unabated greenhouse gas emissions continue, leading to an average warming of almost 5°C by 2100.

A note on how these SSPs relate to the RCPs used in CMIP5: using SSP1-2.6 as an example, this scenario represents a world with socioeconomic trends consistent with SSP1 (which is an environmentally friendly world) combined with a set of policies that ensure that radiative forcing does not exceed 2.6 W/m^2 and global temperature increases do not exceed 2°C (i.e., consistent with RCP2.6). An overview of the CMIP5 and CMIP6 scenarios and the relationship between them is shown in **Figure 9.1** below.

Figure 9.1. Shared Socio-economic Pathways and Radiative Forcing Combinations for 2100



Source: O'Neill et al. (2016)

Using these scenarios as input, GCMs then simulate future changes in the characteristics of earth systems. Due to differences across different models, each individual RCP leads to a range of simulated increases in global mean temperatures, precipitation, storm tracks and intensity, among other variables.

9.2.3. Downscaling and Bias-correcting

While Global Climate Models are run on very sophisticated supercomputers, the large number of computations limits the spatial resolution of the model's output. Furthermore, these models were not designed to simulate regional or local climate. They have fairly coarse spatial resolution, on the order of hundreds of kilometers. This limits the direct application of model outputs for regional and local analyses, meaning that an additional processing step is needed before model outputs are ready to use in risk assessment. This process of inferring high-resolution information from the low-spatial-resolution information provided by GCMs is known as **downscaling**.

Two main categories of downscaling methods exist:

- **Empirical/statistical downscaling** is based on developing statistical relationships that link the large-scale atmospheric variables with local/regional climate variables (IPCC 2013).
- **Dynamical downscaling** uses the output of a GCM as boundary conditions to run a higher resolution regional climate model (Troin et al. 2015)

Statistical downscaling is currently the more commonly used method of the two, largely because it is computationally inexpensive, is able to produce finer scale outputs than dynamical methods and is applicable to parameters that cannot be directly obtained from dynamical downscaling outputs. That said, stationarity (i.e., whether the derived statistical relationships remain valid under altered future climate regimes), remains a concern with these methods. It is crucial to note that downscaling is intended to increase precision (not accuracy) by providing information at regional scales. It does not reduce the inherent uncertainties associated with climate models (as discussed in Section 9.3 below).

In some cases, statistical downscaling can be used to simultaneously bias correct the model output. Output from GCMs exhibit systematic errors (i.e., biases) for a variety of reasons including their limited spatial resolution, simplified physics and thermodynamic processes, numerical schemes or incomplete knowledge of climate system processes. Errors in GCM simulations relative to historical observations are sometimes large and it is important to bias-correct the raw climate model outputs. **Bias correction** uses statistical differences between GCM outputs and observed climate observations to correct raw GCM output, so it is more consistent with the recorded data for a particular timeframe. Statistical downscaling may simultaneously bias-correct GCM output but requires a sufficient record of observed data, meaning downscaled model outputs may not be effectively bias corrected in areas where weather measurements are sparse.

Many different methods have been developed to conduct downscaling (e.g., change factor of mean methods, quantile perturbation methods, weather generators) and bias correction (e.g., delta method, linear scaling, power transformation, empirical quantile mapping, gamma quantile mapping, gamma-pareto quantile mapping), with the different methods each associated with their own limitations and assumptions. There is no single best downscaling and bias correcting method for all applications and regions, meaning that **the choice of an appropriate method for the application in question should be made based on an evaluation of an individual method's strengths and limitations, the information needed as output (e.g., desired spatial and temporal resolutions) and the available resources (data, expertise, computing resources and project time frames).**

9.3. Uncertainties in Climate Projections

When working with climate projections, it is important to be aware of and effectively deal with a range of different uncertainties. There are three main sources of uncertainty in climate projections, each of which is inherently irreducible in the near future:

- **Natural climate variability:** Climate is influenced by important unpredictable natural fluctuations that occur even without any change in greenhouse gas concentrations e.g., El Niño Southern Oscillation. While this type of variability has always been a part of earth's climate system and is included within climate models to the best of the scientific community's ability, there are still other determinants of climate variability that are external to the climate system (e.g., volcanic activity and changes to solar output) which are not effectively captured in simulations of future climate.
- **Model uncertainty:** As introduced in Section 9.2.1 above, diverse climate models exist, and all have been developed drawing on the best available science. These models continue to evolve as our understanding of the climate system improves, and while sophisticated, they remain imperfect tools. No two models are exactly the same, meaning that no two models produce exactly the same output, even when using identical inputs.
- **Uncertainty about future emissions:** The evolution of greenhouse gas emissions is also uncertain and it is not possible at this time to determine exactly what future emissions will be. As discussed in more detail in Section 9.2.2, models are run with different trajectories of emissions in the form of RCPs to explore how future conditions will change given different possible emissions trajectories.

The importance of these three sources of uncertainty varies and should be assessed depending on the specific application. Of relevance is the **scale at which the model output will be applied** (e.g., the whole African continent, a certain country, or a particular project location), the **climate variables of interest and their temporal resolution** (e.g., temperature or precipitation, at seasonal, monthly or daily timesteps), and the **project planning horizon** (e.g., a hydropower project with a lifespan of 50+ years). Sub-Saharan Africa experiences significant natural climate variability, and this variability is often particularly pronounced when looking at local precipitation patterns.

These sources of uncertainty can be managed by:

- **Using a weather generator to capture the stochastic nature of weather at a fine resolution.** Weather generators are computer algorithms that produce long series of synthetic daily weather data, with model parameters conditioned on existing meteorological records to ensure that the characteristics of historical weather emerge in the daily stochastic process (Steinschneider and Brown 2013). This helps address uncertainty due to natural climate variability as weather generators can easily produce many different climate permutations by systematically changing one or more model parameters. This generates new combinations of weather variables that exhibit plausible but not necessarily previously recorded characteristics.
- **Using an ensemble of different climate models, instead of a single climate model.** An ensemble is a collection of comparable datasets that reflect variations within the bounds of one or more sources of uncertainty, and that when averaged can provide a more robust estimate of underlying behavior (IPCC 2013). Using output from an ensemble helps address model uncertainty as using an ensemble demonstrates where different models show agreement and/or discrepancies in future projections.
- **Utilizing multiple different emissions scenarios to show a range of potential futures**, rather than one single emissions scenario.

9.4. Using Climate Projections to Evaluate Project Robustness

As discussed in Section 9.3 above, climate projections derived from climate models are subject to a variety of different uncertainties. This so-called 'cascade of uncertainties' (Schneider 1983) combines uncertainties in future emissions, the response of the carbon cycle and then the climate to increased emissions. Together, these make the process of estimating the likelihood of different climate projections an extremely controversial one. Increasingly, climate change is treated as being **deeply uncertain**, meaning there is no single agreed upon probability distribution that credibly represents the expectation of future outcomes. This means that evaluating projects under diverse possible climate futures is not as simple as computing the mean of performance indicators of interest across the probability distribution of all climate futures. In general, the use of ranges and variability (e.g., 90th and 10th percentiles) for climate variables of interests should be prioritized over highly uncertain, inferred probabilities. (It is worth differentiating here that while future emissions scenarios are often treated as being deeply uncertain, within a single emissions scenario, it is more common to develop probability distributions of future change from the output of large ensembles of climate models). In general, there are two overall classes of approaches when it comes to using climate projections to evaluate project robustness and search for possible adaptation strategies:

- **Top-down approaches** start with a selection of climate projections, which serve as input to other models (e.g., hydrologic models) to then estimate variables of interest used to evaluate project robustness to different future climate conditions (e.g., reliability of water supply under different climate futures).
- **Bottom-up approaches** start by stress testing the project of interest to a wide range of climate conditions (e.g., what happens to project outcomes if precipitation increases by 5 percent? By 10 percent? 15 percent, 20 percent, 25 percent …?), identifying which conditions a project is particularly vulnerable to. The relative chance of these vulnerability conditions actually occurring is then assessed using existing climate model output.

A number of new decision-support approaches have been developed in recent decades that focus specifically on addressing sources of uncertainty that are not straightforward to characterize and for which no accepted probability distributions exist, such as climate change. These approaches are detailed in the technical note on decision-making under climate uncertainty that is included in this Compendium Volume.

9.5. Where to Obtain Climate Projections?

Having introduced various characteristics of climate projections in the preceding sections, where can project teams actually obtain climate projections for a specific project? Typical project assessments will use climate projection information that has already been downscaled and bias-corrected and is therefore ready to use in project analyses. In a minority of cases (for instance a high tier project that is anticipated to be highly climate sensitive), project teams may wish to utilize raw GCM outputs and complete their own bias-correcting. This will depend on the right level of climate expertise and experience being available within the project team, without which this should not be attempted. Or there may be situations where insights can be derived by carefully using non-bias corrected data to explore the degrees of relative change between climate projections and modeled baselines. Possible sources to explore are listed below.

- The World Bank's Climate Change Knowledge Portal has both historical data and future climate simulations from the IPCC's Sixth (and Fifth) Assessment reports available for every country/sub-national unit/drainage basin in the world. All information contained within the Knowledge Portal is consistently produced and thus directly comparable. As well as being free of charge, it is well-suited to project teams who are not used to working with raw, unprocessed output from climate models and it saves time on data searches and data processing. The portal includes an easy-to-use tool for visualizing and downloading data/projections corresponding to more than 40 climate variables.

- National meteorological agencies often provide localized climate information, which can be accessed through the World Meteorological Organization's website.

- Global observations and computer simulations from the IPCC's various assessment reports can be obtained directly from their Data Distribution Centre. Similar information can also be collected from the KNMI/World Meteorological Organization Climate Explorer. These sources provide raw, unprocessed model outputs, which require significant time and expertise to process and bias correct, before they can be utilized in project analyses.

- Weather observations and long-range projections for Africa are available at the African Regional Climate Center website. Climate information services, for instance Eastern Africa's Climate Prediction and Applications Centre (an institution of the Intergovernmental Authority on Development), are also being developed under the United Nations Economic Commission for Africa's African Climate Policy Centre.

- Africa-oriented climate and weather data, along with training material, is also available from the University of Cape Town's Climate Systems Research Group.
- The United States National Aeronautics and Space Administration's Earth Exchange Global Daily Downscaled Projections dataset is comprised of downscaled climate scenarios for the globe that are derived from GCM runs conducted under CMIP5.
- Regional sea-level observations and projections can be obtained from the United States' National Aeronautics and Space Administration's Sea-Level Change Tools for the IPCC's Sixth Assessment Report.
- The Consultative Group for International Agricultural Research's Climate data portal provides global and regional future high-resolution climate datasets that serve as a basis for assessing the climate change impacts and adaptation in a variety of fields including biodiversity, agricultural and livestock production, and ecosystem services and hydrology.
- The Inter-Sectoral Impact Model Intercomparison Project focuses on climate impact models and provides output from simulation model experiments that convert GCM output to predictions of flow, water quality, ecological responses, disease risks, etc.
- Climate Analytics' Climate Impact Explorer is a data portal that provides climate impact projections for select indicators based on a range of global climate scenarios from the Inter-Sectoral Impact Model Intercomparison Project. The dataset includes sub-country level impacts for the following indicators: agricultural yields for maize, rice, soy, and wheat; soil moisture; economic damages from tropical cyclones, river flooding, and heatwaves; extreme event impacts on population and land; crop failures; heatwaves; wildfires; river floods; river flood depths and discharge levels.

Whichever source of climate projections is selected, it is important that end-users of the projection understand how to appropriately interpret downscaled climate projections given that the method used to obtain a downscaled climate projection has implications for interpreting the resulting climate scenario and any subsequent analytical results.

9.6. How to Select Climate Information for Use in Project Evaluation?

Given the multitude of GCMs, emissions scenarios and climate projections that exist, how does a project team choose which to consider for evaluation of their project's climate vulnerability and robustness? Some factors to consider are summarized below:

- **It is recommended to draw from the climate projections produced for the IPCC's fifth or sixth assessment reports, as presented in the CMIP5 or CMIP6 collections.** These are the most recent sets of climate projections available and thus embody the best scientific understanding to date.
- **An analysis should not 'mix' output derived from CMIP5 or CMIP6 collections**, selecting one or the other, as the two collections are not directly comparable.
- **Project managers are strongly encouraged to explore variability through the use of multiple climate projections, as many as project resources will allow**. Considering a range of possible future climates rather than one single, best guess future enables identification of actions that perform acceptably across a broad set of potential conditions, especially given that there is no single "best" downscaled dataset for all applications across regions or even within a single region. When it comes to choosing individual projections, recent World Bank guidance (2022) recommends considering **an optimistic and a pessimistic scenario of greenhouse gas concentrations** (for example, ensemble means for SSP1-1.9 and SSP3-7.0 respectively) as driven by global greenhouse gas emissions trajectories and mitigation policies, as well as **several scenarios that represent a "dry and hot" and a "wet and warm" future**. The first set of scenarios allows one to assess the impact of uncertain global mitigation efforts on project outcomes, whereas the second set helps assess local climate risks and overall uncertainty in climate model outputs on project outcomes.
- While more rather than fewer scenarios are desirable, analyzing results from **every** possible combination of climate model and emissions scenario is likely not possible given time, budget and capacity constraints. When selecting a subset of climate projections that maximize the range of projections to the extent practical, **many analysts consider a GCM's ability to reproduce relevant climatic processes (such as El Nino Southern Oscillation or sea surface temperatures) for the region of interest and select those GCMs that are better than others in replicating these key processes for particular regions.** This approach is preferable over

selecting those GCMs that are best at reproducing historic 20th century climatic conditions for the region of interest (e.g., multi-year averages in precipitation and temperature). This latter approach favors models that have been tuned to perform well when compared to historic data, but such historical tuning offers little guarantee of a model's ability to adequately simulate future conditions.

- **For analyses focused on projected changes over the next three to four decades, the choice of emissions scenarios to consider is less important than the choice of GCMs** given that the differences in cumulative emissions across different emissions scenarios do not begin to generate significant differences in projected climate until mid-century. After about 2050, cumulative emissions from different scenarios and their respective influences on climate begin to diverge significantly, meaning that **for analyses out to 2100, emissions scenario selection becomes a more important consideration.** As such, it may be helpful to break down the analysis for long-lived projects into different eras, for instance one from the present to mid-century and one from mid-century to the end of the century.

- Furthermore, **it is recommended to use a multi-model ensemble rather than projections from a single climate model**. The multi-model ensemble mean provides information about the most likely future outcome, and differences over the ensemble of models provide information about the uncertainty.

- **For many infrastructure projects, the occurrence of extremes is important for decision making and one can select models that are associated with more extreme climate projections.** In these cases, using model ensembles could be misleading as the average value of an ensemble presents a 'smoothed' output that may hide important extreme cases. Project teams may wish to use data from individual model runs in these cases, sampling models runs from the full climate model spread in order to explore the range of potential outcomes.

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TECHNICAL NOTE:

A Primer on Economic Modeling

The attached Compendium Volume and six individual guidance notes are all built on a step-by-step framework for evaluating and enhancing the climate resilience of development projects in Sub-Saharan Africa. The second and third steps of this framework involve assessing the economic performance of a particular investment project. Economic analysis assesses the costs and benefits of implementing a project, program, or policy from a societal welfare perspective. It is used to determine if resources are being used effectively (resulting in a net gain in welfare) and efficiently. The costs and benefits of a course of action are evaluated, and the best course of action is selected.

There are several different types of economic analysis. Two of the most common are:

- **Cost-benefit analysis** measures the benefits and costs of a decision or action and determines a monetary value of costs as well as benefits. The costs are subtracted from the benefits and a net benefit is determined. Other measures derived from a cost-benefit analysis include net present value, benefit-cost ratio, and return on investment.
- **Cost-effectiveness analysis** compares the costs of different activities ending in a specific outcome. It is used to determine what activity or method is the most cost-effective in producing the desired outcome e.g. the cost of producing a unit of potable water.

This primer focuses on cost-benefit analysis, which is the primary tool used in economic decision-making. Decision-making under uncertainty, which typically relies on the results of an economic evaluation, is covered in the technical note on decision-making under climate uncertainty, included in this Compendium Volume.

This technical note starts with a brief introduction to cost-benefit analysis (Section 10.1). It then presents all the necessary elements to conduct a cost-benefit analysis (Section 10.2). Next, the note focuses on the valuation of costs and benefits (Section 10.3). Finally, it covers the valuation of additional outcomes of the project (Section 10.4).

10.1. Introduction to Cost-Benefit Analysis

One of the basic tools of economics is cost-benefit analysis, used in project/program appraisal and the evaluation of policy decisions. It is essentially a decision support tool that evaluates the range of costs and benefits surrounding a decision (Pearce 1998). **Cost-benefit analysis offers an accounting framework that prescribes the types of costs and benefits to consider, how to measure them, and how to aggregate them.** The tool also includes ways to deal with uncertainties and other issues. It can be applied at a project level right up to a policy analysis level and can be applied from either a financial perspective (i.e., costs and benefits to the investor) or an economic perspective (i.e., costs and benefits to society as a whole). Given that the focus of the accompanying guidance notes in this Compendium Volume is primarily on the **project level**, the remainder of this technical note refers only to project-level decisions, but the principles described here do apply more broadly. Thus economic analysis includes the welfare implications of any impacts on the environment.

Economic cost-benefit analysis differs from financial cost-benefit analysis in that it takes the perspective of society, whereas the latter is only from the private investor's perspective. It has its roots in welfare economics theory, and as such, attempts to include all of the costs and benefits that might accrue to society over the time period under consideration. These include external costs and benefits that are not compensated by the developer. The main challenges in undertaking cost-benefit analysis include accounting for all costs and benefits, including changes in the environment and intangible values, as well as removing price distortions to provide an accurate assessment of welfare change.

When properly conducted, cost-benefit analysis assesses the economic efficiency of a proposed project and allows the identification of *potential* Pareto improvements. A project results in a Pareto improvement if it yields benefits to at least one person and nobody is made worse off. In reality, every project is likely to disadvantage some segment of society, thus economists generally accept the criterion of a potential Pareto improvement. A project may constitute a potential Pareto improvement if those who benefit gain more than the losses of those who were made worse off. If this holds, then those who gain could theoretically compensate the losers for their losses, and everyone would still be better off. Indeed, if compensation were to occur, the potential Pareto improvement would become an actual Pareto improvement. However, this "Pareto criterion", an ideal win-win scenario, is difficult to achieve in reality. In most situations involving choices, there will be both winners and losers.

Since the Pareto criterion can usually not be met, acceptability is defined in terms of the Hicks-Kaldor criterion that winners should be able to adequately compensate losers, i.e., that there should be a net increase in utility (Graaf 1968). What this means in practice is that **the benefits must exceed the costs.** Although the Hicks-Kaldor compensation criterion provides a simple way to address the problems of winners and losers, it assumes that all parties value a unit of income equally. If this is unacceptable, then distributional issues have to be considered by introducing income weights, normally assessed through a sensitivity analysis (Pearce 1983, p59-66).

10.2. Conducting a Cost-Benefit Analysis

The following steps are taken when conducting a cost-benefit analysis:

1) **Define the project alternatives**: This step involves identifying the main elements of each project alternative. At its simplest, this could be a single project versus a do-nothing scenario. The project objectives, lifespan, beneficiaries, and likely impacts are clearly described.

2) **Decide on the time frame**. The time frame of the analysis is decided not only based on the project lifespan but also on the duration of any extremal impacts of the project, e.g., on the environment.

3) **Identify relevant costs and benefits**. In this step, one then lists all of the costs and benefits of the project, and who they accrue to. This list is then laid out in a spreadsheet, in which costs and benefits occurring in each year of the analysis are estimated.

4) **Convert to economic prices (shadow prices).**[9] At this point, the analyst should adjust any market-based values that might be distorted (e.g., as a result of government policies such as minimum wage or fixed agricultural prices). These prices are corrected to reflect society's marginal willingness to pay[10] or the marginal opportunity cost[11] of resources that would be found in a competitive market.

5) **Incorporate environmental values**. In this step, estimates of the non-market welfare impacts[12] of changes in environmental conditions are estimated. The methods for doing this are by now fairly well established but add considerable effort and cost to a cost-benefit study. However, omitting this step can result in distorted decision-making that is not optimal for society.

6) **Decide on the discount rate.** Discounting is used to reduce a stream of values over time to a single figure that represents the amount of capital that one would have to have now to generate those benefits over time. The choice of discount rate can have an important bearing on the results and reflects a decision on the importance of future values in the analysis. For this reason,

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[9] A **shadow price** is the estimated price that would be seen in a competitive market in which there are no government influences such as price thresholds or subsidies. For example, the price of labor based on what people would be willing to work for, versus the minimum wage.

[10] Typically, the more you have of something, the less you are willing to pay for an additional unit of it. **Marginal willingness to pay** is how much an individual will pay to obtain one more of something.

[11] Opportunity costs quantify the fact that resources used in one project can no longer be used for other alternative purposes. For instance, to complete an infrastructure project, workers must be hired. As the size of the project increases, the number of workers needed increases. The opportunity cost of this resource rise as more and more are sought. The **marginal opportunity cost** is a measure of the opportunity cost for the production of an extra unit of something.

[12] **Non-market welfare impacts** are changes to societal welfare that are not reflected in transactions in traditional markets. For instance, an infrastructure project may change the livability of an area due to added noise, obstruction of views, etc.

it is a controversial topic. However, for economic analysis, analysts typically use a social discount rate, which is relatively low, recognizing the importance of values in the future as well as the present. This is a key difference from financial analysis, which takes a shorter-term perspective.

7) **Assess the relative worth of the project alternatives**. Finally, metrics such as net present value and cost-benefit ratio are calculated and compared to evaluate the project alternatives.

10.2.1. Costs and Benefits

Project costs include the acquisition of land (which may also involve relocation costs), physical structures, and operating costs over time. For example, a restoration project may involve up-front tree planting costs, followed by monitoring and upkeep until the trees are established. Benefits will include the main revenue streams associated with the project, such as tourism income, or irrigation project outputs. The analysis should also include any changes in welfare associated with negative or positive environmental changes that change the supply of ecosystem services. These include changes in biodiversity. For example, if the project secures a habitat for an endangered species, then there should be an estimate of the public's willingness to pay for this. Approaches used to value environmental changes are described below. An example of the costs and benefits considered in an ecosystem conservation project is shown in **Table 10.1** below.

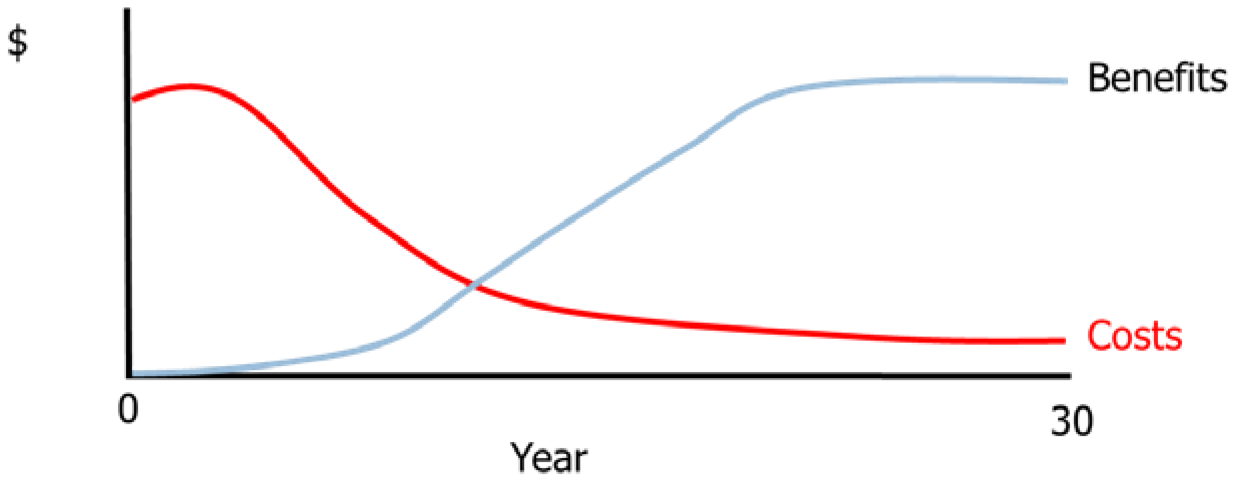
Table 10.1. **Example of the Layout of Costs and Benefits Considered in an Ecosystem Conservation Project**

Year		1	2	3	4	5	..
Costs	Infrastructure	100	100	0	0	0	
	Relocation	55	55	0	0	0	
	Operating	0	0	5	5	5	
	Subtotal	155	155	5	5	5	
Benefits	Tourism fees	0	0	3	8	15	
	Regulating services	0	0	15	15	15	
	Subtotal	0	0	18	23	30	
Net		-155	-155	15	18	25	

10.2.2. Time and Discounting

Whether the investment is in water supply infrastructure, a conservation project, or an agricultural project, costs tend to be higher upfront, while benefits only accrue some time after the project has been started (see **Figure 10.1**). Thus the choice of time frame can have a strong bearing on the results of the analysis. In the example illustrated, a time frame of 5 years would give quite a different result than a time frame of 10 years. For public investments, social planners tend to think in a somewhat longer time horizon, in the region of 20 to 30 years at least. This is the typical time frame for an economic analysis, and it is longer than a private investor might consider. Nevertheless, 20-30 years would be considered a very short time frame for an ecological restoration project, since some ecosystems can take decades to reach maturity. It might also be argued that future generations need to be taken into consideration.

Figure 10.1. **Illustration of a Typical Profile of Project Costs and Benefits Over Time**



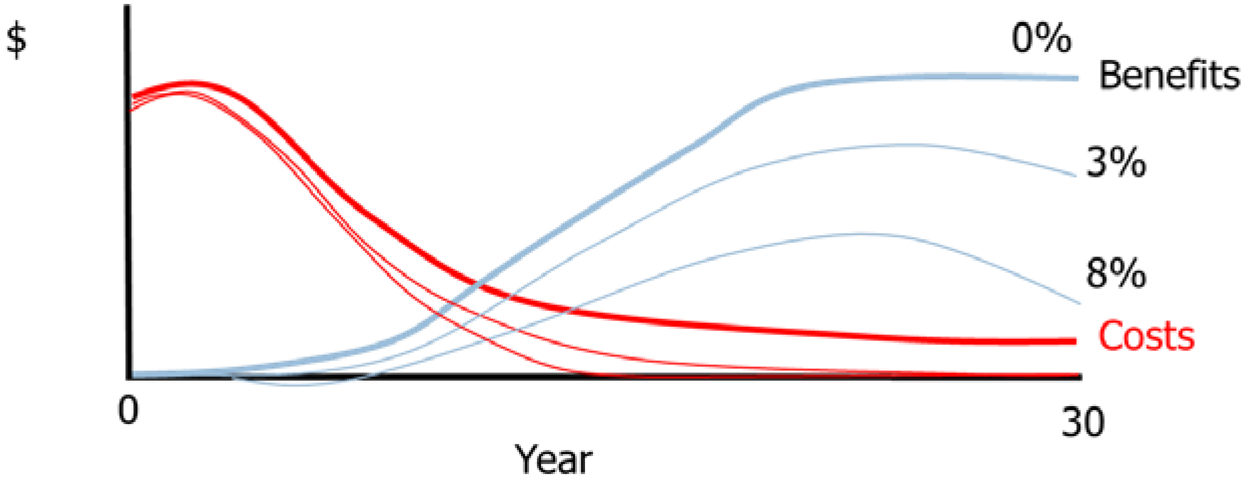
In cost-benefit analysis, the stream of costs and benefits are summed over the time period of the analysis, but with future values discounted. Discounting effectively down weights values that are further in the future relative to values that are closer to the present. The discounted value of a future cost or benefit is its value in present day money.

To understand discounting, it is useful to begin with revising the calculation of compound interest. For example, an investor may have $100 to invest, and the best investment opportunity gives 5 percent real interest rate (real means over and above inflation). Inflation does not need to be considered in the analysis. The wise investor will leave the money invested to earn compound interest. After a year the invested capital is going to grow to $105.00. The total value of the investment after a period t years (V_t) can be calculated as: $V_t=V_0(1+r)^t$ where V_0 is the initial investment, and r is the real rate of interest as a fraction (0.05 in this case).

Now consider how the value of money changes over time. Given that 5 percent is the best interest rate available, the investor would be indifferent between receiving \$163 in 10 years' time or \$100 now. If she gets \$100 now, she will invest it and have \$163 in year 10. She will be equally happy to receive a signed agreement that she will get \$163 in ten years' time. Based on the equation, we can also deduce that she will be indifferent between receiving \$100 now and \$122 in year four, and so on. In fact, \$100 is the present value of \$163 in year 10, and the present value of \$122 in year four. Thus the calculation of present value is the inverse of the compound interest calculation: $V_0=V_t/(1+r)^t$.

The present value of a future benefit is the amount that would need to be invested today to obtain that value in the specified future year. However, when working from the future to the present, the name of r changes from the interest rate to the discount rate, because the result is getting smaller. Note that if t gets bigger, in other words the value is further in the future, then the denominator will have a larger value. That means for numbers further in the future, the value gets divided by an increasingly large number, so it will be more greatly reduced. That makes logical sense, because to get to \$100 in year 100, it would only be necessary to invest a very small amount of money, compared to if we were trying to get to \$100 in 5 years time. Larger discount rates also have a stronger effect on value than smaller discount rates. The effect of different discount rates on value over time is illustrated in **Figure 10.2**.

Figure 10.2. **Illustration of the Effect of Discount Rates on Future Flows**



The choice of discount rate in cost-benefit analysis is controversial (Nyborg 2012). High discount rates reduce the weight of benefits accruing in the distant future relative to present costs. This means that projects that involve up-front costs to generate benefits some time in the future have to have relatively high benefits in order to be viable. This raises concerns about intergenerational equity in economic analysis and has led to a large body of research on appropriate discount rates. For example, cost-benefit analysis of decisions such as reducing carbon emissions to mitigate the potential damage due to climate change suggest that these kinds of projects are inefficient under almost any reasonable discount rate. This highlights the importance of considering intergenerational equity, rather than intra-generational efficiency, to take the rights of future generations into account. While some advocate a zero or even negative rate of discount in such analysis due to uncertainty in economic growth (Fleurbaey and Zuber 2013), in general, it is argued that a small positive social rate of time preference is justified, taking into account that economic growth will occur and policies to reduce current consumption in favor of future consumption essentially transfer wealth from the poorer current generation to the wealthier future generation.

10.2.3. Evaluation of Alternatives

A project would be considered viable if the net present value of its costs and benefits is greater than zero. A project might also be evaluated in terms of its potential rate of return. If the rate of return is higher than that of a competing investment, then it is attractive. The rate of return is the discount rate that would generate a net present value of zero. Thus the higher this rate, the better.

There are three main measures used in cost-benefit analysis:

- Net present value
- Internal rate of return
- Benefit to cost ratio, or return on investment

For a project to be acceptable, its net present value should be positive (greater than zero). In a comparison of alternatives, the project with the greatest net present value would be most favored. The net present value is the sum of the discounted benefits minus the sum of discounted costs. It can also be calculated as the sum of discounted benefits (B) minus discounted costs (C) in each time period (δ is the discount rate as a fraction):

$$\Sigma(B\text{-}C)/(1+\delta)^t$$

The internal rate of return is the discount rate at which the net present value becomes zero. This provides an indication of how the project compares with competing investment opportunities. Many lending institutions will only consider projects whose internal rate of return exceeds a certain “hurdle rate”, such as 10 percent.

The benefit to cost ratio is the present value of benefits divided by the present value of costs:

$$\Sigma(B/(1+\delta)^t): \Sigma(C/(1+\delta)^t)$$

This is also sometimes referred to as the return on investment. For example, it could be expressed as “for every dollar invested, the project yields another 50c”.

10.2.4. Dealing with Risk and Uncertainty

Economic analysis is fraught with uncertainty. It involves estimating costs and benefits which can be challenging in certain cases, and it also involves projection into the future. Ideally, analysts need to consider the probability of a positive outcome, or of the order of preference remaining stable, on the basis of the range of possible outcomes. This can involve a simple sensitivity analysis, where results are compared under a range of assumptions and discount rates, or it could involve a more sophisticated statistical analysis, such as a Monte Carlo analysis. Methods for addressing uncertainty, particularly climate uncertainties, are presented in the technical note on decision-making under climate uncertainty contained in this Compendium Volume.

No tool is perfect, and many criticisms are leveraged at cost-benefit analysis. These mostly pertain to the deficiencies in techniques to measure diverse benefits and costs in monetary terms, and the failure to deal adequately with equity and environmental concerns. It often cannot measure the broader aspects of overall project desirability such as sustainability; altruism; ethics; public participation in the decision process; and other social values. The more that the trade-offs can be reduced to common monetary terms, the more likely they are to be accounted for in decision-making. This is the original basis for the development of methods for the monetary valuation of environmental changes.

10.3. Valuing Costs and Benefits

While private investors tend to be interested in the financial returns, decision-makers are usually interested in the effect of a project on people's wellbeing. This analysis of development options typically takes the form of an economic analysis, rather than a financial analysis. This means that non-transactional value is also taken into account: economic analysis takes the view of the social (government) planner, and ideally takes all changes in welfare into account, including changes in welfare resulting from positive or negative externalities of the interventions, such as changes in environmental quality and ecosystem services, and including impacts on future generations.

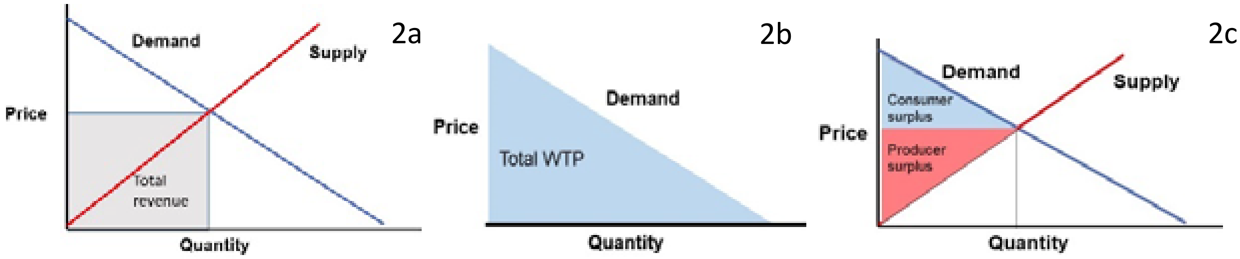
All of these impacts need to be taken into consideration in economic cost-benefit analysis. In addition, decision-makers may also want to know the impact that the interventions have on Gross Domestic Product since this is a familiar indicator of economic performance. This section covers the valuation of direct costs and benefits, while the valuation of externalities is covered in Section 10.4 below.

10.3.1. Welfare Value

Economic value can be thought of as the amount that people are willing to give up to attain or retain a good, service, or a certain state of the world. This is measured as their "willingness to pay". Total willingness to pay for something consists of what people actually pay for it, plus the additional amount that they would have been willing to pay but didn't have to, which is called the "consumer surplus". One can then estimate the net economic value by subtracting what the producers had to pay to produce it. Thus, "net economic value", which is the measure of welfare to be used in the analysis, is the sum of producer surplus (the net benefit to producers) and consumer surplus (the net benefit to consumers).

Consumer and producer surplus arise from the characteristics of demand and supply, and their interaction in markets, which determines the equilibrium prices and quantities of goods and services that are traded (see **Figure 10.3**). The amounts of goods and services demanded typically decrease in relation to increasing price, as consumers turn to substitutes. Supply typically increases with increasing price, as the prospect of making a profit increases. The quantities demanded for any particular price are dependent on a whole suite of factors, such as people's preferences (often influenced by information and marketing), income, and prices of alternatives, while the quantities supplied depend on the costs of production. Since all of these factors fluctuate over time, it is worth bearing in mind that values are seldom constant, even after correcting for inflation.

Figure 10.3. Illustration of Consumer and Producer Surplus



Notes: (a) Prices and quantities traded are determined by the interaction of demand and supply; (b) the area under the demand curve is the total willingness to pay; (c) net economic value is the sum of consumer and producer surplus.

In a welfare economic analysis, the impact of an investment is estimated in terms of changes in welfare, based on estimated changes in demand and/or supply.

10.3.2. Gross Domestic Product and Gross Value Added

For large-scale interventions, decision-makers may be interested in evaluating project outcomes in terms of their contribution to the country's Gross Domestic Product. This is usually one of the elements of "economic impact assessment" (along with impacts on employment), the results of which may form an input into a cost-benefit analysis. On its own, this is not strictly the correct basis on which to make decisions, since Gross Domestic Product is not a measure of welfare but is a much simpler measure that only takes exchange values (value of actual transactions) into account.

Gross Domestic Product is the total value of goods produced and services provided in a country during one year and is measured using standard techniques as set out in the International System of National Accounting. In theory, it is assumed that this total value, which is called the National Output, is equal to the National Expenditure (the sum of what everyone spent) and is also equal to the National Income (the sum of everyone's incomes). For this reason, there are three different ways of calculating Gross Domestic Product. Most significant here is that an estimate of the country's production is also an estimate of income, so Gross Domestic Product per capita is an estimate of average income. The word "domestic" means everything or everyone in the country. Other indicators such as Gross National Product measure production and income of the country's nationals, wherever they live in the world.

Gross value added measures the contribution made to an economy by one individual producer, industry, sector, or region, and is used when describing impacts at these levels. It is the value of production minus the intermediate costs of production. Net value added is obtained by deducting consumption of fixed capital (or depreciation charges) from gross value added. Net value added therefore equals gross wages, pre-tax profits net of depreciation, and indirect taxes less subsidies.

It is effectively a measure of the direct income generated by all players including the government. Gross value added is used for measuring gross regional domestic product and other measures of the output of entities smaller than a whole economy. Its relationship to Gross Domestic Product is:

$$\text{Gross Value Added} = \text{Gross Domestic Product} + \text{Subsidies} - \text{Indirect taxes}$$

Economic impacts are commonly described in terms of direct, indirect, and induced impacts on outputs (revenues), value added, and employment. The indirect impact on gross value added is the gross value added that is generated in other sectors as a result of intermediate (business to business) expenditures. For example, tourism expenditure on accommodation would lead to income being generated in businesses supplying laundry services. Induced impact is from employees spending their wages. The total value added impact estimates the change in gross regional product, which is similar to the nation's Gross Domestic Product and represents the total size of the local economy. This impact estimates the increase in local employee wages plus local business profits.

In certain situations, a natural resource may not be worth much in monetary terms but may be critically important to the survival of poorer households. Measures in these instances need to capture the contribution of natural resources to people's livelihoods, or the way that they sustain themselves, maintain sufficient income to meet basic needs and cope with external shocks such as droughts. Assessing the contribution to livelihoods involves an assessment of the degree to which low-income households depend on the environment for their income and general well-being, and this requires social survey methods.

10.4. Valuing the Outcomes of Infrastructure or Ecosystem Investments

Economic analysis of projects such as water supply projects (see the accompanying water guidance note), agricultural projects (see the accompanying agriculture guidance note), or projects to enhance ecosystem services (see the accompanying ecosystems guidance note) necessitates the consideration of a wide range of costs and benefits. Such projects will deliver a range of benefits that would be felt over the short to medium term, but will also contribute to longer-term economic growth. Models are best able to deal with the short to medium-term impacts and help to prioritize investments, while the longer-term impacts are the expected long-term goal.

For example, the main short to medium-term benefits that are provided by water security interventions include:

- **Improved public health** as a result of better sanitation and reduced water pollution;
- **Increased productivity** through reduced flood risk and/or reliable supply of water to households and businesses;
- **Reduced cost of water supply** through reduced pollution of raw water; and
- **Improved supply of ecosystem services** due to securing or restoring the health of aquatic ecosystems, including the provision of natural resources (e.g., fisheries), cultural services (e.g., recreation), and regulating services (e.g., water purification, flood attenuation).

These benefits are inter-related, and to some extent, synergistic. For example, interventions such as sanitation services that divert sewage away from the environment, coupled with interventions that restore the functionality of downstream wetlands will both contribute towards the improvement of raw water quality. Indeed, in this example, the first type of intervention is necessary for the second type of intervention to add value. Thus, the context of the wetland restoration intervention

> Models are best able to deal with the short to medium-term impacts and help to prioritize investments, while the longer-term impacts are the expected long-term goal.

(whether it is being implemented in conjunction with a suite of complementary interventions or not) makes an important difference to the value of the intervention. For this reason, the construction of portfolios involving different combinations of interventions, or grouped in different spatial ways, may be a critically important part of the analysis. In general, **we expect to see much greater benefits from following a treatment train approach that is focused on a single catchment area, rather than implementing a range of single projects in different catchments with a view of spreading the benefits among more stakeholders.** The former approach is also likely to lead to tangible outcomes that will help to leverage similar suites of investment projects in new catchment areas.

10.4.1. Valuing Public Health Benefits

There are many examples of the valuation of public health benefits associated with infrastructure or ecosystem conservation projects. The most common approach is to establish household willingness to pay for the proposed improvements. This is done using stated preference methods such as contingent valuation or choice experiments, where willingness to pay is elicited in questionnaire surveys, using best practice methods. Alternatively, one can estimate the cost savings in terms of reduction in rates of illness and working time losses, based on empirical studies. These studies involve econometric analysis of data on illness and health costs that can be linked to household access to water and sanitation. If such data exist, this is a more robust technique for estimation.

10.4.2. Valuing Risk Reduction and Productivity Gains

Interventions that result in benefits such as improved water supply and flood amelioration can have major cost savings, through avoided damages, avoided costs of manually getting water, or avoided business interruptions. All of this leads to a more productive society. In some instances, it might be possible to estimate the cost savings, such as through econometric analysis of long-term production in relation to flood events, etc., were such data readily available. However, this is generally difficult, and most analysts rely on people's stated willingness to pay for such improvements. In rural situations, water supply projects are sometimes valued in terms of the time and costs saved by households in fetching and preparing water for consumption.

Areas predisposed to flooding have expanded as a result of increased hardened, impermeable surface cover, enhancing runoff during rainfall events. Across the globe, and especially in African cities, the number of people living in flood risk areas has increased. Estimating the economic value of reducing flooding requires the modeling of floods with and without management interventions, and estimation of damages (avoided cost methods) based on the value and fragility of the structures in the flood path. The quality and precision of models depend on the accuracy of digital elevation data (lidar data), and the availability of long-term monitoring data of rainfall and river flows. Therefore, this type of approach is only feasible where sufficient data are available.

10.4.3. Valuing Cost Savings

Many investment projects are designed to reduce costs being incurred by the public or avoid future costs. For example, projects that lead to a reduction in pollution of urban or agricultural runoff into water bodies from which drinking water is sourced, will result in decreased costs of water treatment in the shorter term. In the longer term, they result in reducing the need to invest in infrastructure improvements or relocation. The shorter-term impacts can be estimated on the basis of models of the relationship between landscape outputs of pollutants and raw water quality (biophysical models) coupled with models of the relationship between raw water quality and water treatment costs (econometric models). The latter models require reliable long-term data series, which are often absent, unreliable, or difficult to obtain, especially in Sub-Saharan Africa. In these situations, and especially for this type of application, it is possible to use models that have been devised from data from similar situations in other locations. This approach is called "benefits transfer". **Textbox 10.1** provides an example of benefits transfer used to estimate this value in Kampala.

Textbox 10.1: Benefits Transfer in Kampala

Increasing eutrophication and subsequent algal blooms in the waters of Murchison Bay near Kampala, Uganda has led to significant treatment costs in treating water that is extracted here, to a potable level. Restoring natural water purification services was explored as a means of reducing these costs.

Incomplete and unusable local datasets resulted in estimates being derived through benefit transfer techniques based on models from other areas. The study concluded that rehabilitation (excluding a reduction in sludge removal costs) can potentially generate savings of $845,000 per year (Turpie *et al.* 2015).

When determining an individual or household's willingness to pay for a service, the type of use, the amount of a service the user already has, and the amount of money the user has, all need to be examined. Whilst the overall risk levels (for individuals) of flood disasters are quite low, water-related health risks are greater, with 50 times more deaths globally. This is especially true for children under the age of 5 years living in low-income countries. While water-related health risks have started to decrease on a global scale, they are still peaking in Africa. Household willingness to pay for interventions that reduce these risks is generally quite low, and poor households especially lack the financial resources to intervene and adjust their risk profiles. They also face multiple different risks and shocks. Thus, making choices is difficult without a complete understanding of the nature and extent of these different shocks. Furthermore, because of the commonly-held belief that it is the government's responsibility to pay for the development of water provisioning and risk reduction services, it is not always easy to elicit household willingness to pay.

10.4.4. Valuing Impacts on Ecosystems

Many, if not most, projects have an impact on ecosystems. These may be positive impacts, such as restoration projects. Alternatively, projects may lead to the degradation of ecosystems, for example, due to increased abstraction from freshwater systems to increase urban or agricultural water supply. Changes to the health of aquatic ecosystems lead to changes in the supply of ecosystem services, which can have both financial and welfare implications. Understanding these impacts requires understanding the ecosystem services supplied, how these are affected by the proposed development, and how to value that change.

The concept of ecosystem services stems from the perception of ecosystems as natural capital which contributes to economic production. Ecosystems can be seen to provide a range of 'goods' and 'services' and have 'attributes' that generate value and contribute to human welfare (Barbier 2011 and Barbier 1994). Goods include harvested resources, such as fish. Services are processes that contribute to economic production or save costs, such as water purification and attributes related to the structure and organization of biodiversity, such as beauty, rarity, or diversity, and generate less tangible values such as spiritual, educational, cultural, and recreational value. Goods, services, and attributes are often referred to collectively as 'ecosystem services', or 'ecosystem goods and services'. More recently, the Millennium Ecosystem Assessment (2003) defined ecosystem services as "the benefits people obtain from ecosystems" and categorized the services obtained from ecosystems into 'provisioning services; such as food and water, '**regulating services**' such as flood and disease control, '**cultural services**' such as spiritual, recreational, and cultural benefits and '**supporting services**', such as nutrient cycling, which maintain conditions for life on Earth. The first three align well with the definitions of goods, services, and attributes described above. Only changes in final goods and services should be valued, in order to avoid double counting.

The values produced by ecosystem services are also categorized into different types. The Total Economic Value of an ecosystem comprises direct use, indirect, option, and non-use values. Direct use values may be generated through the consumptive or non-consumptive use of resources. Indirect use values are values generated by outputs from ecosystems that form inputs into production by other sectors of the economy, or that contribute to net economic outputs elsewhere in the economy by saving on costs. These outputs are derived from ecosystem functioning such as water purification and nursery functions. Non-use values include the value of having the option to use the resources in the future (option value), and the value of knowing that their biodiversity is protected (existence value). Although far less tangible than the above values, non-use values are reflected in society's willingness to pay to conserve these resources, sometimes expressed in the form of donations. The relationships between the concepts of ecosystem services and values are shown in **Table 10.2.**

Table 10.2. Broad Relationships Between the Concepts of Ecosystem Services and Values

	Ecosystem Services		
Ecological Descriptors	**Barbier 1994, 2011**	**Millennium Ecosystem Assessment 2005**	**Total Economic Value**
Natural resource stocks	Goods	Provisioning services	Consumptive use value
Ecological functioning	Services	Regulating & supporting services	Indirect use value
Ecosystem structure and organization	Attributes	Cultural services	Non-consumptive use value
			Non-use value

For ecosystem goods and services, where there are clear and appropriately functioning markets (such as for food and timber), market information can be used to estimate value. For non-market values, there are a variety of different techniques that can be used (see **Table 10.3**), with each method having advantages and disadvantages over other methods.

Table 10.3. Valuation Measures and the Types of Values that they are Used to Measure

Methods		**Direct use values**	**Indirect use values**	**Option & non-use values**
Market value methods	Production function	x	x	
	Replacement cost		x	
	Damage costs avoided		x	
Revealed preference methods	Travel cost	x		
	Hedonic pricing	x		
	Avoidance expenditure		x	
Stated preference methods	Contingent valuation	x		x
	Conjoin/choice experiments	x		x

Notes: Taken from Turpie (2009). This table shows which measures might effectively be used in eliciting which value sets.

Common approaches look at related markets in estimating values. Production and cost functions can be used to reveal the marginal benefits of environmental inputs such as relative water quality and associated treatment costs. Alternatively, estimates can be generated based on what it would cost to replace a specified ecosystem service, or the costs incurred to avoid losing it. These are known as Replacement Costs or Avoided Cost Methods.

Revealed Preference Methods use actual consumer behavior to estimate values. For example, property premiums paid to live near natural amenities provide a clear measure, or indication, of the value of those amenities when contrasted with sites without such amenities. Travel expenditure or costs spent on traveling to a recreational or conservation area provide a measure of the value of that area.

Directly asking people what they would be prepared to pay, or to be compensated, for a change in service levels, are known as Stated Preference Methods, and are a further method for eliciting value. Here people are either asked directly what, or how much, they would be willing to pay for a specified change in the delivery of a service, or are presented with an array of options with different prices or cost options, and are required to choose between these. Typically, the more intangible a value or type of value is, the fewer approaches and methods there are for deriving and estimating values. This is evident in **Table 10.3** where only two methods are noted for options and non-use values.

The Benefit Transfer Method is a last resort option that can be applied in estimating any type of value. This approach simply draws on the results or values derived from other studies, undertaken in similar areas or environments, and applies these to specific case study areas for specific values. Whilst this method is generally considered unreliable, the increase in the number of valuation studies being conducted is increasing the spatial variability of available data sets and derived values, which will in turn lead to increased accuracy of value estimates established through benefit transfer (Turpie 2018).

Textbox 10.2: Benefits Transfer in Ecosystem Services

Turpie *et al.* (2015) investigated the potential value of cleaning up the Nakivubo wetland and creating the "Nakivubo Wetland Park" in Kampala, Uganda. In estimating the potential recreational values of this park, a total of 644 households were surveyed to understand potential use, visitation, and willingness to pay for its establishment.

Based on this contingent valuation method, the study found that recreational benefits associated with the park were estimated to be between $15-29 million per year.

For example, there are multiple ways of determining the "experiential use value" of ecosystems associated with the active or passive use of ecosystems for recreation, spiritual fulfillment, appreciation of aesthetic qualities, etc. These values manifest in terms of property value premiums, local recreational activities, and tourism. Thus this value might be estimated as the sum of property value premiums estimated using the hedonic pricing method, recreational values estimated using the travel cost method or revealed preference methods (see **Textbox 10.2**), and tourism value estimated using market information. The "non-use values" of the same system would be added to this, estimated on the basis of a revealed preference study such as contingent valuation.

The economic valuation approaches presented here all have limitations and may be prone to bias. Debate continues as to whether it is useful to produce imprecise estimates of value or rather to have none. There are risks that estimated values could undervalue ecosystem services and thereby lead to ecosystem loss. Others argue that it is better to draw attention to ecosystem values than to ignore these. There are, however, clear challenges to providing monetary valuations for some ecosystem service benefits, such as the role they play as well-being safety nets in times of crisis where individuals extract resources from nature when they have no other alternatives. This ecosystem characteristic is particularly important where state welfare functions are limited and inadequate (Turpie 2018). Economic values are usually expressed in monetary terms. From an instrumental viewpoint, the value of an ecosystem should also account for the system's capacity to maintain ecosystem service values in the face of variability and disturbance. This is the so-called Insurance Value and it is closely related to an ecosystem's resilience and self-organizing capacity.

10.4.5. Estimating Economy-Wide Effects

The methods described above provide estimates of changes in value at a household or sectoral level. The analyst may go further in estimating the economy-wide effects that result from the changes in one sector having effects on other sectors. Economic impact analyses usually employ one of two methods for determining impacts. The first is an input-output model for analyzing the regional economy. These are static models of relationships, where transactions and transfers between different activities, stakeholders and institutions within an economy, are captured and recorded. A key advantage of this approach is traceability, where multiplier effects of one activity can be observed in other sectors of the economy. In addition, input-output models also estimate the share of each industry's purchases that are supplied by local firms (versus those outside the study area). Based on this data, multipliers are calculated and used to estimate economic impacts. The input-output model needs to be relatively recent, since these relationships change over time.

Social Accounting Matrices go one step further than input-output models, in that they also capture information on how benefits accrue to different sectors of society, highlighting the impacts on poor households.

A more sophisticated approach involves the use of dynamic economic simulation models known as Computable General Equilibrium models. These models include expected changes over time through feedback relationships in the economy. They are based on a complex interrelated series of equations linked to market activities and linkages. For example, they acknowledge that if households or firms spend more in one sector, they are going to spend less in another. These models are far more challenging to construct and need to be very well constructed in order to be reliable. They can provide realistic, but fairly broad scale, analyses that are useful for evaluating policy options and investment choices.

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11

TECHNICAL NOTE:

Decision-Making Under Climate Uncertainty

The attached Compendium Volume and six individual guidance notes are all built on a step-by-step framework for evaluating and enhancing the climate resilience of development projects in Sub-Saharan Africa. The fourth and final step of this framework involves recommending a course of action from among a set of possible adaptation strategies. There exists a multitude of decision-making frameworks that can help identify a preferred course of action, while effectively taking the impacts of uncertainty into account. This technical note serves as a primer on these different approaches.

This note starts with a brief introduction to classic decision analysis and the traditional methods used for handling uncertainties in decision analysis (Section 11.1). It then takes a closer look at the nature of climate change uncertainty and explains why traditional decision and uncertainty analysis methods struggle to meaningfully capture and address the impacts of uncertainty when faced with evaluating development projects (Section 11.2). Finally, this note presents a class of formalized analytical processes suitable for decision-making under climate change and other sources of deep uncertainty (Section 11.3).[13]

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[13] This note draws from material originally prepared by the authors for the Millennium Challenger Corporation as a contribution to a project titled Climate-informed project assessment with decision making under deep uncertainty.

11.1. Expected Decision Analysis and Traditional Methods for Addressing Uncertainty

Decision analysis is the systematic and quantitative study of evaluating choices in support of making good decisions. One of the most widely used decision analysis approaches is Expected Utility Theory. Expected Utility Theory is founded on the assumption that a decision-maker chooses between different options by selecting the choice that has the highest expected utility, where expected utility is the product of the utility (i.e., outcome) of a choice (e.g. return on an investment) and the probability of that outcome actually occurring.

When it comes to analyzing uncertainty within the context of classic decision analysis, there are numerous well-established methods. Most involve varying uncertain variables as inputs to a model (including a conceptual model) in order to explore how different input values influence outcomes of interest. Ultimately, the recommended decision among multiple uncertain outcomes is the outcome that produces the highest expected utility value. Given the particular features of uncertainty as it relates to climate change, the remainder of this section presents an outline of three principal approaches to handling uncertainty in the context of decision analysis, namely **Sensitivity Analysis, Scenario Analysis** and **Monte Carlo Analysis**,[14] as well as a brief discussion of their respective advantages and constraints. An understanding of these methods is necessary before then discussing why these methods fall short when it comes to climate uncertainty (Section 11.2).

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[14] Note that there are other methods such as Safety margins, Bayesian Analysis, Qualitative causal models that can be used to address uncertainty, but these are not covered here.

11.1.1. Sensitivity Analysis

Sensitivity Analysis is the process of adjusting inputs or parameters of a model and analyzing outputs to characterize the effects of the uncertain variables of interest. Sensitivity analysis is a fundamental means of uncertainty assessment that "aims to ascertain if the inference of a model-based study is robust or fragile in light of the uncertainty in the underlying assumptions" (Saltelli and D'Hombres 2010). Uncertain variables may include exogenous conditions (such as climate, input costs, demand) or factors that are internal to the system such as the effectiveness of components of an investment. Sensitivity Analysis is used to identify which uncertainties are most influential on the results of interest. This then serves as the basis for investigating the means to either reduce the uncertainty associated with the influential uncertain factors, or to develop the means to otherwise minimize the implications of the uncertainty in terms of possible project outcomes. Sensitivity Analysis is distinguished from Monte Carlo Analysis because it does not typically seek to characterize the possible range of outcomes probabilistically.

The strength of Sensitivity Analysis is that minimal information about the uncertain factors is needed to conduct an analysis, with only some range over which to vary the factors required. This means it is very effective for situations where there is a lack of information regarding the uncertain factors, or else indeterminism regarding the possible ranges. The primary drawback is that the results are rarely conclusive from a decision standpoint: they indicate whether factors do or do not influence outcomes of interest, and provide information regarding the magnitude of the effect. However, Sensitivity Analysis is not designed to rank alternatives, provide inputs to performance metrics or underpin expectations. Instead it is an entry point to further analysis and project development. In addition, Sensitivity Analysis typically requires models and specialized analytical tools.

11.1.2. Scenario Analysis

Scenario Analysis is an approach to uncertainty analysis that relies on the creation of discrete scenarios, or "states of the world" that are used to understand the implications of uncertainty on the decision at hand. The process begins with defining a small number of exogenous variables that are influential and uncertain which the analyst desires to explore. The variables may be identified via Sensitivity Analysis. Next, scenarios are created by combining different values of the uncertain variables, chosen to illustrate different possible realizations of those uncertainties. The resulting scenarios are developed and described in narrative fashion, often named, to create realistic and self-consistent possible futures. Finally, the features of these different possible futures are used to evaluate the decision at hand.

The strength of Scenario Analysis is its accessibility. It is not statistical in nature and does not require specialized analytical tools. It is easily explained and intuitive. The weakness from a decision standpoint is that it does not always lead to conclusive results. As there is no attempt to assign probabilities to alternative futures, there's no clear way to draw conclusions regarding the ranking of alternatives. In addition, unlike in classic decision analysis, the scenarios are not intended to be collectively exhaustive, which impedes ranking of alternatives. In some cases, one alternative may outperform others across enough scenarios to enable its conclusive selection, or elimination in the inverse case. That said ultimately, Scenario Analysis is meant to improve understanding of plan performance and for this it is typically effective. It can be combined with analytical tools or conducted in a strictly conceptual fashion.

11.1.3. Monte Carlo Analysis

Monte Carlo Analysis is a probabilistic assessment approach to uncertainty analysis. Probability distributions are assigned to uncertain variables and through the use of specialized tools, the distributions are sampled and served as input to the model of interest in order to generate a probability distribution of model outcomes. The process is repeated many times to generate a full distribution of probabilities and outcomes. The resulting probability distribution can then be analyzed to assess the statistics of the outcome possibilities.

The strength of Monte Carlo Analysis is its ability to calculate the statistics of the outcome distribution, which can be used as metrics for evaluating and comparing alternative investments. For example, the mean expectation, variance, and quantiles of interest can all be calculated from the outcome distribution and can be used to compare projects. The drawbacks of Monte Carlo Analysis are the requirement for specialized analytical tools and the need for credible information regarding the distributions of uncertain variables. Put simply, the quality of the results is entirely dependent on the quality of the inputs. It is most appropriate for cases where the probability distributions and parameters of those distributions are known for the uncertain variables. This is probably rarely achievable in investment analysis for economic development in least developed countries.

By employing Monte Carlo Analysis, uncertainty in key parameters affecting costs and benefits is expanded since a single estimated metric is replaced with a range of values based on their attributed probability distributions. A step-by-step procedure for Monte Carlo Analysis is provided below (Sullivan *et al.* 2015):

1) First, an analytical model of the actual decision is constructed. This may be as simple as an equation of discounted cash flows or as complex as the economic effect of proposed environmental regulations. From such models, important uncertain parameters in the analysis can be identified by preliminary sensitivity analysis.

2) Next, a probability distribution for the uncertain parameter is specified. This can be developed from historical data from previous studies or specified based on subjective judgement by experts.

3) Sample outcomes for each input variable are randomly generated based on the probability distribution specified (which could be normal, triangular, uniform, lognormal, etc.) These samples generated are then used to determine a trial outcome for the model.

4) This sampling process is repeated (typically thousands of times, with the aid of computer software packages) and a frequency distribution of the trial outcome for a desired metric is obtained.

The resulting frequency distribution is then used to make probabilistic statements about the original problem.

11.2. Why These Methods Fall Short When it Comes to Climate Change Uncertainty

As described in Section 11.1 above, many of the traditional methods of addressing uncertainty assume, either implicitly or explicitly, that uncertainties can be effectively characterized with probability distributions. In techniques like Monte Carlo Analysis, this is explicit as probability distributions are assigned to uncertain variables. However, by not explicitly assigning any probabilities, techniques like Sensitivity Analysis implicitly assume a uniform distribution such that all outcomes are equally likely. This reliance on probability distributions becomes a challenge when key design variables are **deeply uncertain**, meaning there is no single agreed upon probability distribution that credibly represents the expectation of future outcomes for that variable. In some cases, key variables are binary in nature (for example, a regime change occurs after a tipping point, or not), with significant consequences for investment outcomes. Yet there is no quantitative basis for estimating the probability of the two outcomes. The pervasive uncertainties that an investment project faces can call into question the results of project evaluation efforts, especially in the case of developmental work in many Sub-Saharan African countries which are characterized by data limitations and other significant uncertainties.

Climate change is an example of a source of deep uncertainty that poses fundamental challenges for project planning and development. Climate change encompasses global warming driven by human emissions of greenhouse gases, and the resulting large-scale shifts in weather patterns as well as the internal variability of the climate system, that is, the natural season-to-season, year-to-year and decade-to-decade changes in climate that are known to occur. The effects of anthropogenic climate change and its anticipated future progression have become a key concern in project development where investments have long economic lifetimes, most notably infrastructure projects. Future climate is uncertain due to three factors that are each inherently irreducible in the near future:

- Future greenhouse gas emissions
- Response of the earth's climate system to increasing greenhouse gas emissions
- Natural climate variability

While there are other factors that may be even more challenging to address (e.g., political instability), the amount of attention that climate change currently receives suggests that development practitioners who make infrastructure investment recommendations are very likely to need credible strategies for addressing this uncertainty more than others. (These guidance notes and technical notes, for instance, were written in response to this need).

In addition, climate change-related analyses are complicated by the plethora of information sources, their technical nature, and the existence of many wasteful or unhelpful practices that pervade the field. Many costs and benefits in development projects are partially or significantly sensitive to prevailing climate conditions and weather extremes (e.g., floods, droughts, heat waves). Consequently, the estimation of costs and benefits of such projects may be contingent on the assumptions of climate and the frequency of occurrence of extreme events. Climate change implies that historically observed probabilities of occurrence are likely to change in the future, undermining standard assumptions that underpin traditional methods for project design and evaluation. (Traditional Monte Carlo simulation may remain useful even if probability distributions are unknown as it can identify the worst possible outcomes when many different uncertainties are combined.)

Furthermore, the inherent uncertainty of the climate system and insurmountable limitations of climate modeling preclude the possibility of confidently replacing historical assumptions with a projected climate future. Climate projections from General Circulation Models (GCMs, also known as Global Climate Models) are helpful for providing general indications of how mean conditions might change over large regions, but at the scale of a typical project, the information provided is best viewed as a limited and potentially biased sample of what is possible. (A fuller discussion of this topic is provided in the technical note on working with climate projections included in this Compendium Volume).

In light of these challenges, happily, a number of approaches have been developed that focus on addressing sources of uncertainty that are not straightforward to characterize, such as climate change. These approaches are presented in the next section.

11.3. Approaches to Decision-Making Under Climate Uncertainty

Having established some of the difficulties encountered when using traditional methods to handle climate change uncertainty, this section surveys prominent examples of formalized analytical processes that shift from methods that simply characterize uncertainty to techniques that characterize uncertainty and evaluate options available for an improved project design. This shift broadens the discussion beyond simply computing the expected value outcomes for a project to include other measures of project performance, such as robustness, worst-case and best-case performance, and flexibility/adaptability.

All of these approaches embrace the "prepare and adapt" concept rather than the traditional notion of "predict and act". "Prepare and adapt" strategies incorporate robustness and flexibility into the decision-making process. These decision-making processes identify a project or system's sensitivity to uncertainties and reduce a project's vulnerability to unfavorable conditions and surprises. This family of approaches all involve framing the analysis and conducting an exploratory uncertainty analysis, choosing initial and contingent actions and then performing iterations and re-examination. Typically, such approaches to decision-making under uncertainty evaluate a variety of project options, across broad uncertainties, and accommodate multiple metrics of success (Hallegatte *et al.* 2012). Additionally, these methods can help decision-makers analyze tradeoffs across multiple objectives as they emphasize exploratory modeling that allows stakeholders to understand tradeoffs that arise under uncertain conditions, as compared to traditional approaches which focus on recommending a single decision. One way to understand this group of "prepare and adapt" approaches is to summarize them this way:

1) **Techniques that emphasize robustness** through simulation of some kind of response surface. We describe two approaches in this category: *Robust Decision Making* and *Decision Scaling*. These approaches are principally concerned with achieving acceptable project performance across a wide range of possible future conditions. Generally, these approaches focus on the decision to be made now (what to build, or not, now), and plan conservatively, with contingencies for future conditions that are significantly different from the past. The primary differences between the two approaches we will examine in this category are their uncertainty sampling strategy and use of climate information.

2) **Techniques that emphasize flexibility**, in which the design can switch at some point in the future in response to changing external conditions. We describe *Engineering Options Analysis* and *Adaptation Pathways*. Generally, these approaches value the agility of a design more highly than its robustness and keep an eye always on "tipping points" in the future which would precipitate a change in adaptation approach, from one set of actions or policies to another. As a group, these approaches might be described as less conservative than those in the previous group.

While a brief introduction to these techniques is provided below, more comprehensive, step-by-step information on applying these techniques, as well as detailed case studies can be found in the 2019 book titled Decision Making under Deep Uncertainty: From Theory to Practice, by Marchau *et al.*

11.3.1. Robust Decision Making

As presented by Lempert *et al.* (2003), Robust Decision Making is a set of concepts, processes, and enabling tools that use computation, not to make better predictions, but to yield better decisions under conditions of deep uncertainty. Robustness can be described as t*he ability of a system to tolerate perturbations that might affect its functionality*. (**Textbox 11.1** introduces a commonly used approach to identify robust choices, namely the use of the concept of MiniMax Regret). Giuliani and Castelletti (2016) define a robust decision as one which is *as insensitive as possible to a large degree of uncertainty and ensures certain performance across multiple plausible futures*.

Textbox 11.1: MiniMax Regret as a way to identify robust solutions

The MiniMax regret criterion helps with the modelling of decision problems and the identification of robust solutions that have the best performance in the worst-case scenario. It involves the minimization of regret, that is, maximum deviation over all possible scenarios when a decision has been made from amongst a set of alternatives and the payoff is less than expected (Aissi *et al.* 2007). This approach is particularly useful in situations where the worst-case scenario in the functioning of a system needs to be anticipated ahead of time to facilitate adequate planning, design and implementation.

The MiniMax approach is beneficial because it helps to hedge against variations in input data, which may occur when there is uncertainty in prices, yields, benefits accruing etc. The Minimax regret principle is also relatively easy to use since it does not require additional information and it is often considered as a starting point and reference criteria in robustness analysis. That said, this approach may be inappropriate for decision-makers as it is quite pessimistic (i.e., prepares for the worst-case scenario) and decision-makers may be willing to accommodate some degree of risk. This challenge can be handled to some degree by including only scenarios relevant for decision-makers within the scenario set (Aissi *et al.* 2007).

There are of course a number of different variants of this kind of MiniMax approach that can be used for ranking alternatives that do not have well-defined probability distributions. Another conservative strategy similar to MiniMax Regret selects the strategy that gives the best worst-case outcome (maximin). A less conservative strategy could interpolate between selecting the strategy with the best case and the best worst case. Or one could assume equal weight over all possible futures and select the strategy that maximizes expected utility in the greatest number of futures.

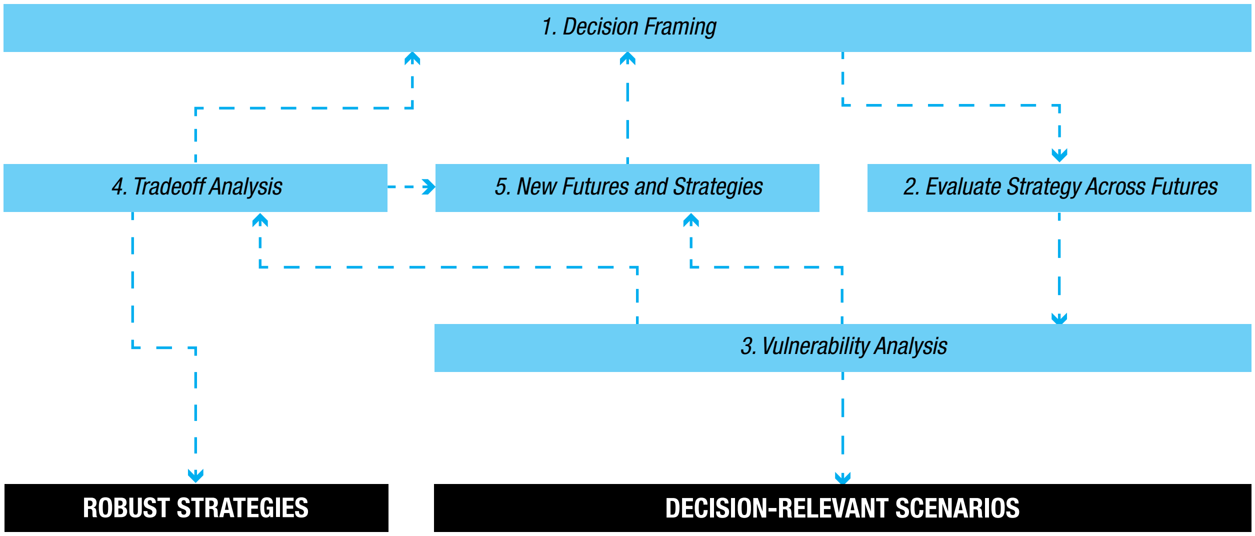
Specifically, Robust Decision Making uses decision analysis to stress test strategies over myriad plausible paths into the future and then to identify **policy-relevant scenarios** (see Textbox 11.2 for more detail on what is meant by a policy-relevant scenario) and robust adaptive strategies (Lempert *et al.* 2003). The general steps involved in a Robust Decision Making analysis are shown in **Figure 11.1** below. Specifically, within Robust Decision Making, policy-relevant scenarios are identified using so-called statistical cluster-finding algorithms. These kinds of algorithms scan the full landscape of possible outcomes to pinpoint those areas where alternative decisions by project managers result in significantly different project outcomes. (Said differently, these algorithms identify which parameters and/or decisions greatly influence eventual project outcomes versus those which have a smaller influence). A sample application of Robust Decision Making is briefly described in **Textbox 11.3**.

Robust Decision Making proves most valuable in situations with multiple, deep uncertainties, varying world views and priorities, and long-term commitments. Although Robust Decision Making can be time and cost intensive and requires extensive quantitative modelling of the project area, a full vulnerability analysis of proposed projects can be carried out using this technique. Also, its transparency reduces over-confidence bias, and the adaptive decision-making process addresses the limits of human ability to anticipate the diverse possible futures of projects (Hallegatte *et al.* 2012).

Textbox 11.2: What are "Policy-Relevant" or "Decision-Relevant" Scenarios?

Fundamental to several of the approaches described in Section 11.3 is the quantification, bounding, and illustration (through visualizations, statistics, and narrative storylines) of scenarios in which the project under consideration fails to perform satisfactorily (relative to one or more thresholds). Importantly, the scenario being described is not available prior to the uncertainty analysis. It is an output of the uncertainty analysis. A single Representative Concentration Pathway forcing of the current generation of General Circulation Models presented by the Intergovernmental Panel on Climate Change is a "scenario" of the future, but it is neither informative of system vulnerabilities, nor "policy-relevant". It does not, by itself, justify investment action. A scenario of system vulnerabilities, on the other hand, motivates targeted action to reduce those system vulnerabilities, improving system robustness, regardless of the level of agreement, political controversy, or scientific credibility with which the scenario of potential future climate conditions (or demographic conditions, or other) is perceived.

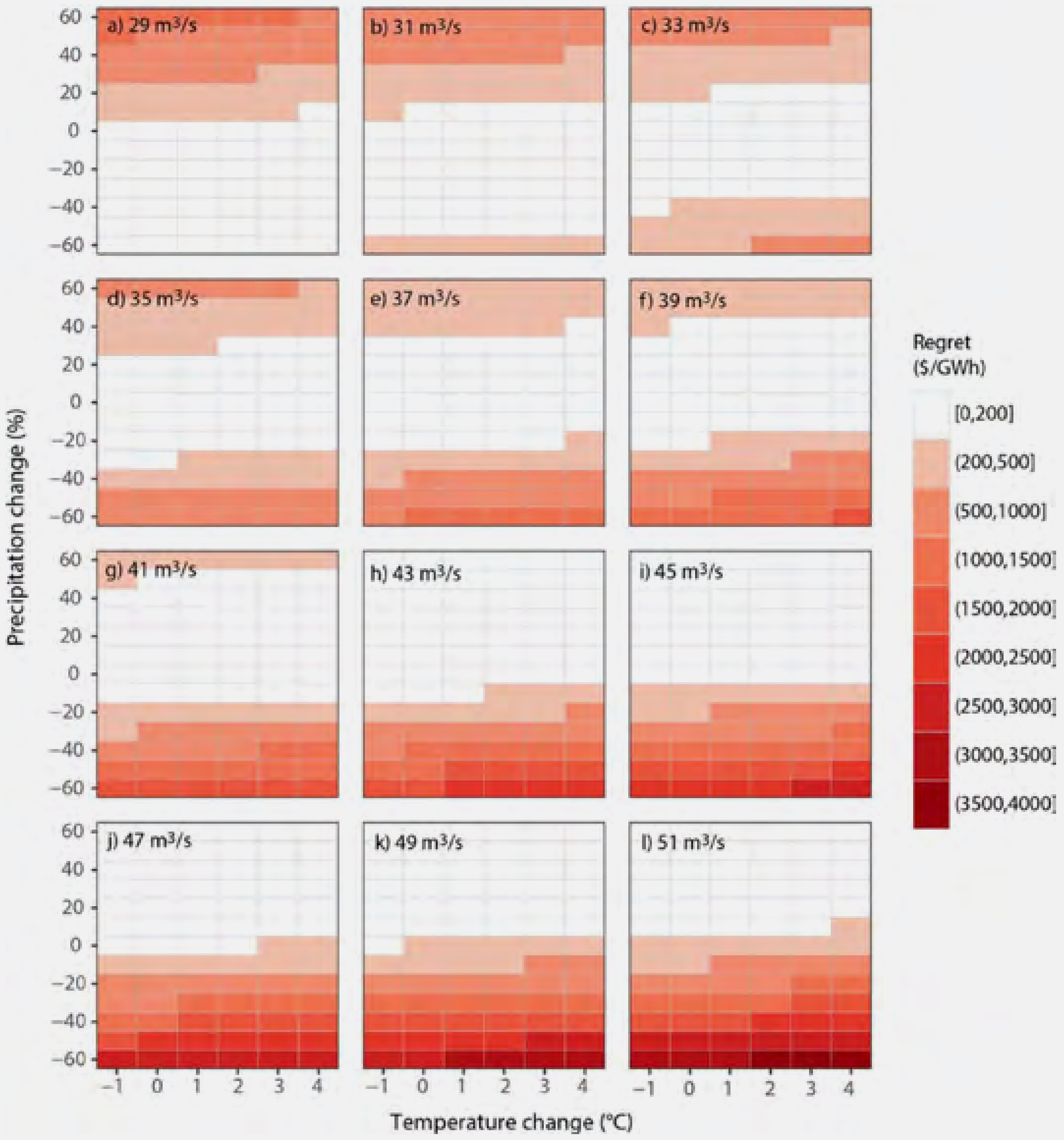
Figure 11.1. **Steps in a typical robust decision making analysis**



Source: Lempert *et al*. 2013.

Textbox 11.3: Application of Robust Decision Making (from Taner et al. 2017)

A planned investment in northern Malawi will combine water resources from the North Rumphi and South Rukuru rivers for generating hydropower through a run-of-the-river plant. The design problem consists of the choice of an economically viable hydropower facility size among the twelve pre-specified design alternatives (from 84 to 148 MW) which were defined by project stakeholders prior to the analysis. In the final phase of the analysis, the twelve alternatives were evaluated in terms of their ability to perform acceptably under different future climate conditions. This was done by calculating the robustness of each alternative from the set of levelized cost of energy regret values calculated through a climate stress test.



Computed range of levelized cost of energy regret across the domain of climate change under each design alternative (in $/GWh). The white cells mark the climate conditions that lead to low (acceptable) regret. (Source: Taner et al. 2017.)

Textbox 11.3 (continued): Application of Robust Decision Making (from Taner et al. 2017)

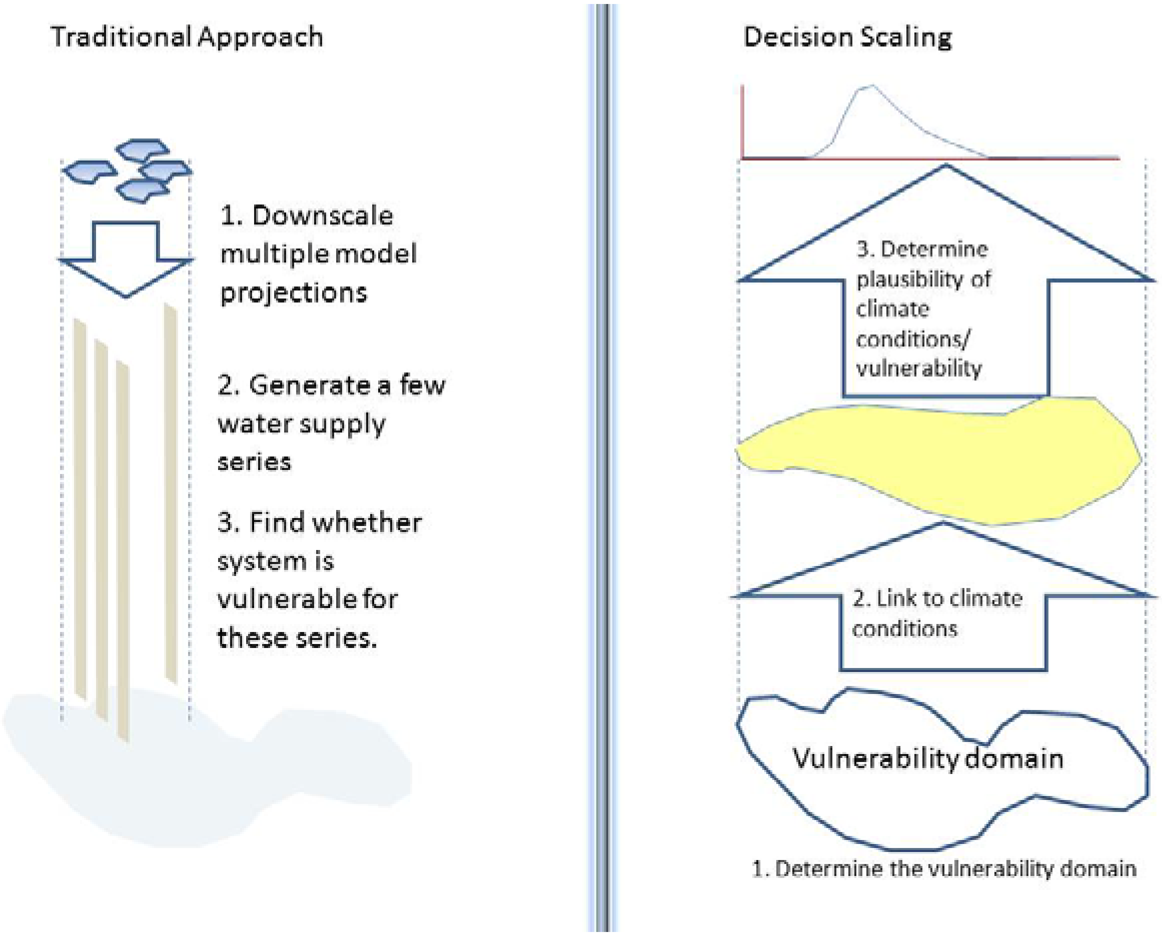
The figure above shows the regret for each alternative under evaluated climate changes. The relatively sharp changes over the y-axis (precipitation change) indicate that the results are more sensitive to precipitation than to temperature. Among the twelve alternatives, the smallest project design (29 m^3/s) results in a regret of less than $200/GWh, and therefore performs acceptably when the mean annual precipitation is less than the historical mean. However, for the smallest option, the regret increases to $1,500 /GWh under wetter futures. In contrast, larger options, i.e., 45 m^3/s or greater, are vulnerable to drier futures, with a maximum regret of $2,000/GWh or greater. As no single option dominates, the choice varies whether the future is expected to be drier or wetter. Under deep uncertainty regarding future climate conditions, irreversible and costly infrastructure planning decisions need to be made with risk-aversion. However, the level of acceptable risk, and the trade-offs between performance and robustness are highly subjective and dependent on the decision maker's (stakeholder's) perspectives.

11.3.2. Decision Scaling

Brown *et al.* (2012) use Decision Scaling as decision support for climate change. Although designed to make the most efficient use of uncertain but potentially useful climate change projections, it is typically generalized to accommodate additional forms of uncertainty. Decision Scaling uses a decision analytic framework to first identify the climate conditions to which the project performance is vulnerable (i.e., similar to Robust Decision Making, it first identifies policy-relevant scenarios), and then supplements the scenario-neutral vulnerability assessment with likelihood information derived from careful study of the most up-to-date climate science (and projections), exhaustive analysis of historical patterns and trends, and local expert opinions (Brown *et al.* 2012).

Decision Scaling consists of three steps: (1) decision framing, (2) climate stress test, and (3) estimation of climate-informed risks (combinations of impact and likelihood), achieved by using weather generator tools and systematic sampling algorithms to create an unbiased description of system responses to plausible climate changes (Brown *et al.* 2012 in Marchau *et al.* 2019). The general steps involved in a Decision Scaling analysis are shown in **Figure 11.2** below and contrasted to the steps taken by more traditional approaches. A sample application of Decision Scaling is briefly described in **Textbox 11.4**.

Figure 11.2. Overview of decision Scaling and how it differs from traditional approaches to incorporating climate uncertainty



Source: Brown 2011.

Decision Scaling does not attempt to reduce uncertainties or make predictions, rather, it highlights the decision options that are robust to a variety of plausible futures. Decision Scaling is particularly useful when there are poorly characterized climate change uncertainties, and the best use of available climate information needs to be made. Although it is partly reliant on subjective judgement and requires quantitative modelling of the project and its response to climate change, Decision Scaling helps to identify climate vulnerabilities, allows alternative visions of the future, gives clear mapping of decision options to climate futures and explicitly addresses the limits of our ability to anticipate the future of projects. Furthermore, this method is beneficial in the assessment of multiple uncertainties simultaneously, including climate, financial and even political uncertainties.

Textbox 11.4: Application of Decision Scaling (from Taner et al. 2019)

Mombasa is Kenya's second largest city and is projected to approximately double in size within the next 20 years. The Mwache Dam is a flagship water resources development project in Coastal Kenya, intended to provide a total of approximately 80 million cubic meters of water per year (MCM/year) for domestic water use in the greater Mombasa area, and for irrigation in the adjacent Kwale County. A decision scaling approach was taken to assess the risks to the Mwache Dam due to climatic and demographic change, and to evaluate adaptation and risk management options from a water supply perspective.

Mean climate change projections for Coastal Kenya from the latest ensemble of General Circulation Models suggest an increase of between 1 and 4 degrees Celsius by 2055-2085 relative to the period between 1961-2000. The models do not offer consensus on the projected changes in precipitation for the region. Domestic water demand, which is closely tied to population growth and regional socio-economic development, is projected to grow by up to 200 percent in 2035 relative to the 2015 level of 38 MCM per year. A stress test was conducted for the Mwache Dam by simulating the hydrology and the water resources operations across thousands of possible conditions representing plausible future climatic and demographic changes.

The hydrologic model developed for this purpose was a simple rainfall-runoff model, with two storage compartments (soil moisture and groundwater). The water resources system model accounted for the incremental effect of sediment accumulation on reservoir storage volume. System performance was assessed using two related metrics: i) safe yield (95 percent delivery reliability), and ii) reliability.

The stress test produced calculated safe yield values ranging from 65 to 120 MCM per year, encompassing the intended annual delivery of 80 MCM. Unsatisfactory yield estimates occurred only under substantially warmer (3°C to 5°C temperature increase) and drier (-30 percent precipitation change) conditions. The likelihood of these conditions occurring during the lifespan of the Mwache Dam is small according to the most current generation of downscaled climate model projections. There is therefore low risk that the Mwache Dam will fail to meet the target safe yield of 80 MCM/year.

Finally, the analysis identified adaptation options capable of reducing the overall system vulnerability, and developed trade-offs between domestic, irrigation, and environmental uses of water. The performance of four dam sizes (80, 100, 130, 140 MCM) was evaluated, as alternatives to the baseline design capacity of 120 MCM. As shown in the figure below, it was found that the larger design sizes offered minimal benefits in terms of average yield. However, the larger design capacities may significantly increase system resilience to drought conditions by decreasing the duration of deficit events. In addition to reservoir design size, no-regret adaptation options could include optimization of reservoir operation rules, adjustment to baseline water allocation policies, and improvements to sediment management strategies.

Textbox 11.4 (continued): Application of Decision Scaling (from Taner et al. 2019)

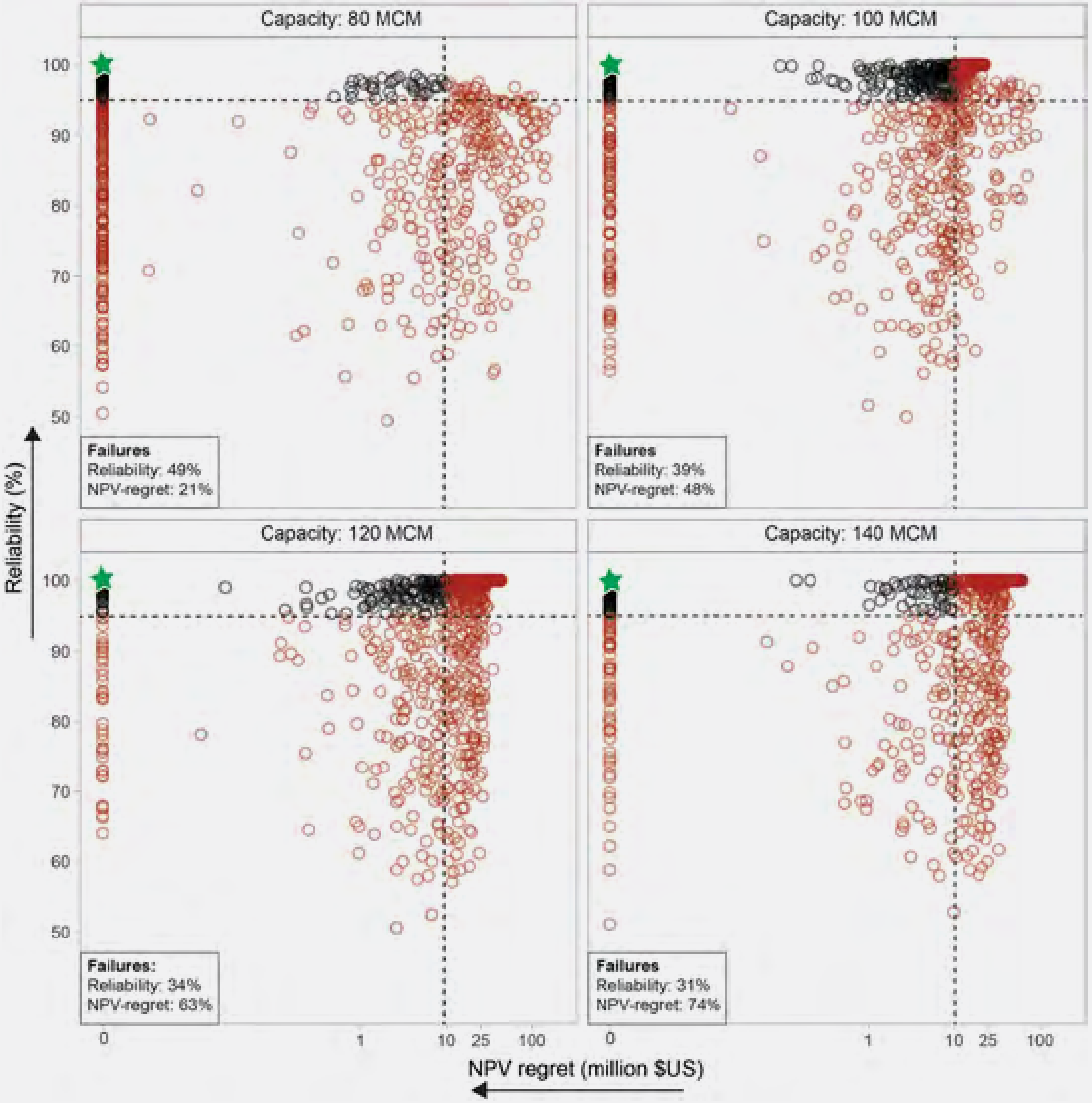


Figure: Vulnerabilities from four design alternatives (80, 100, 130 and 140 MCM) quantified based on net present value regret and reliability metrics. In each panel, the dashed line indicates the thresholds that define acceptable and failure performance outcomes. The simulations with acceptable performance are shown by the black circles. The star shows the ideal solution. (Source: Taner et al. 2019.)

11.3.3. Engineering Options Analysis

Options Analysis can be simply defined as the process of evaluating every possible pathway that leads to a desired outcome. It finds very useful application in project management and decision-making processes and involves identification of alternatives as well as consideration of their feasibility. Engineering Options Analysis is a tool for decision making under uncertainty that applies the technique of Options Analysis to capital budgeting decisions and can be tailored to applications that involve climate change uncertainty. Buurman and Babovic (2016) note two types of engineering options: those describing the structure of the system (the here-and-now design options) and those describing how the system may be operated in the future. The former are built into the design of a system and require sound engineering knowledge, for example, making allowances in the project's engineering design for future expansion. The latter include financial and managerial options, such as the options to defer or abandon a project, or switch to another project. Both types of options are relevant in climate adaptation investment decisions. In addition, Engineering Options Analysis improves the accuracy of economic evaluation when the uncertainty encountered is more "dynamic than deep"; that is, knowledge improves over time and when the project involves significant irreversible investments, among other things. Hence, an options-based approach provides additional flexibility for investors (Wang *et al.* 2019). A sample application of Engineering Options Analysis is provided in **Textbox 11.5**.

Engineering Options Analysis is commonly conceptualized as a branching decision tree. The implementation of the approach becomes more complex (and sometimes limiting) as the number of branches of the tree (i.e., the decision stages and different options being considered) expands. A strength of this approach is its ability to provide a different perspective on uncertainties by showing that they cannot be avoided but can in fact offer valuable opportunities, when coupled with appropriate preparation and monitoring. Incorporating Engineering Options Analysis within a broader Adaptive Policy Making process can assist in the design of comprehensive adaptive plans, evaluate the costs and benefits of each plan and possibly eliminate pathways that clearly have higher costs than benefits. Welfare maximizing climate adaptation decisions can also be identified using this approach. In a policy context, one of the merits of using Engineering Options Analysis is that it provides a manner to objectively—though within the limitations of quantification of costs, benefits and uncertainty—compare options and provide a valid argument to incorporate flexibility, which are at times associated with higher up-front investment costs and increased design complexity in order to keep future options open.

Textbox 11.5: Application of Engineering Options Analysis (from de Neufville *et al.* 2019)

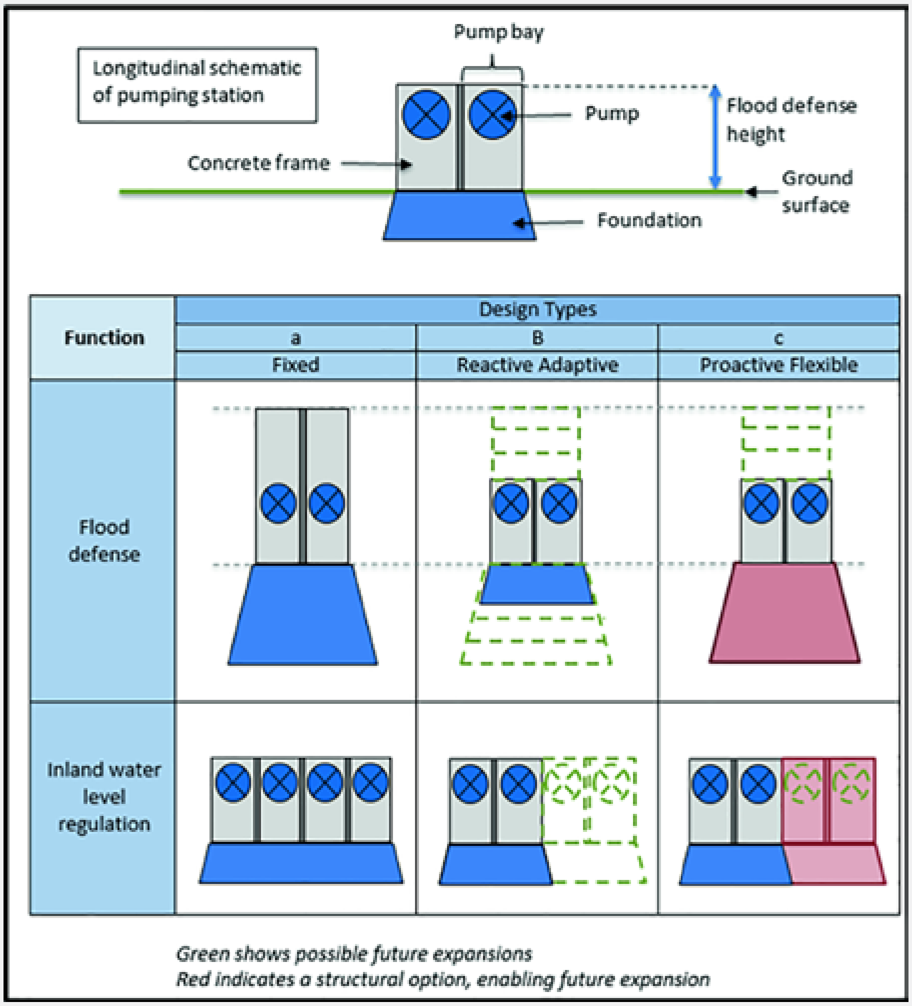
Options analysis has previously been used to explore investment in water management infrastructure, using the example of a pumping station on the North Sea Canal in the Netherlands. The pumping station is multi-functional, fulfilling several different roles including flood defense, regulation of inland water levels, water quality management and ecological management. As it approaches the end of its design lifespan, the question of designing the next generation of structures is growing increasingly relevant: given uncertainty about the future, what is a wise structural replacement strategy?

This case used two sea level rise scenarios and four precipitation scenarios to inform its analyses over an 85-year project horizon to 2100. It did not assign probabilities to these discrete scenarios. By looking across all these scenarios, we can get a sense of how the performance of different courses of action vary across a wide spectrum of future scenarios, despite not having clear probabilistic information.

This case investigated several proposed replacement designs, as shown in the figure below. Each design maintains the same minimum level of service throughout the entire planning horizon. The differentiation among the design alternatives lies in the choice of initial structural design and how further capacity is added over time:

- *Fixed design*, consistent with the traditional predict-then-act approach to water resource planning. The structure provides at least the minimum level of service through to the end of its design life, with a safety margin added for any uncertainties that may not be captured in the analysis.
- *Reactive Adaptive design*, which acknowledges that a fixed structure may represent an over-investment and hence emphasizes designing for the best-available current information and making changes as needed as the future unfolds. Designers size reactive adaptive designs for the short-term, but make no explicit preparations to facilitate possible future adaptations.
- *Proactive Flexible design*, which goes a step further than the reactive adaptive design in that it prepares for the future by choosing to include options within the initial structure. Designers size flexible designs for the short term, but proactively incorporate options that enable easy adaptation in the future.

Textbox 11.5 (continued): Application of Engineering Options Analysis (from de Neufville *et al.* 2019)



Green shows possible future expansions
Red indicates a structural option, enabling future expansion

The analysis ultimately generated distributions of lifecycle costs for the different designs, over many possible simulated futures. The analysis indicated that for those design elements contributing to the pumping station's ability to regulate inland water levels:

- Reject the Fixed design, which sees all the pumping capacity that might eventually be needed installed at the outset. Choose one of the two incremental strategies, with the Reactive Adaptive design preferred for decisionmakers more willing to accept higher long-term costs in exchange for short-term savings by building a smaller structure. The Proactive Flexible design is the preferred design for decisionmakers who anticipate and want to be prepared for large degrees of environmental change in the future.

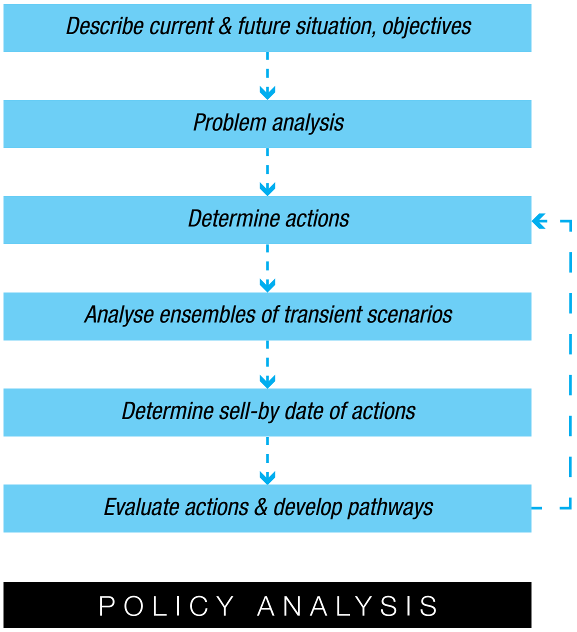
For those design elements contributing to the station's ability to withstand floods on the North Sea:

- Reject the Reactive Adaptive design because the short-term cost savings from choosing a smaller structure do not outweigh the future risks. The Fixed and Proactive Flexible designs demonstrate comparable lifetime economic performance. Thus, all else being equal, the preferred policy may be to simply adopt the traditional Fixed design.

11.3.4. Adaptation Pathways

The Adaptation Pathways approach was originally developed to support water management decision-making in view of climate change adaptation and has since been applied to other issues such as sea level rise. The approach considers alternative states of the world and analyzes the possible extension over time of feasible options under climate change. The focus of Adaptation Pathways is the anticipation of "tipping points" in the future, when the current project design will no longer be preferable over some available alternative. The steps involved in the construction of adaptation pathways are shown in **Figure 11.3** below.

Figure 11.3. **Stepwise policy analysis to construct Adaptation Pathways**

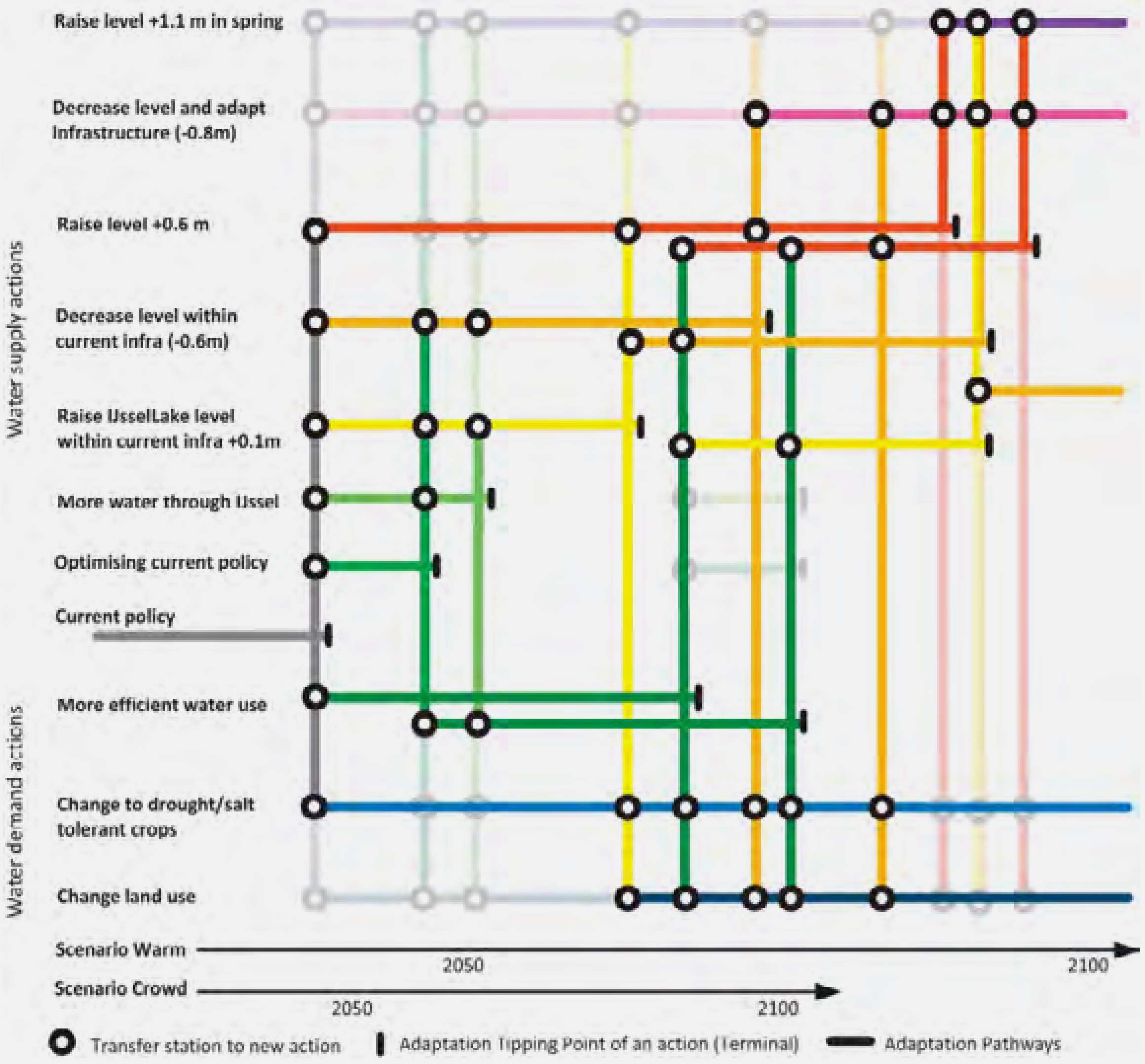


Source: Haasnoot *et al.* 2013.

Adaptation Pathways have in turn been incorporated into an approach to develop Dynamic Adaptive Policy Pathways. This is a generic, structured approach for designing policy plans that can adapt to changing circumstances. It has multiple steps which help to make the approach robust through preparing shaping actions (to reduce failure or enhance success), mitigating actions, hedging actions and actions to seize opportunities. Haasnoot *et al.* (2013) describe the focus of this approach as creating a strategic vision of the future, committing to short-term actions and establishing a framework to guide future actions. A sample application of Dynamic Adaptive Policy Pathways is provided in **Textbox 11.6**.

Textbox 11.6: Application of Dynamic Adaptive Policy Pathways (from Haasnoot et al. 2013)

Haasnoot *et al.* (2013) illustrate Dynamic Adaptive Policy Pathways using the Rhine Delta in the Netherlands as a case study. The aim of the work was to produce an adaptive plan for long-term water management, taking into account the deep uncertainties about the future, as influenced by social, political, technological, economic, and climate changes. One of the outputs of this work was in the form of an adaptation pathways map showing when different actions are expected to lose their effectiveness, under different future scenarios. (The adaptation pathways map below shows proposed actions to safeguard fresh water supply in the IJsselmeer area).



This approach to dealing with uncertainty is particularly attractive because it encourages a wide range of plausible scenarios to be explored (Lawrence *et al.* 2019). As Haasnoot *et al.* (2013) also mention, Dynamic Adaptive Policy Pathways consider the timing of actions explicitly in its approach and produces an overview of alternative routes into the future. Due to the iterative nature of this methodology, it is well suited to projects carried out in phases which involve periodic evaluation over time.

11.4. Selecting an Approach

An overview of several techniques for decision making under deep uncertainty has been provided above, but how is one of these available approaches selected for a project? While there are any number of crossovers and hybrids between these methods, the primary motivation with which any of these techniques would be selected will be informed to a substantial degree by the preference either to **account for future uncertainty now through robustness-based measures, or leave options open in the future for adaptation transitions**. This choice might be governed partly by the availability of funds (now or in the future), and the control/ownership of the project manager over changes to the project in the future. Also at play is the optimism of the project manager that future information will clarify the decision, and/or that future information will arrive gradually enough to allow for an appropriate response. Most project managers would prefer to proceed with robustness to a certain degree of future uncertainty (especially to anticipatable forms of near-term potential catastrophe), AND with flexibility to adjust the project design or functionality to larger changes in baseline conditions as they gradually occur.

Table 11.1 below offers some high-level guidance in terms of which approaches for decision-making under deep uncertainty should be prioritized when faced with investment projects of different characteristics. Note that for large and complex problems that deserve careful analysis, it may be best to do multiple methods, such as vulnerability assessment from Robust Decision Making, likelihood estimation from Decision Scaling, and decision staging from Adaptation Pathways.

Table 11.1. **Overview of which decision making approaches are best suited to different situations**

Approach	Strengths of the approach	Situations where this approach is recommended
Robust Decision Making	Scenario-neutral vulnerability assessment	Particularly large and/or complex decision contexts with multidimensional trade-offs, and where the assignment of likelihoods to scenarios of future conditions is especially difficult, or undesired.
Decision Scaling	Climate-informed risk assessment	Design problems where the question of primary interest concerns climate-change-related risks, and achievement of resilience to climate-change-related uncertainties (in the context of uncertainties of many kinds).
Engineering Options Analysis	Staged decision making and simulation to explore diverse futures	Most useful for assessing flexible strategies when there are a relatively small number of alternatives to compare, as is often the case in engineering decisions like infrastructure design.
Adaptation Pathways	Staged decision making and pathway visualization	Design problems with particularly long planning periods (greater than approximately 20 years), with multiple branching adaption options than can be staged and inter-changed to identify the best combination and timing of actions.

11.5. Concluding Remarks

This technical note reviewed different well-established methods for addressing uncertainty that are relevant for investment project evaluation, and highlighted a group of emerging methods that are well-suited to sources of deep uncertainty such as climate change and provide insights about identifying climate resilient investments. Failure to manage uncertainty effectively when it comes to planned investment projects could lead to expensive retrofitting or total replacement of such infrastructure before the end of their design life, hence it is crucial that sources of uncertainty are considered in any decision-making process.

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TECHNICAL NOTE:

Overview of the Africa Climate Resilient Investment Facility's Training Program that Builds on these Notes

The attached Compendium Volume, including the sector-specific guidance notes as well as the complementary technical notes all serve as guide on how to enhance the climate resilience of infrastructure development projects in Sub-Saharan Africa. The material presented in this Compendium Volume is one half of a two-part approach, with this Volume serving as the basis for a training and capacity building program run by the Africa Climate Resilient Investment Facility. This technical note provides a brief overview of the training and capacity building program.

12.1. Program Overview

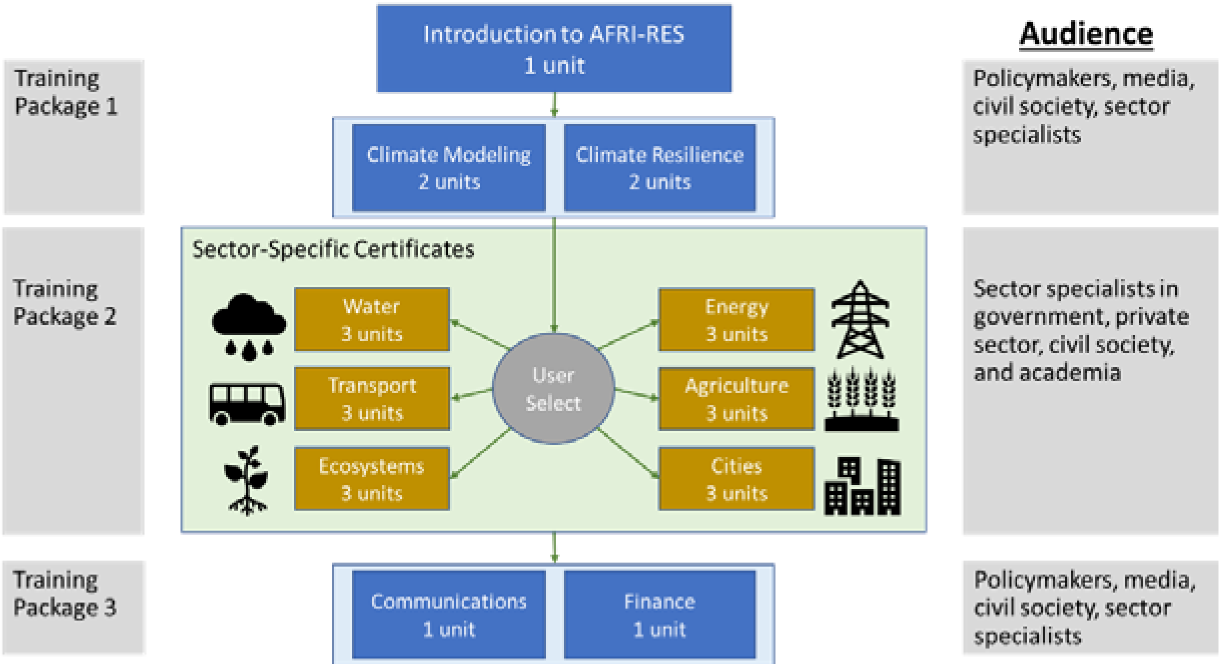
The integration of climate risks in the planning of climate-sensitive investments requires a change in mindset away from entrenched and siloed behavior and practices to an integrated framework approach that brings together climate information, climate impact assessment and decision-making. This comprehensive training program focuses on the integration of climate resilience in investments in various key sectors, including agriculture, energy, water, transport, cities and ecosystems. This program aims to (i) capacitate and strengthen governments officials, private sector, legislators, media professionals, civil society and academia in all African countries with enhanced understanding and contextualization of climate resilience in policy making processes and development planning, and (ii) strengthen the technical capacity of infrastructure sector (energy, water, agriculture, transport, cities and ecosystems) specialists in government, private sector and civil society to understand and use tools and methods to integrate climate resilience in investment planning and implementation.

12.2. Training program

Figure 12.1 provides a high-level overview of the program. Overall, the program includes a set of Voice-over PowerPoint lectures that are organized into 25 units (of 2 to 3 lectures each), which are further organized into 10 modules (excluding the Introduction to AFRI-RES). These are organized into three Training Packages (TPs):

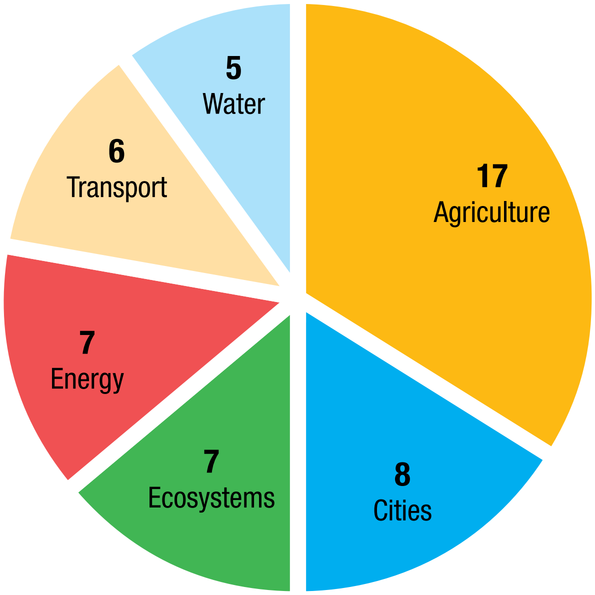
- **TP1:** Introduces the AFRI-RES program and presents lectures on climate modeling and climate resilience, where the climate modeling component provides an important background on climate science and General Circulation Modeling that serves as a foundation for the rest of the program. The audience for this TP includes both technical and non-technical individuals.
- **TP2:** Covers six subject areas (modules), including water, energy, transport, agriculture, ecosystems, and cities. Each of these have three units focused on sector specialists. Participants each selected one of these modules.
- **TP3:** Includes two modules: climate communication and finance. One of the central challenges of climate resilient planning and design is effectively communicating findings of analyses and using the data to make decisions, and then financing climate-related investments. The audience for this TP broadens to encompass both technical and non-technical groups.

Figure 12.1. **Capacity Building Program Overview**



In addition to the three phases of remote work, there was also a multi-day in-person workshop that introduced participants to the TP2 program. The in-person component of the course was held 10 to 12 October 2022, and hosted by IDEP in Dakar, Senegal. Figure 12.2 presents the sectors selected by the 50 participants of the in-person program.

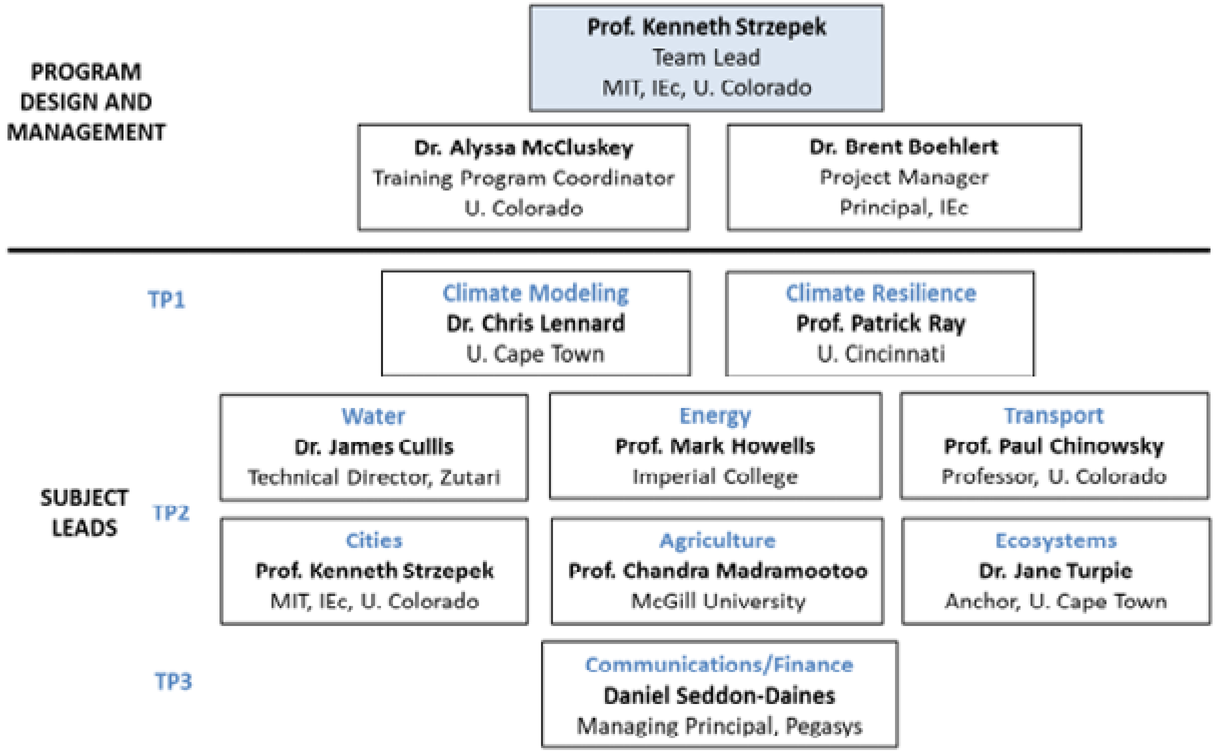
Figure 12.2. **Breakdown of In-Person Workshop Participants**



12.3. Program Instructors and Staffing

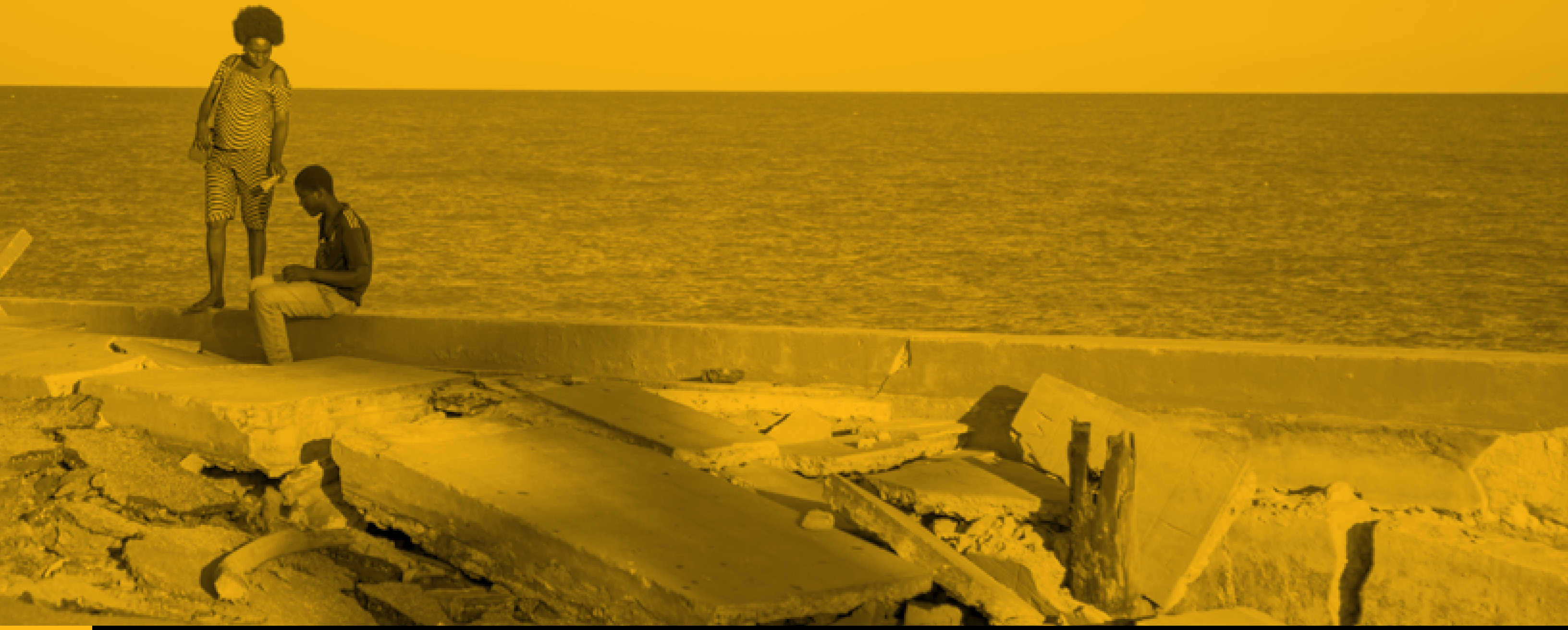
Figure 12.3 shows the staffing structure for coordination of the capacity building program in 2022, and the lead instructors for each course module.

Figure 12.3. Team Structure



TECHNICAL NOTE:

Working With Consultants on Project-Level Climate Vulnerability and Resilience Assessments

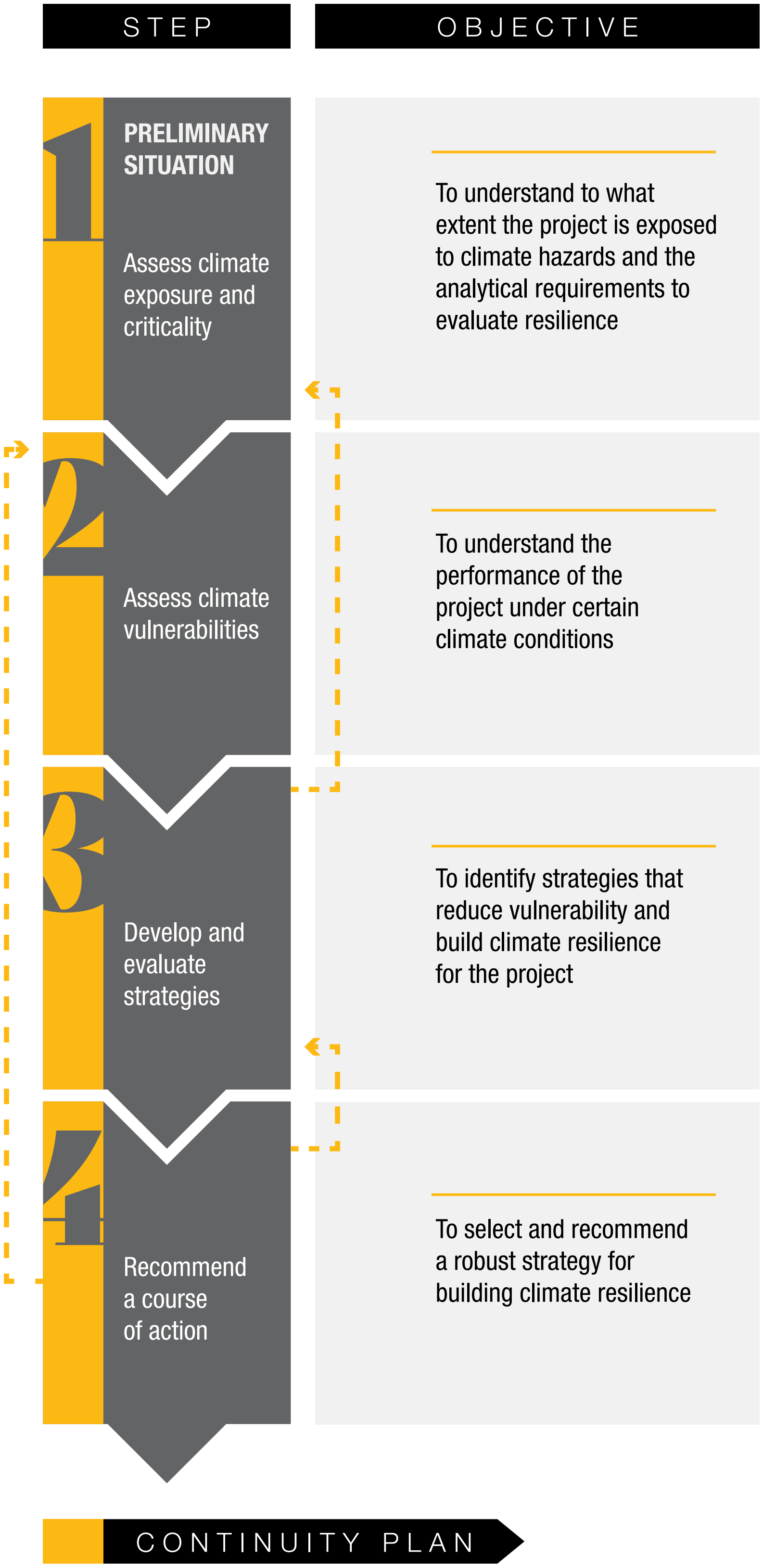


The attached Compendium Volume and six individual guidance notes are all built on a step-by-step framework for evaluating and enhancing the climate resilience of development projects in Sub-Saharan Africa. A number of the steps of this framework involve technical and modeling activities that will likely be undertaken by consulting firms under contract. This technical note looks in more detail at key considerations when working with consultant teams on conducting project-level vulnerability and resilience assessments. The note first discusses which steps in the framework are likely to involve consultants (Section 13.1), before describing which competencies consultants should possess (Section 13.2). Finally, Section 13.3 provides a high-level structure that can be used when developing consultant Terms of Reference for project-level climate vulnerability and resilience assessments.

13.1. Which Steps in the Framework for Enhancing Climate Resilience Are Consultants Likely to be Involved in?

As introduced in each of the individual guidance notes, the general framework for enhancing climate resilience that underpins this Compendium Volume consists of a series of interlinked steps, shown in **Figure 13.1**. This general framework is intended to be useful for and used by three separate target audiences (practitioners, government ministries, and donors and development banks). "Practitioners" are understood to be those who are primarily responsible for completing technical project analyses and on-the-ground project implementation and can include consulting firms as well as technical experts within government ministries. This technical note focuses specifically on working with those practitioners who are involved in project-level climate vulnerability and resilience assessments **on a contractual basis**.

Figure 13.1. **Framework for Enhancing the Climate Resilience of Investment Projects**



As shown in Table 13.1, practitioners are expected to lead Step 1 that assesses the project's exposure to climate hazards and determine the project's criticality as well as Step 2 that assesses the project's vulnerability to the identified climate hazards. They are also expected to play a significant role in Step 3 to develop and evaluate adaptation strategies to enhance the project's climate resilience and may provide input to Step 4 in which a course of action is identified. Given the sequential nature of each step, it is recommended that, whenever possible, the same consultant group conducts all those steps in the framework that are to be contracted out, rather than involving multiple consultants for different steps.

Table 13.1: Role of Consultants in the framework for climate resilience

	Practitioners	Government Staff	Donors and Development Banks
Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality			
Activity 1a. Screen for climate hazards	Lead	Kept informed & provide input	May influence activities through funding pre-requisites
Activity 1b: Determine the project criticality to establish the appropriate level of effort required to assess project resilience			
Activity 1c. Establish a biophysical modeling approach based on the project tier			
Step 2: Assess the Vulnerability of the Project to the Identified Climate Hazards			
Activity 2a. Determine performance indicators and targets to assess climate vulnerability	Lead	Kept informed & provide input	May influence activities through funding pre-requisites
Activity 2b. Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions			
Activity 2c. Analyze project and system performance under the selected climate scenarios		Kept informed	
Activity 2d. Assess the vulnerability of the project in the form of a stress test			
Step 3: Develop and Evaluate Adaptation Strategies to Enhance the Project's Climate Resilience			
Activity 3a: Identify individual interventions to enhance the climate resilience of the project	Co-lead		Kept informed; may influence strategies considered
Activity 3b: Develop adaptation strategies to enhance resilience	Co-lead		
Activity 3c: Evaluate the contribution to the resilience of the selected strategies	Lead	Kept informed & provide input	

	Practitioners	Government Staff	Donors and Development Banks
Step 4: Recommend a Course of Action			
Activity 4a: Select a decision-making approach	Provide input	Lead	Kept informed; may be required to pursue financing
Activity 4b: Assess the trade-offs of each strategy			
Activity 4c: Develop a recommendation and continuity plan			

13.2. Which Compentencies Should Consultants Possess to Complete the Relevant Steps in the Framework?

Step 1 of the framework includes three different activities, namely screening for climate hazards, determining the project's criticality to establish the appropriate level of effort required to assess project resilience and establishing a biophysical modeling approach based on the project tier. The level of expertise and effort required to conduct Step 1 will vary depending on the tier of the project (a high tier project, by definition, will require a more rigorous and in-depth assessment than a low tier project) and by the characteristics of the project being considered (for instance, an urban greenspace project will require different biophysical modeling expertise than a municipal water supply project). In terms of expertise, **this step requires both sectoral knowledge as well as knowledge of climate change, and would likely be best suited to sector-specific consultants**. Ideally, the consultant would have **pre-existing familiarity with relevant climate screening tools**. In instances where a project is determined to require a high tier vulnerability assessment, it is recommended to work with consultants who have significant prior experience running applicable technical analyses and models, rather than having to design and learn how to use these tools from scratch.

Step 2 of the framework includes four different activities, namely determining performance indicators and targets to assess climate vulnerability, establishing a climate baseline and future climate scenarios to analyze project performance under current and future conditions, analyzing project and system performance under the selected climate scenarios and assessing the vulnerability of the project in the form of a stress test. The expertise needed to conduct Step 2 is consistent with that for Step 1, **requiring both sectoral and climate change knowledge and experience**. Ideally, the consultant would have **pre-existing familiarity with relevant models and potential climate data sources**.

Step 3 of the framework includes three different activities, namely identifying individual interventions to enhance the climate resilience of the project, developing adaptation strategies to enhance resilience and evaluating the contribution of the selected strategies to the project's resilience. In terms of expertise, this step **requires both sectoral knowledge as well as knowledge of climate change adaptation in particular**. This step would also benefit from stakeholder engagement, likely facilitated by government ministries, to identify context-appropriate adaptation options.

Step 4 of the framework includes three different activities, namely selecting a decision-making approach, assessing the trade-offs of each strategy and developing a recommendation and continuity plan. While it is unlikely that a consultant will lead the activities in this step given that it involves a decision about project development, t**he consultant involved in the implementation of the previous steps in the framework may be called upon to bring judgment to the technical results produced in Steps 1 to 3**.

13.3. Sample Structure for Consultant Terms of Reference

This next section presents a generalized structure that can be used when preparing Terms of Reference outlining how consultant will complete the relevant steps in the resilience framework. This structure includes not just high-level section headings that will be relevant across most projects, but importantly draws attention to the specific levels of detail, tasks and outputs that must be specified in order for the consultant to produce material that is ultimately suitable for recommending a resilient course of action.

1) **Introduction to the Project**

This brief opening section should provide a short and accessible summary of the key features of the project and its objectives.

2) **Background**

This section should provide a brief overview of relevant background, which can include:

Country context: description of country's location, population, population growth rate, proportion of population that is rural vs. urban, political system, overview of economy, future economic prospects and government development perspectives.

Sectoral context: description of key features characterizing the relevant sector, including current strengths and sources of vulnerability within the sector.

Institutional context: description of the policy and institutional context within the country and sector, including any recent investments and/or reforms undertaken.

3) **Project Description**

This section should provide a more detailed description of the project, including a location map, key technical and financial indicators and sources of risk to the project (including climate change).

4) **Project Resilience Assessment**

This section should provide an introduction to the resilience framework illustrated in **Figure 13.1** and **Table 13.1** above, referencing this Compendium Volume and the relevant sector-specific guidance note. This section should define which of the activities contained in the four steps of the framework the consultant will be responsible for completing. Further detail on these steps should be provided in the sub-sections below, including only those steps which the consultant is being contracted for.

5) **Details on Step 1: Assess Exposure to Climate Hazards and Determine Project Criticality**

This section should outline the following specifics:

Activity 1a — Screen for climate hazards: If known at the outset of the project, which hazards will be screened for? If not, how will a list of relevant hazards be developed? Which methodology/tool(s) will be utilized for the screening? Will stakeholders be consulted to validate the screening results? How will these stakeholders be identified and engaged? What form will the output of the screening be provided in?

Activity 1b — Determine the project criticality: What features of the project will be utilized to determine project criticality? How will this selection be validated?

Activity 1c — Establish a biophysical modeling approach based on the project tier: What models will be utilized to assess the project's vulnerability/resilience, given the tier identified in Activity 1b? What prior experience does the consultant have with these models? What data do these models require and is this data available for the project? If not, how will any data gaps be addressed?

6) **Details on Step 2: Assess Exposure to Climate Hazards and Determine Project Criticality**

This section should outline the following specifics:

Activity 2a — Determine performance indicators and targets to assess climate vulnerability: Which performance indicators and targets will be used? If not known at the outset of the project, how will relevant indicators and targets be determined? Will the choice of indicators and targets be validated through stakeholders consultations?

Activity 2b — Establish a climate baseline and future climate scenarios to analyze project performance under current and future conditions: What historic data exists that is relevant to the project and how will it be used to establish a climate baseline? Will this baseline assume unchanging historic conditions or already incorporate the degree of climate change that has occurred to date? How will future climate scenarios be selected? What climate projections exist for the region and are they ready for inclusion in the analysis (e.g., downscaled and bias corrected)? What prior experience does the consultant have with working with these specific projections/future scenarios? Are any non-climate sources of future uncertainty important to include in the analysis?

Activity 2c — Analyze project and system performance under the selected climate scenarios: What form will the output of the analysis be provided in (e.g., summary data tables, specific visual summaries)?

Activity 2d — Assess the vulnerability of the project in the form of a stress test: Which parameters will be varied for the stress test and in what increments? How will the output of the stress test be provided?

7) **Details on Step 3: Assess Exposure to Climate Hazards and Determine Project Criticality**

This section should outline the following specifics:

Activity 3a — Identify individual interventions to enhance the climate resilience of the project: How will resilience-enhancing measures be identified?

Activity 3b — Develop adaptation strategies to enhance resilience: How will individual interventions be developed into broader adaptations strategies? How will these strategies be validated with relevant stakeholders?

Activity 3c — Evaluate the contribution to the resilience of the selected strategies: How will the existing modeling chain be updated to evaluate the impact of different possible adaptation strategies? What additional data may be required? If this data is not available, how will the analysis be completed? How will the output of this step be provided and visually illustrated?

8) **Details on Step 4: Recommend a Course of Action**

This step should first explain what role, if any, the consultant is expected to play in the process of recommending a course of action, before outlining the following specifics:

Activity 4a — Select a decision-making approach: How will a decision-making approach be selected and who will be consulted in the process of making this selection? What experience does the consultant have in implementing the chosen decision-making approach and what tools are required?

Activity 4b — Assess the trade-offs of each strategy: Which trade-offs will be assessed? Will trade-offs be assessed qualitatively or quantitatively? In what form will the output of this assessment be provided?

Activity 4c — Develop a recommendation and continuity plan: How will a recommendation and continuity plan be developed? Which stakeholders will be consulted in the process? What form will the recommendation and continuity plan take?

9) Duration of the Assignment and Place of Work

This section should describe the duration of the contract, where the consultant team will conduct the work, as well as describe how communication between the consultant and client teams will take place and how frequently.

10) Travel

This section should describe what (if any) travel is required for the contract, providing details such as the number of people traveling, the destination and duration.

11) Final Outputs

While the outputs of individual steps are mentioned in Steps 1 through 4 above, this section should summarize the expected outputs for the project, including reports, slideshow presentations, datasets etc.

12) Schedule of Payments

This section should outline the schedule of payments for the project.

All photos courtesy of The World Bank Group

Compendium Volume:

Climate-Resilient Investment in Sub-Saharan Africa

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