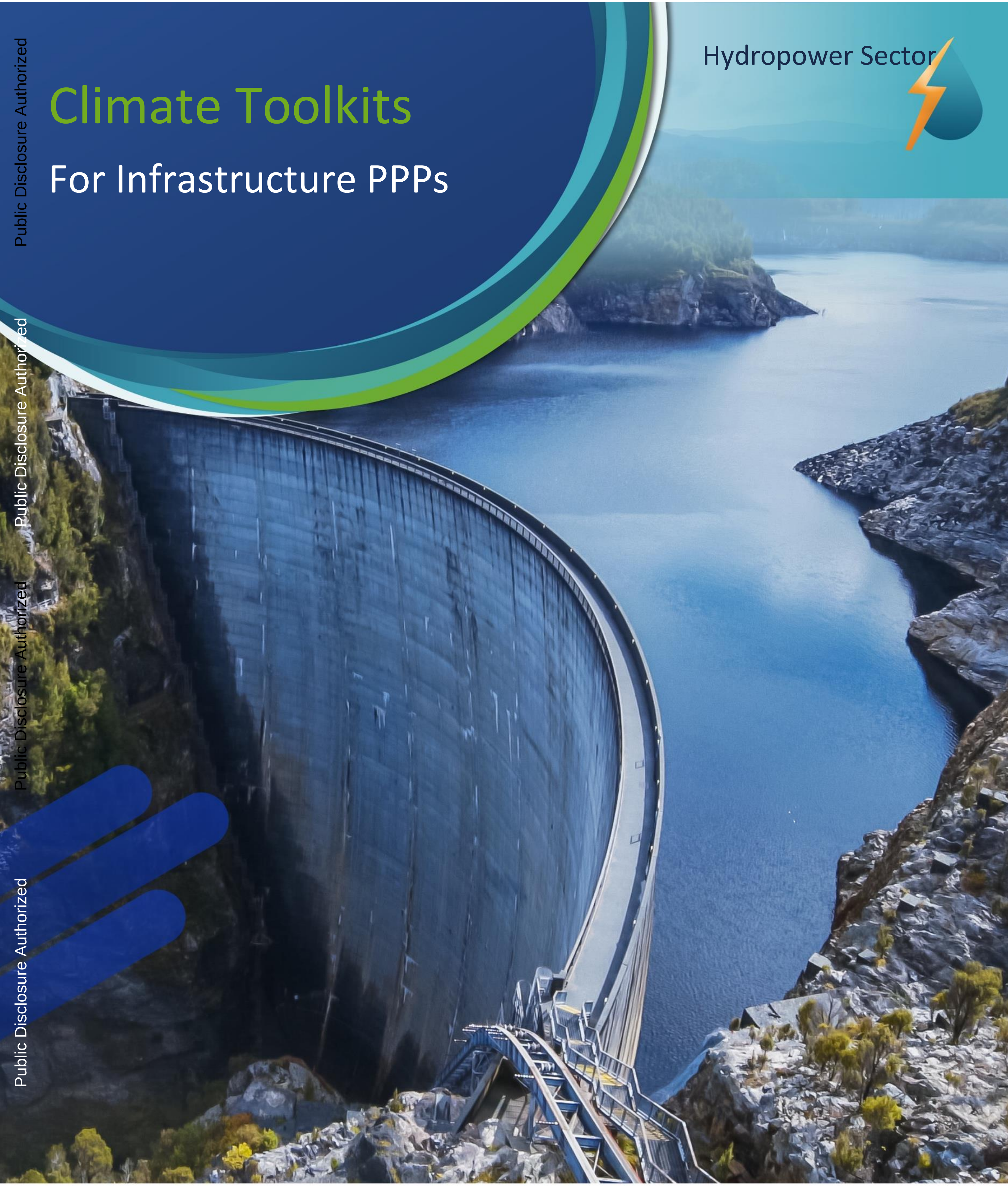
Hydropower Sector

Climate Toolkits

For Infrastructure PPPs



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PPIAF
Enabling Infrastructure Investment

Global Infrastructure Facility
A G20 INITIATIVE

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About PPIAF

PPIAF helps developing-country governments strengthen policy, regulations, and institutions that enable sustainable infrastructure with private-sector participation. As part of these efforts, PPIAF promotes knowledge transfer by capturing lessons while funding research and tools; builds capacity to scale infrastructure delivery; and assists sub-national entities in accessing financing without sovereign guarantees. Donor-supported and housed within the World Bank, PPIAF's work helps generate hundreds of millions of dollars in infrastructure investment. While many initiatives focus on structuring and financing infrastructure projects with private participation, PPIAF sets the stage to make this possible.

About the GIF

The Global Infrastructure Facility, a G20 initiative, has the overarching goals of increasing private investment in sustainable infrastructure across emerging markets and developing economies, and improving services that contribute to poverty reduction and equitable growth aligned with the Sustainable Development Goals (SDGs). The GIF provides funding and hands-on technical support to client governments and multilateral development bank partners to build pipelines of bankable sustainable infrastructure. The GIF enables collective action among a wide range of partners—including donors, development finance institutions, and country governments, together with inputs of private sector investors and financiers—to leverage both resources and knowledge to find solutions to sustainable infrastructure financing challenges.

About CTA

IFC's PPP Transaction Advisory (CTA) advises governments on designing and implementing public-private partnership (PPP) projects that provide or expand much needed access to and/or improved delivery of high-quality infrastructure services—such as power, transportation, health, water and sanitation—to people while being affordable for governments. In doing so, CTA assists on the technical, financial, contractual, and procurement aspects of PPP transactions. To date, CTA has signed over 400 projects in 87 countries, mobilizing over $30 billion of private investment in infrastructure, and demonstrating that well-structured PPPs can produce significant development gains even in challenging environments.

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List of Abbreviations and Acronyms

AHP	analytical hierarchy process
CAPEX	capital expenditures
CBA	cost-benefit analysis
CBI	Climate Bonds Initiative
CMIP	coupled model intercomparison project
CO2	carbon dioxide
CO2e	carbon dioxide equivalent
CTIP3	Climate Toolkits for Infrastructure PPPs
DEM	digital elevation map
EI	emission intensity
EIRR	economic internal rate of return
EMDE	emerging market and developing economy
GCM	general circulation model
GHG	greenhouse gas
HESG	Hydropower Sustainability Environmental, Social and Governance Gap Analysis
HGIIP	Hydropower Sustainability Guidelines on Good International Industry Practice
HSAP	Hydropower Sustainability Assessment Protocol
IEA	International Energy Agency
IFC	International Finance Corporation
IHA	International Hydropower Association
IPCC	International Panel on Climate Change
IRENA	International Renewable Energy Agency
KPIs	key performance indicators
LC	life cycle
LCA	life-cycle assessment
LTS	long-term strategy
LULC	land use/land cover
MCDM	multi-criteria decision-making
MDB	multilateral development bank
MIGA	Multilateral Investment Guarantee Agency
NAP	national adaptation plan
NAPA	national adaptation program of action
NAS	national adaptation strategy
NBS	nature-based solutions
NDCs	Nationally Determined Contributions
NPV	net present value
O&M	operation and maintenance
OSM	OpenStreetMap
PD	power density
PPP	public-private partnership
RoR	run-of-river
SDGs	Sustainable Development Goals
SC	stakeholder council
VfM	value for money
WBG	World Bank Group

Foreword

The time for action to build a better future and green recovery has never been stronger as we navigate the uncertainty of a world dealing with multiple crisis on top of climate change. As governments across the globe face fiscal constraints, it has become imperative to crowd in private sector solutions, innovation, and finance to create new solutions and pathways to meet Paris Agreement goals on climate change and UN Sustainable Development Goal (SDG) commitments.

Participation of the private sector in Paris-Aligned infrastructure investments is critical and public-private partnerships (PPPs) are among the key solutions. PPPs are critical in supporting governments to bridge the infrastructure gap not only for the additional capital they bring but sector expertise and innovation as well. However, the PPP model is not without challenges, climate change creates uncertainty that can be difficult to account for in the framework of PPPs, which require a certain degree of predictability to attract investment and finance.

This sector-specific toolkit on the hydropower aims to address this challenge by embedding a climate approach into upstream PPP structuring. If structured correctly, PPPs in hydropower can increase climate resilience offering market-based solutions to address both mitigation and adaptation challenges. PPPs are able to provide well-informed and well-balanced risk allocation between partners— offering long-term visibility and stability for the duration of a contract (typically 20 to 30 years)- compensating climate change uncertainty through contractual predictability.

The toolkit attempts to address questions like:

- In what ways—in terms of likelihood and impact—does climate change affect hydropower projects, and what measures can be taken to alleviate these impacts through a PPP structure?
- How can we innovate to allow for optimal risk allocation and contractual predictability in an environment marked by uncertainty and the need for resilience to unpredictable scenarios?

The Global Infrastructure Facility (GIF), The Public Private Infrastructure Advisory Facility (PPIAF) and International Finance Corporation, Transaction Advisory, Public-Private Partnership and Corporate Finance Advisory Services in collaboration with sector specialists across the World Bank Group (WBG)—have joined forces to build upon best practice on a topic at the cross-roads of climate change, infrastructure, and private sector participation. It is a field in evolution where there will be a great deal of innovation ahead of us.

Currently an insufficient focus is given to considering climate change in the framework of PPPs. For instance, the PPP tender selection criteria are currently ultimately based on the least cost approach, which may promote assets not resilient enough to withstand climate impacts. This may in turn result in total asset loss with devastating effects on the economy and society. This toolkit is indeed about providing solutions to public officials and their advisors on how to better align interests and incentives towards climate-smart investments and tap into private sector financing capacity.

The hydropower sector toolkit as part of the Climate Toolkits for Infrastructure PPPs (CTIP3) suite is ultimately a call for action for decision makers, to push for bold initiatives so that infrastructure investments become a critical and steady pathway to achieve Paris Agreement and SDG commitments.

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Introduction

Combating climate change through investments in hydropower

Hydropower is the world's largest source of renewable energy, supplying, according to the International Hydropower Association (IHA), nearly 16 percent of global electricity demand. Global capacity has been growing at an average rate of 2.1 percent per year since 2015,[1] and the International Renewable Energy Agency (IRENA)[2] suggests that 850 gigawatts (GW) of new hydropower capacity will be needed by 2050 to limit the global temperature increase to 2°C above pre-industrial levels. This number would have to rise to 1,300 GW to achieve the goal of 1.5°C set by the Paris Agreement (PA). Indeed, numerous countries in South America, Africa, and Asia have committed to hydropower to supply affordable energy with net-zero emissions by 2050.

Hydropower projects offer some of the lowest life-cycle greenhouse gas (GHG) emissions per unit of energy generated. Yet their design characteristics greatly affect not only their ability to produce electricity, but also their impact on the environment and local communities. Consideration of climate resilience and sustainability is at the core of hydropower development and must be embedded in the pre-transactional and structuring phase of relevant public-private partnerships (PPPs), in line with national climate policies and global good practices.

Shifting towards green and resilient projects

Hydropower holds a two-fold relationship with climate change. Under certain conditions, reservoir-based hydropower projects can be sources of substantial GHG emissions, adding more stress to an already fragile climatic equilibrium. At the same time, hydropower assets may be vulnerable to many types of stressors exacerbated by climate change: extreme heat, droughts, and fires; extreme rainfall and floods; and avalanches.

It is obvious that failure to adequately and promptly consider the climate when planning new hydropower projects (as well as in the upgrading of existing plants) may lead to significant shortcomings in projects' technical and financial performance. By contrast, embedding climate mitigation and resilience against climate risks into the life-cycle planning of a hydropower project enables hydropower to serve its role as a clean energy source that can simultaneously provide valuable adaptation capabilities, minimizing the impact of climate change on local communities and on the environment.

Climate considerations reflect on project economics

The decision to invest upfront in climate adaptation and mitigation should depend on many criteria, including the current and future exposure of the project to climate risks, the consequences of failure, and the overall social benefits to the community.

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[1] IHA (International Hydropower Association). 2020. *Hydropower Status Report*. IHA. https://www.hydropower.org/statusreport.

[2] IEA (International Energy Agency). 2020. *Global Energy Review 2020*. Paris: IEA. https://www.iea.org/reports/global-energy-review-2020.

Delivering a hydropower project as a PPP could in certain cases endow it with certain benefits (e.g., potentially more effective use of its flood control capabilities for broader, catchment-scale adaptation) compared to traditional procurement. On the other hand, financing climate-resilient designs by the private sector can be challenging, especially when adaptation options are limited. Therefore, the costs, benefits, and economic viability of projects when taking climate risks into account, as well as the value for money (VfM) aspect of the project as a PPP, should be checked at the early stages of project selection, to identify any potential weaknesses and to make the necessary adjustments.

Well-defined, measurable indicators are essential

For stakeholders involved in hydropower project planning, meeting the mitigation and adaptation goals may be a long process, including iterative assessments, adequate monitoring, sustainable operations, and efficient maintenance.

To ensure that all strategic climate objectives are fully addressed, it is recommended that agencies provide strict specifications and output requirements in the form of clear and measurable indicators.

The hydropower sector toolkit and its intended users

The present document is intended for use by emerging market and developing economy (EMDE) government agencies to assist them in incorporating climate-related risks and opportunities in the pre-structuring phase of water supply infrastructure projects procured through PPPs. The toolkit complements the World Bank Group's Climate Toolkits for Infrastructure PPPs (CTIP3) (the "Umbrella Toolkit[3]") by providing step-by-step instructions on how to apply its provisions to PPPs related to hydropower infrastructure.

The toolkit is intended to familiarize non-experts with the potential effects of climate change on the project and the resulting considerations for climate mitigation, adaptation, and resilience, so that these can be adequately appraised as early as possible when pursuing such projects. As such, the toolkit focuses on preliminary steps aiming to help users understand how climate change could affect their hydropower infrastructu re project, the potential consequences, and what measures can be taken to alleviate the project's impact. (Note that this toolkit is not intended for the design to structuring and tendering phases, but should be consulted as a complementary tool to the Umbrella Toolkit.)

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[3] World Bank, IFC (International Finance Corporation), and MIGA (Multilateral Investment Guarantee Agency). 2022. Climate Toolkits for Infrastructure PPPs. Washington, DC, World Bank. Referred to as the Umbrella Toolkit in this document.

Essential complementary resources

Agencies involved in the development of hydropower projects should be familiar with the following tools and frameworks supporting hydropower resilience and sustainability:

- The Hydropower Sector Climate Resilience Guide, which has been developed by the IHA, with support from the European Bank for Reconstruction and Development (EBRD), the World Bank Group (WBG), and the Korea Green Growth Trust Fund, to help hydropower practitioners identify, assess, and manage the risks of climate change to safeguard the resilience of hydropower projects under variable, uncertain climate conditions.
- The Hydropower Sustainability Guidelines on Good International Industry Practice (HGIIP), a normative document that defines the processes and outcomes constituting good practices in the sector. Performance against the guidelines can be measured through two complementary tools: the Hydropower Sustainability Assessment Protocol (HSAP) and the Hydropower Sustainability Environmental, Social and Governance Gap Analysis (HESG) tool:
  - The HSAP is a performance measurement tool addressing environmental, technical, and economic aspects, applicable to all the stages of a project's life cycle.
  - The HESG can be used to identify where the project might be falling short of good practices on relevant environmental, social and governance topics. It includes a gap management plan for how to improve processes and outcomes.

EXECUTIVE SUMMARY

This toolkit contains a set of tools covering the major climate entry points (identification of risks, incorporation of climate considerations in the project's selection, and appraisal of climate effects in the project's economics). It uses as inputs preliminary project data, readily available climate-related resources, and tools produced by the World Bank Group and international organizations. The outcome should be a project-specific collection of considerations that will need to be further evaluated and quantified during the subsequent phases of implementation of the Umbrella Toolkit.. The toolkit is divided into five modules:

Module 1 (Project alignment with climate policies) aims to assist users with mapping climate policies and screening the project's alignment with them to identify corrective actions.

Module 2 (Assess climate risk and plan adaptation actions) guides users in estimating climate risks and reducing their impact on the project to acceptable levels.

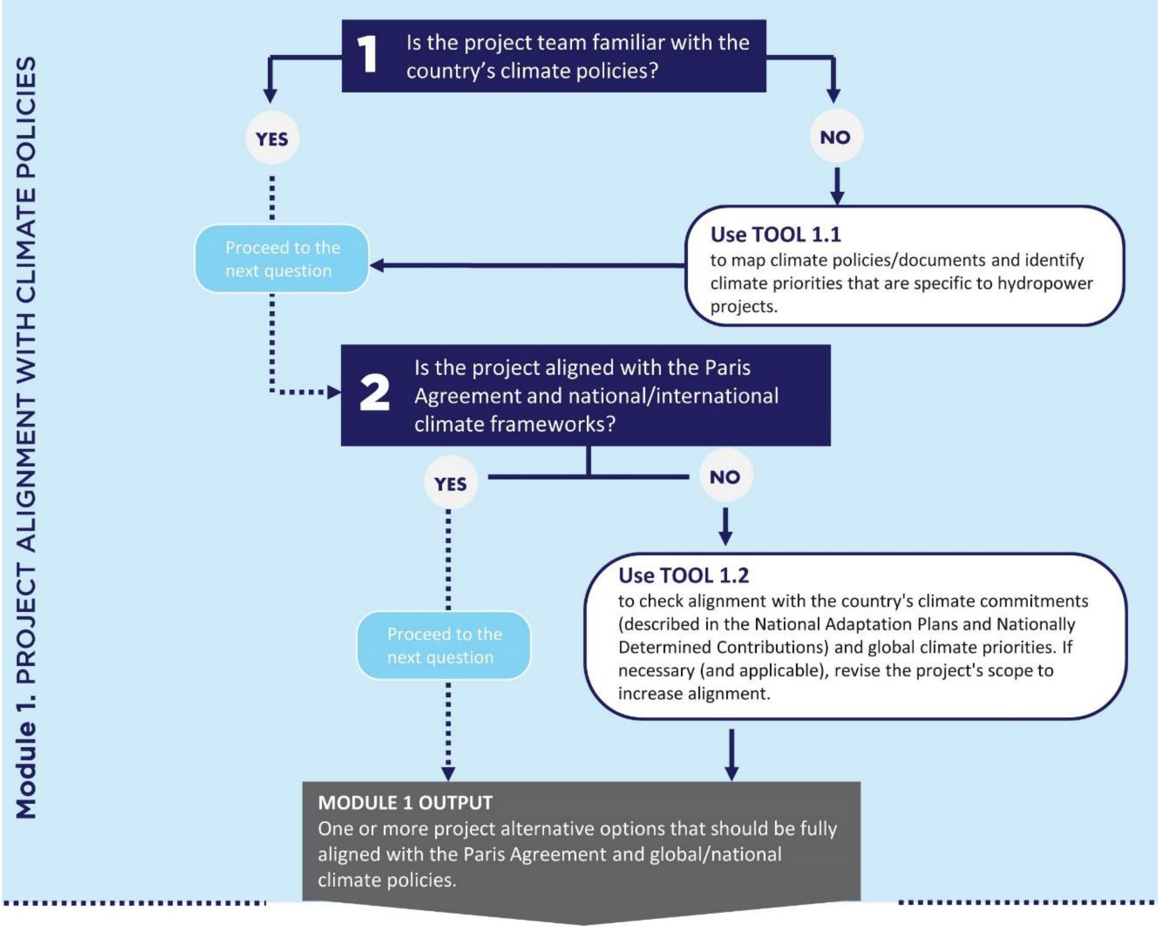
Module 3 (Assess GHG emissions and plan climate mitigation strategies) assists users in the process of appraising the project's carbon footprint and identifying potential mitigation measures.

Module 4 (Climate considerations for assessing project's economics and finances) guides users in checking climate strategies' economic soundness and putting them into action.

Module 5 (Key performance indicators for climate-resilient and sustainable hydropower) presents a set of key performance indicators (KPIs) for hydropower projects; these KPIs serve as entry points for relevant activities.

The interconnections between the modules and their tools are explained schematically in the **Toolkit Navigator** provided on the next page.

Toolkit Navigator



Module 1. PROJECT ALIGNMENT WITH CLIMATE POLICIES

1 Is the project team familiar with the country’s climate policies?

YES

Proceed to the next question

NO

Use TOOL 1.1
to map climate policies/documents and identify climate priorities that are specific to hydropower projects.

2 Is the project aligned with the Paris Agreement and national/international climate frameworks?

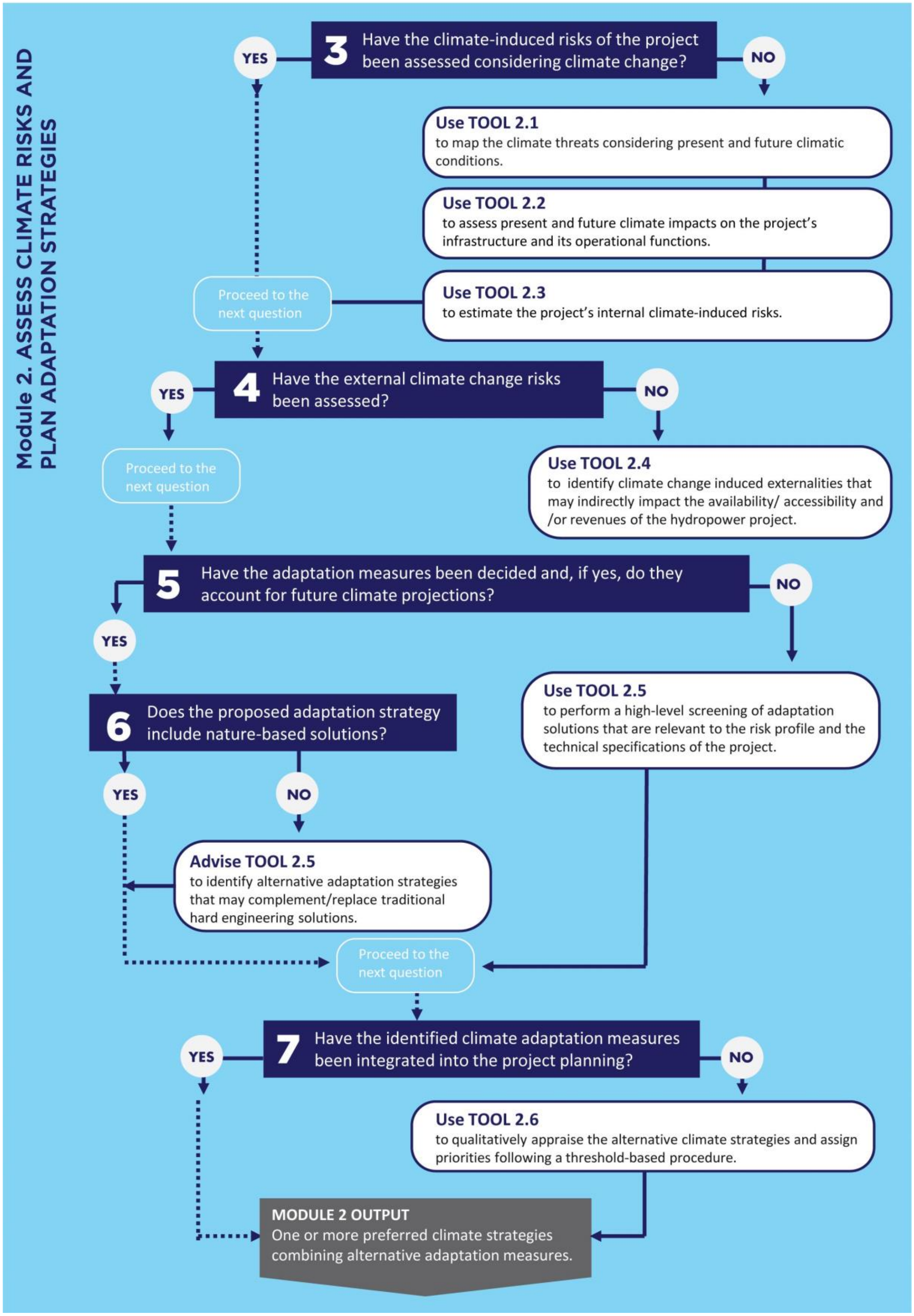
YES

Proceed to the next question

NO

Use TOOL 1.2
to check alignment with the country's climate commitments (described in the National Adaptation Plans and Nationally Determined Contributions) and global climate priorities. If necessary (and applicable), revise the project's scope to increase alignment.

MODULE 1 OUTPUT
One or more project alternative options that should be fully aligned with the Paris Agreement and global/national climate policies.



Module 2. ASSESS CLIMATE RISKS AND PLAN ADAPTATION STRATEGIES

3 Have the climate-induced risks of the project been assessed considering climate change?

YES → Proceed to the next question

NO →

Use TOOL 2.1
to map the climate threats considering present and future climatic conditions.

Use TOOL 2.2
to assess present and future climate impacts on the project's infrastructure and its operational functions.

Use TOOL 2.3
to estimate the project's internal climate-induced risks.

Proceed to the next question

4 Have the external climate change risks been assessed?

YES → Proceed to the next question

NO →

Use TOOL 2.4
to identify climate change induced externalities that may indirectly impact the availability/ accessibility and /or revenues of the hydropower project.

5 Have the adaptation measures been decided and, if yes, do they account for future climate projections?

YES →

6 Does the proposed adaptation strategy include nature-based solutions?

YES → Proceed to the next question

NO →

Advise TOOL 2.5
to identify alternative adaptation strategies that may complement/replace traditional hard engineering solutions.

NO (question 5) →

Use TOOL 2.5
to perform a high-level screening of adaptation solutions that are relevant to the risk profile and the technical specifications of the project.

Proceed to the next question

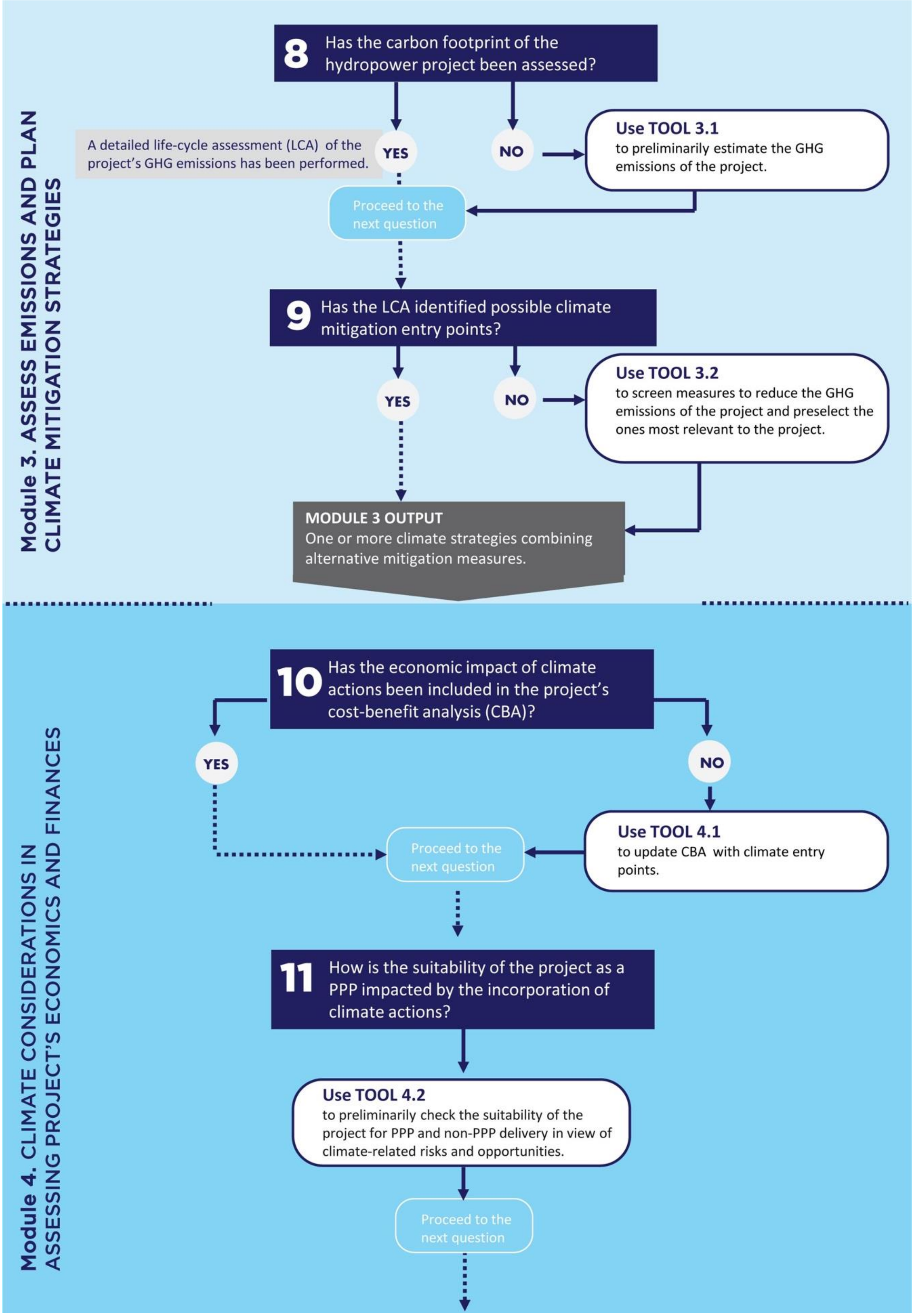
7 Have the identified climate adaptation measures been integrated into the project planning?

YES → MODULE 2 OUTPUT

NO →

Use TOOL 2.6
to qualitatively appraise the alternative climate strategies and assign priorities following a threshold-based procedure.

MODULE 2 OUTPUT
One or more preferred climate strategies combining alternative adaptation measures.



Module 3. ASSESS EMISSIONS AND PLAN CLIMATE MITIGATION STRATEGIES

8 Has the carbon footprint of the hydropower project been assessed?

YES – A detailed life-cycle assessment (LCA) of the project's GHG emissions has been performed.

NO → **Use TOOL 3.1** to preliminarily estimate the GHG emissions of the project.

Proceed to the next question

9 Has the LCA identified possible climate mitigation entry points?

YES

NO → **Use TOOL 3.2** to screen measures to reduce the GHG emissions of the project and preselect the ones most relevant to the project.

MODULE 3 OUTPUT
One or more climate strategies combining alternative mitigation measures.

Module 4. CLIMATE CONSIDERATIONS IN ASSESSING PROJECT'S ECONOMICS AND FINANCES

10 Has the economic impact of climate actions been included in the project's cost-benefit analysis (CBA)?

YES

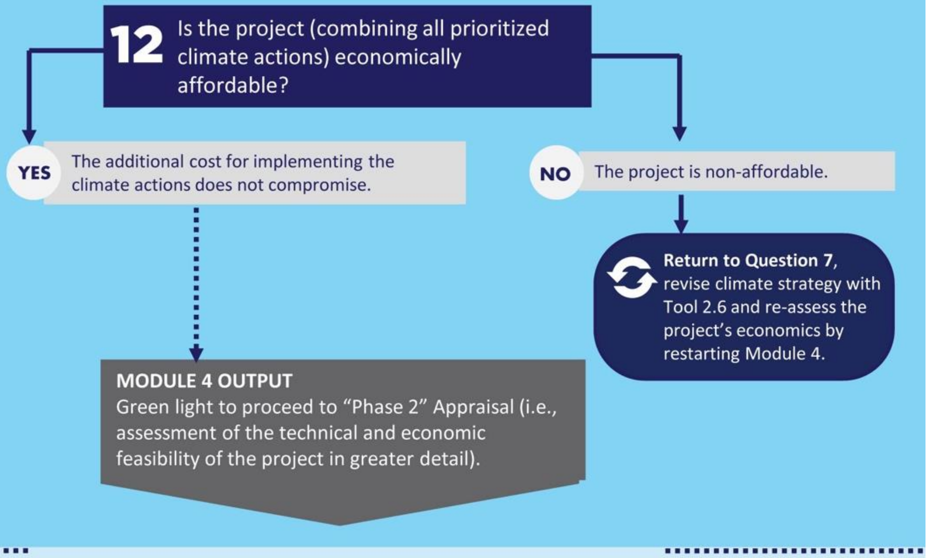
NO → **Use TOOL 4.1** to update CBA with climate entry points.

Proceed to the next question

11 How is the suitability of the project as a PPP impacted by the incorporation of climate actions?

Use TOOL 4.2 to preliminarily check the suitability of the project for PPP and non-PPP delivery in view of climate-related risks and opportunities.

Proceed to the next question



12 Is the project (combining all prioritized climate actions) economically affordable?

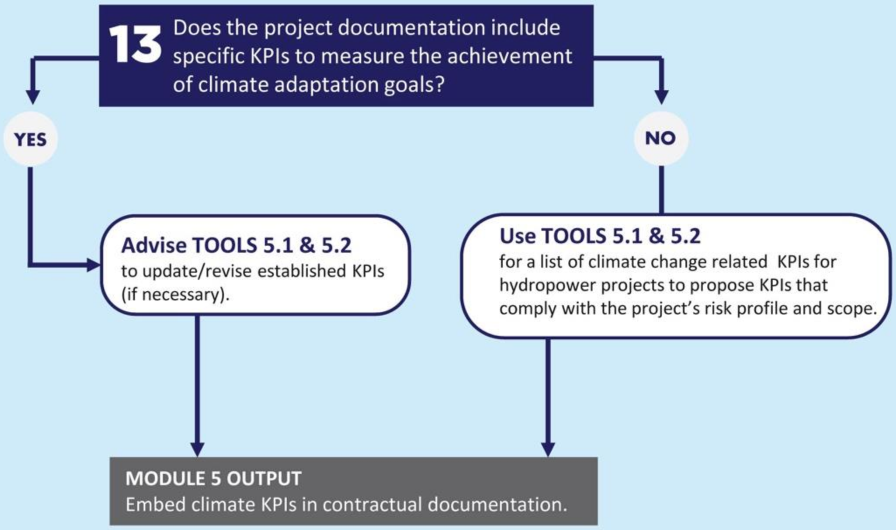
YES The additional cost for implementing the climate actions does not compromise.

NO The project is non-affordable.

Return to Question 7, revise climate strategy with Tool 2.6 and re-assess the project's economics by restarting Module 4.

MODULE 4 OUTPUT
Green light to proceed to "Phase 2" Appraisal (i.e., assessment of the technical and economic feasibility of the project in greater detail).

Module 5. KPIs FOR CLIMATE-RESILIENT AND SUSTAINABLE HYDROPOWER PROJECTS



13 Does the project documentation include specific KPIs to measure the achievement of climate adaptation goals?

YES

Advise TOOLS 5.1 & 5.2
to update/revise established KPIs (if necessary).

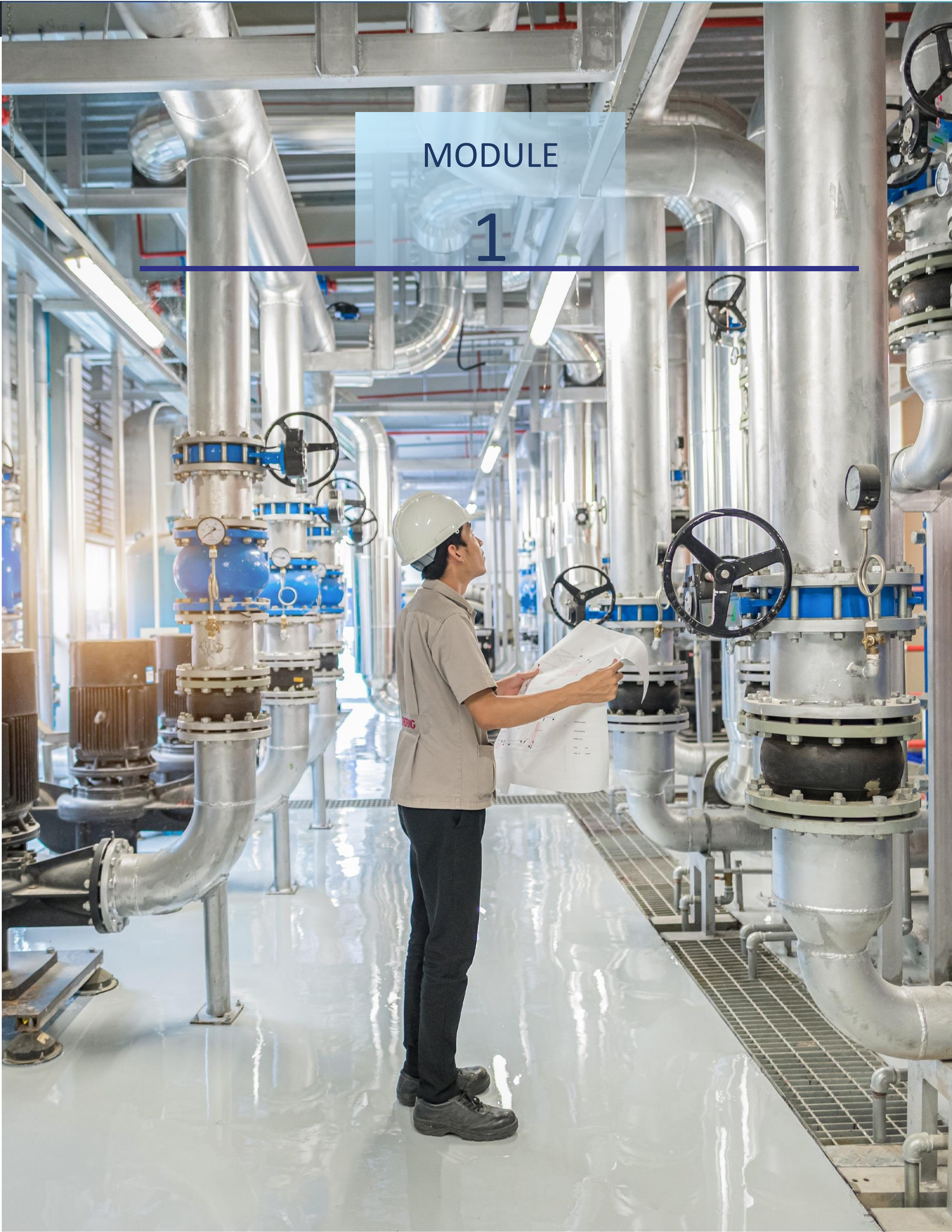
NO

Use TOOLS 5.1 & 5.2
for a list of climate change related KPIs for hydropower projects to propose KPIs that comply with the project's risk profile and scope.

MODULE 5 OUTPUT
Embed climate KPIs in contractual documentation.

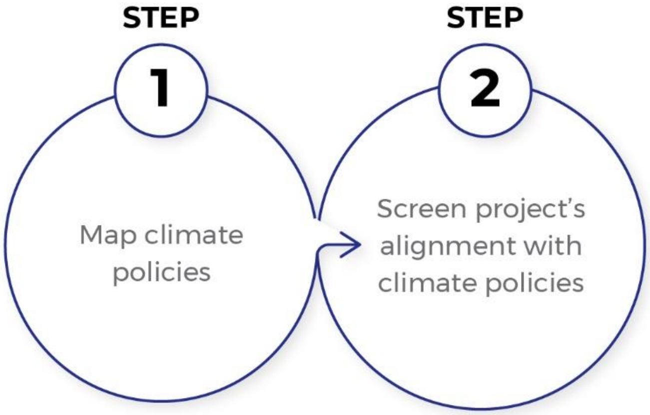
MODULE

1



Module 1

PROJECT ALIGNMENT WITH CLIMATE POLICIES



This module is analyzed in two steps. **Step 1** maps climate ambitions and national (or regional) policies detailing the specific strategies and action plans of the government regarding adaptation to and mitigation of climate change, and characteristics that are relevant to hydropower infrastructure. **Step 2** provides a methodology for assessing the strategic fit of a hydropower project with these characteristics. This exercise will define the periphery of climate considerations that will be identified, detailed, and appraised in **Modules 2** and **3**.

Step 1

Map Climate Policies

SCOPE	This step supports the systematic documentation of global and national climate strategies, policies, and action plans that set the framework for developing hydropower infrastructure. By understanding underlying principles, targets and commitments, the relevant agencies will be better prepared and equipped to design and deliver sustainable hydroelectricity projects that align with the climate mitigation vision of the PA and strengthen the capacity of communities to adapt to the adverse effects of climate change.
PROCESS	The process starts with a quick scan of the country's Nationally Determined Contributions (NDCs), national adaptation plans (NAPs), national adaptation strategies (NAS), and long-term strategies (LTS), which are the main national guidance documents for achieving the goals of the PA. It continues with a compilation of all the important documents that constitute the national climate policy landscape, whether climate laws/policies or other official governance documents on climate change.
TOOLS	**TOOL 1.1** Mapping climate policies and actors
OUTPUT	A country-specific inventory of the most important policy documents on climate change with specific references to the renewable energy sector, and more specifically to hydropower

TOOL 1.1

MAPPING CLIMATE POLICIES AND ACTORS

This tool is designed to facilitate a desk study of the landscape of climate policies and frameworks governing the planning and delivery of new hydropower projects and the sustainability assessment and upgrade of existing plants, based on the mapping methodology presented in the Umbrella Toolkit (Introductory Phase and Module 1.1), while focusing on priorities and provisions that are specific to hydropower projects.

For a more in-depth analysis of the country-specific policies and governance mechanisms, agencies are encouraged to seek support:

- From the PPP unit of the country/agency/ministry (which is expected to have a general mapping exercise for the country's completed PPP portfolio).

- Within relevant ministries (e.g., Ministry of the Environment and Energy, Ministry of Infrastructure, Ministry of Industry and Trade) and their corresponding departments (e.g., Department of New and Renewable Energy, Department of Climate Change).
- Within municipalities and other sub-national agencies, which are better informed about the climate adaptation activities that happen locally and that may not necessarily be reflected in national policy documents (outlined below).

INPUT

This mapping exercise requires users to gather and consult the following sources of climate policy documents, including provisions and guidance on the climate mitigation and adaptation potential of hydropower plants and their components. Each source is accompanied by a list of prompt questions meant to shape the respective focus areas.

1. National documents describing the country’s strategic development vision

Focus areas:

- Is the development of new hydropower infrastructure recognized as a strategic vision?
- How does it relate to PA, NDCs, and Sustainable Development Goals (SDGs)?
- Is there a national energy generation plan? What are its specified goals?
- Is there a commitment to increase renewable energy capacity?
- Has the country developed a plan for integrated water resources management?
- Are there any relevant agreements for transboundary developments?
- Is the project to be developed within the jurisdiction of a river basin organization, which may have its own institutional structure, plans and guidelines?
- Are dams favored as infrastructure systems that can enhance climate adaptation and mitigation of water scarcity?

2. Hydropower investment strategy or renewable energy investment strategy

(if available in the country-specific context)

Focus areas:

- What is the strategic role of hydropower investment, and how does it address the current needs for water and energy services?
- What are the emissions intensity thresholds driving the decarbonization pathway of the power sector?
- What is described as clean and sustainable hydropower?
- According to the strategic document, is there a recognized preference in the scheme of hydropower? For example, run-of-river (RoR) hydropower may be preferred over reservoir-based facilities, due to the reduced environmental impact. Alternatively, pumped storage plants may be prioritized because of their high energy storage capacity, which facilitates the generation of wind and solar power.
- What are the recognized priorities for future investment in the water sector that can be linked to hydropower development (e.g., a priority investment that foresees the construction of dams for climate adaptation and water management)?
- Does the strategic document include a description of relevant investment plans or a pipeline of bankable hydropower projects (e.g., a dedicated budget to support an early transition to clean energy generation)?
- Does the document set specific environmental targets? For example, is there a target to achieve no net loss of biodiversity through initiatives for leveraging of ecosystems and

ecosystem services (e.g., floodplain maintenance, connectivity for migratory species, maintenance of wetlands, nutrient and sediment balance, delta sediment replenishment)?

3. **Nationally Determined Contributions** outlining short and mid-term climate action plans

Focus areas:

- What is the emissions reduction target, and what are the adaptation goals described in the NDC?
- What is the contribution of power generation in the national GHG inventory?
- Does it mention hydropower? What are the exact priorities and measures for the sector?

4. **Long-term strategy** (if available) outlining a country's long-term climate change vision

Focus areas:

- Does the LTS describe a long-term emissions reduction goal? What is the horizon?
- Does it specify measures to achieve this goal? How do these measures relate to the power sector? For example, is the need for transformation of the sector explicitly stated? What are the energy targets, both in terms of additional renewable installed capacity and in investment needed?

5. **National adaptation plans** (or National Adaptation Programmes of Action or national adaptation strategies) providing a clear framework of how climate-change adaptation actions can be integrated into the development planning of all economic sectors

Focus areas:

- Does the NAP address hydropower-specific climate vulnerabilities? What are the most prominent climate risks identified?
- Does the NAP include an action plan to enhance climate adaptation and resilience? How is this related to the management of water resources and especially hydropower-related infrastructure?

Example

The NAP of Laos identifies the need to address climate resilience through improved dam safety regulations and guidelines. It highlights the intention to take advantage of reservoirs, through a multipurpose use of dams and associated infrastructure, to tackle climate adaptation and enhance the resilience of surrounding communities.

6. **Climate and environmental legislation** (enforced at either the national or sub-national or state level)

Focus areas:

- Does the legislation specify a "net zero" emissions target? Is this a cross-sectoral target or does it include specific provisions for the energy sector?
- Which ministries are responsible for the implementation of the law? Is it the responsibility of a single ministry, or are several ministries involved?
- What policy measures does the legislation entail, and how are these translated into national action plans and programs? For example, does the law promote the

development of sustainable renewable energy, and what are the action plans that have been developed in that respect?
- Is climate adaptation incorporated into climate legislation? What are the main areas of focus?
- Is there a national disaster risk management policy? Does it prescribe actions to enhance resilience against climate-induced impacts? Are there specific provisions for dams?

7. **National (or regional) energy master plan** or renewable energy master plan

Focus areas:

- Which entities (i.e., ministries) are responsible for the implementation of the plans?
- Have they identified potential hydropower developments at specific river basins?
- Do they mention specific sustainability, environmental, or social considerations?
- Have they estimated projected energy demands and socioeconomic variables that can affect the development of hydropower projects?

8. **Bilateral (or multilateral) agreements** with neighboring or other countries outlining the regime for the use of transboundary water resources

Focus areas:

- Are there aspects of the project with implications that cross state or provincial boundaries?
- What are the applicable policy and planning requirements?
- Are there existing provisions for transboundary environmental and social impact assessments? Are they based on universally approved criteria?

9. **Good practices and climate-related guidelines** describing opportunities and entry points for integrating green attributes/practices in hydropower projects. Details for major climate taxonomies and the definition of eligible activities may be found in the Umbrella Toolkit (Insights 1.3 and 1.4).

OUTPUT

The results of the mapping need to be reported in a systematic and comprehensive way to support the subsequent steps.

IMPORTANT NOTE

Effort and Resources

The more detailed the answers to the aforementioned prompt questions, the easier it will be to identify project-specific entry points and eventually to achieve the highest alignment level with climate policies and targets. For further reading on the importance and benefits of alignment with climate policies, users are referred to the Umbrella Toolkit (Insight 1.5 and Phase 0).

Step 2

Screen Project’s Alignment with Climate Policies

SCOPE	This step examines the project’s scope and description vis-à-vis the mapped climate policies and the country’s national development goals (outcome of **Tool 1.1**). In case of misalignment, specific actions are proposed to re-adjust the project scope towards a more sustainable and climate-resilient pathway.
PROCESS	The alignment process is performed in two stages, which are implemented during different phases of the project preparation: The **preliminary screening** may be performed **immediately after the project inception phase** (when the only available information is the outline of the project scope and the need it addresses). This first-level screening is meant to confirm that the project’s scope aligns with (or at least does not deviate from) the national vision for climate mitigation and adaptation. The **second-level screening** may be performed **towards the end of the project selection, and prior to the appraisal of the economic value of the project**. At this stage, the project's risk profile has been qualitatively assessed, and a preliminary discussion on adaptation/mitigation measures is underway. This is the right time to re-evaluate the project’s alignment with the national climate agenda (focusing now on specific project attributes) and re-adjust where necessary.
TOOLS	**TOOL 1.2** Screening project’s alignment with climate policies
OUTPUT	▪ Decision on climate alignment (preliminary and final) ▪ Actions to enhance the level of alignment (if deemed necessary)

TOOL 1.2

SCREENING PROJECT'S ALIGNMENT WITH CLIMATE POLICIES

The tool may be used to qualitatively assess the project's climate profile and its alignment with the policy framework defined by **Tool 1.1**. It is intended as a complementary attribute of the relevant module of the Umbrella Toolkit (Module 1.1). Therefore, it is structured in the form of a checklist made up of four pillars:

- Overall alignment of the project's scope with the country's SDGs and the Paris Agreement **(Pillar 1,** or **P1)**
- Overall alignment of the project's scope with the national (or regional) climate agenda (NDCs, NAPs, LTS, the energy master plan and renewable energy plans) **(P2)**
- Specific interventions contributing to climate mitigation **(P3)**
- Specific interventions contributing to climate adaptation and resilience of the project and the broader community **(P4)**

INSTRUCTIONS

1 **Define the type of screening**

For a **high-level screening** (performed during the very early stages of the project), users may focus on the first two pillars (P1 and P2) only. During the **second-level screening** (implemented towards the end of the project selection), it is recommended to use the entire checklist (P1 to P4).

2 **Use the input module of the tool to assess the performance of the project against each of the four pillars**.

3 **Use the output module of the tool to appraise the alignment status of the project.**

4 **Propose an action plan** to re-align the project's scope towards a more sustainable and climate-resilient pathway.

The action plan should be targeted to those pillars that have received relatively low scores.

INPUT

The following checklist compiles in P1 to P4 the criteria that can be used to judge the alignment of a hydropower project with the policy framework defined by **Tool 1.1**. Users are prompted to consider all the sub-criteria listed. The goal is to be able to identify areas of poor alignment and seek improvements at an early stage, acknowledging that poor alignment may undermine the project's eligibility for funding by several sources including the multilateral development banks (MDBs).

Four Pillars for Appraising Alignment

P1 PROJECT'S ALIGNMENT WITH THE SUSTAINABLE DEVELOPMENT GOALS AND THE PARIS AGREEMENT FRAMEWORK

Sub-criteria	**Characteristics/actions enhancing the project's alignment** (non-exhaustive list of examples)
What is the project's primary purpose, and how does it support the country's SDGs?	• Ensure alignment with the goal for affordable and clean energy (**SDG7**) and identify contribution to achieving additional goals through the rational management of the water resource: e.g., poverty reduction (**SDG1**), zero hunger (**SDG2**), and sustainable communities (**SDG11**). See example in **Box 1.1**.
Does the project support the country's effort to reduce carbon dioxide (CO2) emissions?	• Ensure that the project's GHG emissions are estimated thoroughly (considering its entire life cycle), and that they are consistent with mitigating carbon emissions.
Is climate adaptation an objective of the project?	• Ensure that there are plans for deploying the project's potential for water storage and supply, and (if applicable) for flood risk mitigation in the region. • Incorporate the changing climate trends into the planning decisions and into risk and vulnerability assessments of the planned hydropower infrastructure components and investments. • Leverage opportunities in disaster response and prevention (e.g., through the improvement of contingency planning and the implementation of early warning systems).
Does the project address greater overall inclusion, gender equality, and does it consider vulnerable groups?	• Ensure that consultations with stakeholders (especially local communities' representatives) are carried out in a respectful and inclusive way, such as following the approaches of free, prior, and informed consent,[4] and that they are tailored to the needs of disadvantaged and vulnerable groups.[5]

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[4] United Nations. 2018. "Consultation and free, prior and informed consent (FPIC)." https://www.ohchr.org/en/indigenous-peoples/consultation-and-free-prior-and-informed-consent-fpic.

[5] The World Bank Group's 2021 document "Green, Resilient and Inclusive Development (GRID)" provides further guidance on gender aspects https://thedocs.worldbank.org/en/doc/9385bfef1c330ed6ed972dd9e70d0fb7-0200022021/green-resilient-and-inclusive-development-grid.

P2 DOES THE PROJECT ALIGN WITH NATIONAL CLIMATE POLICIES?

Sub-criteria	Characteristics/actions enhancing the project's alignment (non-exhaustive list of examples)
How does the project support the implementation of the country's NDCs and energy transformation agenda?	• Consider the degree to which the project satisfies the overall target for decarbonization of the power sector, as determined in the country's NDC. • Use a site-specific estimate of net GHG emissions that will incorporate the carbon footprint of the reservoir (if there is one), the construction activities, and the operation of associated facilities and power lines. • Ensure that the emissions/energy production balance complies with the vision for sustainable hydropower.
How does the project comply with adaptation priorities?	• Ensure that the project will not undermine plans for adaptation in the other priority sectors, such as food security, water supply and sanitation, and protection of biodiversity and ecosystems. Note that cross-sectoral cooperation facilitates a balanced water-food-energy nexus. • Develop a good understanding of the future conditions (e.g., seasonal variations of the water cycle) in which the plant will operate. • Set up climatic and hydro-meteorological scenarios for the dam site. • Prioritize adaptation measures in zones where vulnerabilities are highest and where there is the greatest need for resilience and safety.
Has the country's NDC or NAP diagnosed vulnerabilities of hydropower infrastructure?	• If yes, ensure that associated risks have been addressed in a thorough manner, considering uncertainties (see **Module 2**), and that sufficient mitigation solutions have been planned.

P3 PROJECT'S POTENTIAL TO REDUCE GHG EMISSIONS AND BENEFIT THE ENVIRONMENT

Sub-criteria	Characteristics enhancing the project's alignment (non-exhaustive list of examples)
Will the project include activities to avoid/reduce GHG emissions?	Such activities may include:

Sub-criteria	Characteristics enhancing the project's alignment (non-exhaustive list of examples)
	• Use of green construction materials and processes. • Revegetation and catchment treatment. • Implementation of a monitoring program. Take the above into account in the assessment of the project's carbon footprint.
Will the project facilitate the installation of alternative renewables and contribute to a resilient energy grid?	• Energy storage capacity can be beneficial for the grid integration of intermittent wind and solar energy generation.
What are the associated impacts on the environment?	• Ensure that an environmental impact assessment has been conducted. • Ensure that the current and projected water footprint of the project is in alignment with overall water security and competing uses. • Ensure rational management of sediment flows, to minimize impact on downstream wetlands and ensure that anti-erosion solutions will be implemented, where needed, to mitigate watershed degradation.

P4

PROJECT'S ROLE IN CLIMATE ADAPTATION AND PROTECTION OF LOCAL COMMUNITIES

Sub-criteria	Actions enhancing the project's alignment (non-exhaustive list of examples)
Does the project incorporate methods to reduce its exposure/vulnerability to climatic risks?	• Ensure that a climate risk assessment has been performed (for current and future climate conditions) considering all the possible types of climate hazards (see **Tool 2.1**) applicable to the specific site as well as cascading hazards (e.g., land/mud slides, fires). • The risk assessment accounts for hazards that may directly or indirectly impact the performance of the hydropower plant. For example, extreme precipitation events may provoke overtopping, outages, damage to equipment, and adverse downstream impacts but may also trigger landslides or excessive silting, which can reduce the volume available for water within a reservoir and/or clog the water discharge system.
How will the project adapt to the adverse impacts of climate change?	• Ensure that adaptation strategies have been defined to safeguard the project's resilience for the entire spectrum of climate hazards and their possible future escalation (e.g., extreme flooding events will be managed with the use of proper engineering

Sub-criteria	Actions enhancing the project's alignment (non-exhaustive list of examples)
	options such as spillways, gated systems, and fuse plugs).
Does the project's design include measures to enhance climate resilience at a regional scale and to protect the well-being and livelihoods of the indigenous people?	• Ensure deployment of the project's capacity (for example, plans to increase the water provided for agriculture in the downstream environments during dry seasons) and infrastructure to provide climate adaptation for the surrounding environment and communities. This is often possible, especially regarding hazards linked to extremes in water discharges, e.g., floods and droughts. • Installation of fire protection mechanisms (e.g., warnings and suppression systems) can substantially reduce the wildfire risk in the region.
Will the project include emergency procedures/equipment to enable preparation ahead of extreme events?	• Install smart information systems for disaster risk management during extreme events. • Prepare/update disaster response plans.
Does the project's design incorporate measures to protect the specific needs of women and vulnerable populations from the impacts of climate change?	• Ensure that emergency plans consider the needs of vulnerable groups and that they are communicated to them in the most efficient ways (e.g., information in the local languages, communication to illiterate populations). • Ensure adaptation measures are gender inclusive. • Put together a gender action plan that will ensure that all activities implemented during the development include a gender perspective and promote the considerations of gender issues and vulnerabilities.[6]

OUTPUT

Following the above process, users are expected to have identified the areas where the project is well aligned with the Paris Agreement goals, as well as areas where further improvement is necessary. Users should keep in mind that the World Bank will not be supporting projects which are not fully aligned with the Paris Agreement, according to the Joint MDB Assessment Framework for Paris Alignment for Direct Investment Operations.

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[6] The World Bank Group's 2021 document "Green, Resilient and Inclusive Development (GRID)" provides further guidance on gender aspects https://thedocs.worldbank.org/en/doc/9385bfef1c330ed6ed972dd9e70d0fb7-0200022021/green-resilient-and-inclusive-development-grid.

BOX 1.1 TRADE-OFFS CAN BE TURNED INTO SYNERGETIC OPPORTUNITIES: THE EXAMPLE OF THE MEKONG RIVER

The Mekong is the largest transboundary river in Southeast Asia and one of the world's most actively developed regions for hydropower. Its main stream and tributaries offer about 235,000 gigawatt-hours (GWh) per year in hydroelectric potential. At the same time, agriculture is an essential pillar for economic activity and food security: Cambodia's Tonle Sap lake is home to the world's largest freshwater fishery, with more than 2 million tons of annual harvest (valued at approximately $2 billion).

Intensive reservoir development for hydropower production naturally raised concerns over the trade-offs between water supply, food, and energy. Yet, a recent analysis of extensive data from hydrometeorological monitoring, irrigated crop production measurements, and fish yields indicates that trade-offs are mainly a result of release timing rather than consumptive use. The optimization of dam design, reservoir operations, and water storage using an integrated hydro-economic optimization model leads to multiple benefits across the sectors:

- During droughts, water release from reservoirs in the Mekong can mitigate up to 30 percent of crop loss if irrigation is prioritized over hydropower during the months of peak irrigation demand. This is possible without severe impacts to energy generation.
- Management of water releases from reservoirs can shift the annual lows in river flows, thereby raising irrigated crop revenue by up to 49 percent.
- Applying eco-friendly flow patterns can improve fishing yields in the basin by up to 75 percent (accepting a 17 percent reduction in energy production).

It is possible to manage reservoir operation fairly and efficiently, in a way that will benefit the whole basin, mitigating the effects of flow fluctuations on the livelihoods of farmers and fishers living downstream. The key is a rationally balanced use of the water resource, facilitated by the development of basin-scale, cross-sectoral and transboundary partnerships. Leveraging new technologies allows for data sharing, real-time monitoring, and the use of a cooperative platform for efficient management and dynamically optimized decision-making.

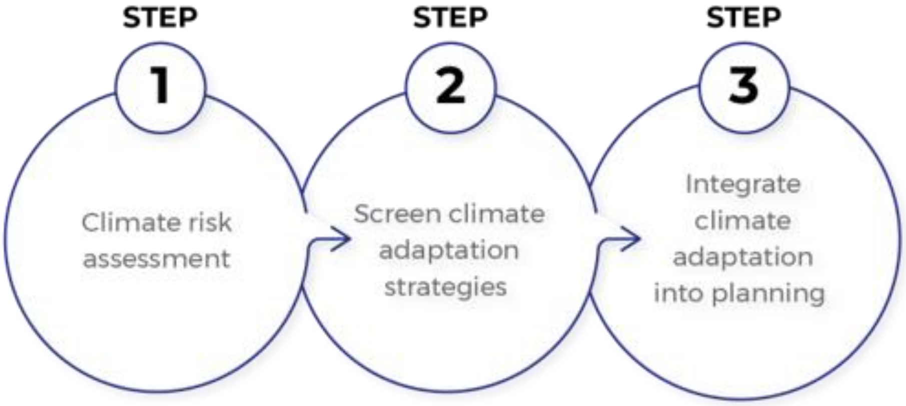
Source: Do, Pierre, Fuqiang Tian, Tingju Zhu, Bahtiyor Zohidov, Guangheng Ni, and Hui Lu. 2020. "Exploring synergies in the water-food-energy nexus by using an integrated hydro-economic optimization model for the Lancang-Mekong River basin." *Science of The Total Environment* 728 (137996).

MODULE

2

Module 2

ASSESS CLIMATE RISKS AND PLAN ADAPTATION STRATEGIES



This module is divided into three steps. It begins with a mapping exercise intended to screen the possible sources of climate-related threats and evaluate their potential risks to the hydropower project (**Step 1 - Assess climate risk**).

Next, users are guided in identifying ways to alleviate these impacts and understand the costs of the various adaptation options that can build resilience at the project scale and at the regional scale (**Step 2 - Screen possible adaptation strategies to reduce climate risks**).

Finally, climate considerations are incorporated into a multi-criteria decision-making framework that aims to assist users in excluding risky or technically unfeasible projects, instead prioritizing those projects that both receive the maximum consensus among stakeholders and that are less susceptible to changing climatic conditions (**Step 3 - Integrate climate risks into the planning of hydropower projects**).

Note that implementation of the module's principles in larger projects will require more extensive analyses by expert consultants.

Step 1

ESS Climate Risks

SCOPE

To identify and qualitatively assess the climate risks affecting the project. The assessment will consider both internal risks (i.e., the risk of damage affecting the hydropower plant's assets, its availability, and its power-generating capacity) and external risks (i.e., a functional hydropower plant with reduced power demand or with conflicting water usages). The identification of these risks early in the planning stage will inform resilience and adaptation priorities and guide decisions in the next step.

PROCESS

The methodology for assessing climate risks is described in detail in the Umbrella Toolkit (Modules 1.2 and 2.1). The underlying assumption is that the risk of an infrastructure or a component may be defined as a combination of the potential impact of a threat/event and its likelihood of occurrence according to the fundamental risk equation:

RISK = [HAZARD INTENSITY x LIKELIHOOD] x IMPACT

The process begins with the identification of the climate threats (hazards) that may affect the project. Then, the intensity and likelihood of the identified threats are considered for a qualitative hazard evaluation on a scale from low to high. This is performed for different climatic futures (representing different climate projections). Next, the impacts of each hazard are assessed in a similar manner. Finally, the risk is estimated as the product of hazard and impact.

The process is assisted by four tools (**Tool 2.1 – Tool 2.4**).

TOOLS

TOOL 2.1	Mapping climate threats considering future projections
TOOL 2.2	Assessment of impact on major asset categories
TOOL 2.3	Assessment of climate risks
TOOL 2.4	Evaluation of climate-change-induced externalities and impacts

OUTPUT	▪ A qualitative risk matrix per hazard indicating the risk of physical damage and operational disruption of the hydropower project ▪ A prioritization/ranking of the most significant risks that will be passed on to **Steps 2** and **3**

TOOL 2.1

MAPPING CLIMATE THREATS CONSIDERING FUTURE PROJECTIONS

This tool defines a threat as any climate-related circumstance, action, or event that might trigger the potential vulnerabilities of the project. Vulnerabilities would include the susceptibility or inability of the infrastructure assets to cope with climate variability and extremes, with the potential of adversely impacting infrastructure serviceability. Such a threat can be:

- An individual extreme event (acute hazard) that may damage or reduce the functionality of the infrastructure asset (e.g., a severe flood that may cause physical damage to the dam structure).
- A chronic change in a climate stressor impacting the energy production of the plant. For example, an increase in the duration or intensity of droughts which may aggravate fire risk.
- A combination of stressors (e.g., an increase in peak annual precipitation with a concurrent decrease in average annual precipitation, which may affect water uses and impact the energy generation capacity of the plant).
- A multiplier of a climate stressor to an already recognized external risk of the system (e.g., changing demographics associated with climate-change projections). This type of threat is separately covered in **Tool 2.4**.

This tool assists users in identifying and mapping the climate stressors or hazards to which a hydropower facility may be exposed throughout its life cycle. The tool provides guidance on how to screen potential hazards, qualitatively assess their intensity, and estimate the likelihood of their occurrence. Preliminary hazard screening may be facilitated by the results of a global survey of the impact of climate change on existing and planned hydropower projects, as reported by Wasti et al. (2022)[7] and summarized in **Box 2.1**.

INPUT

1

Decide on the timeframe of the assessment

The minimum timeframe for assessing climate hazards will be the PPP life cycle. However, the government may wish to extend the timeframe of the study given

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[7] Wasti, A., P. Ray, S. Wi, C. Folch, M. Ubierna, and P. Karki.2022. "Climate change and the hydropower sector: A global review." *WIREs Climate Change* 13(2), 1–29.

that the life cycle of the infrastructure may be longer than the duration of the PPP contract (e.g., infrastructure design life).

2

Identify the climate-related hazards that can affect hydropower development.

A generic list of hazards/climate stressors affecting hydropower projects is provided in **Table 2.1**. All hazards/stressors are classified into four variables—temperature, precipitation, sea-level rise, and wind—that can be retrieved from climate models. Due to climate change, these climate variables change at a global and regional scale, affecting chronic and acute weather patterns.
In addition to the information provided in **Box 2.1**, country- and region-specific climate-related hazards can be found in the following (indicative) sources:

- Climate Change Knowledge Portal (World Bank Group)
- Think Hazard! (Global Facility for Disaster Reduction and Recovery (GFDRR) - World Bank Group)
- Climate links (United States Agency for International Development (USAID))
- The Global Risk Data Platform (GRDP)
- Global Assessment Report on Disaster Risk Reduction
- Forty-Eighth Session of the Intergovernmental Panel on Climate Change (IPCC-48)

3

Leverage local knowledge and experience to confirm/revise hazard findings

This may include already available regional impact maps and previous hazard studies. Past experience in the area can also provide a foundation for identifying the most frequently encountered weather events or characterizing high-risk regions (e.g., recent glacial lake outburst floods). Advice on regional risks may also be sought from local contractors or district engineers.

4

Use the scoring system provided in the graphic below to estimate the current hazard level as a function of the intensity (and duration) of the hazard and its likelihood of occurrence (or frequency of the event). Gradually evolving hazards or chronic stressors (e.g., changes in annual precipitation/temperature), can be scored as "low" if the rate of change with respect to today's values is predicted to be minor during the timeframe of the assessment. If a long-term but notable change is expected, the hazard is scored as "medium." If the change is significant and/or the time-horizon of the projected change is short (i.e., in the case of a rapidly evolving phenomenon), the hazard is scored as "high."

5

Understand the future trend of hazards due to climate change and uncertainty (i.e., increasing, decreasing or stable)
Observe the global and (if available) the regional future projections of the corresponding controlling variable (as listed in the second column of **Table 2.1**) and make reasonable estimates about the future trend of the hazard under

consideration. For example, if the project region is showing an increasing trend in average precipitation (and if no other data are available), it is reasonable to anticipate an increase in extreme rainfall and flood events. It is generally considered good practice to use different climatic projections representing different Representative Concentration Pathways (RCP) scenarios (see the following note). Country-level information on future climate trends may be retrieved from the Climate Change Knowledge Portal (World Bank Group). Additional resources, providing downloadable datasets of projected precipitation and temperature, are freely available through online platforms, such as the KNMI Climate Explorer of the World Meteorological Organization, and the WorldClim portal.

7

Assess the future hazard level by combining the current hazard intensity and the future trend

For example: for a "medium" current hazard level with an "increasing" trend, the future hazard level will be set equal to "high."

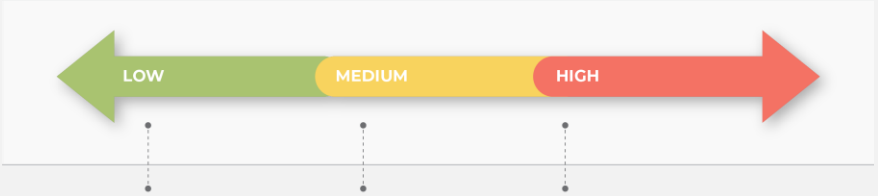
8

Screen climate predictions and estimate how much the likelihood and intensity of climate stressors will change in the future

Users are advised to focus on primary climate stressors and de-prioritize stressors that have subordinate impacts on the project's performance.

6

Use the scoring system provided below to assess climate stressor variability based on the rate of anticipated change of the primary stressor.



LOW	MEDIUM	HIGH
Acute stressor: not likely to occur, and if it occurs its intensity will be low.	**Acute stressor:** moderate intensity expected to occur at least once in the reference period.	**Acute stressor:** likely to occur several times with relatively high intensity.
Chronic stressor: rate of change projected to be minor.	**Chronic stressor:** notable rate of change projected.	**Chronic stressor:** rapid rate of change projected.

* Estimates referring to the timeframe of the assessment ≥ PPP lifecycle

OUTPUT

The result of the above process will be a preliminary profile of climate hazards affecting the project. Such hazard data need to be reported in order to be used as an input in the subsequent risk estimates.

IMPORTANT NOTE

Future Climate Projections RCPs and SSPs

It is common practice to project future climate conditions based on the Representative Concentration Pathways (RCPs), to represent different trajectories of radiative forcing levels over time. Out of the four RCP scenarios, RCP 8.5 represents the highest emissions scenario, whereas RCP 2.6 represents the lowest emissions scenario. RCP 2.6 should be generally avoided when making projections because it is overly optimistic compared to recent emissions trends.

In 2016, the Shared Socioeconomic Pathways (SSPs) were introduced as an update and a substantial expansion over the RCPs. Available through Phase 6 of the Coupled Model Intercomparison Project (CMIP6), the SSP framework contains a total of eight different multi-model climate trajectories based on alternative/plausible scenarios of future emissions and land-use changes by which society and ecosystems will evolve in the 21st century. Global scale predictions of climate parameters for different SSPs are available in the WorldClim database.

BOX 2.1 GLOBAL MAPPING OF CLIMATE CHANGE IMPACTS ON HYDROPOWER

Figure B2.1.1 summarizes the results of a global survey on the effect of climate change on hydropower. Symbols are used to illustrate the category of the hazard, considering glacier melt, early snowmelt, extreme precipitation, streamflow, flooding, drought, and glacier lake outburst floods. The direction of the arrows (up/down) indicates the rising/decreasing trend in the magnitude and frequency of the associated weather phenomenon.

FIGURE B2.1.1 Dominant climate-change-originated hazards for global hydropower projects considering historical observations and near-future projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5). *Source*: “Climate change and the hydropower sector: A global review.”

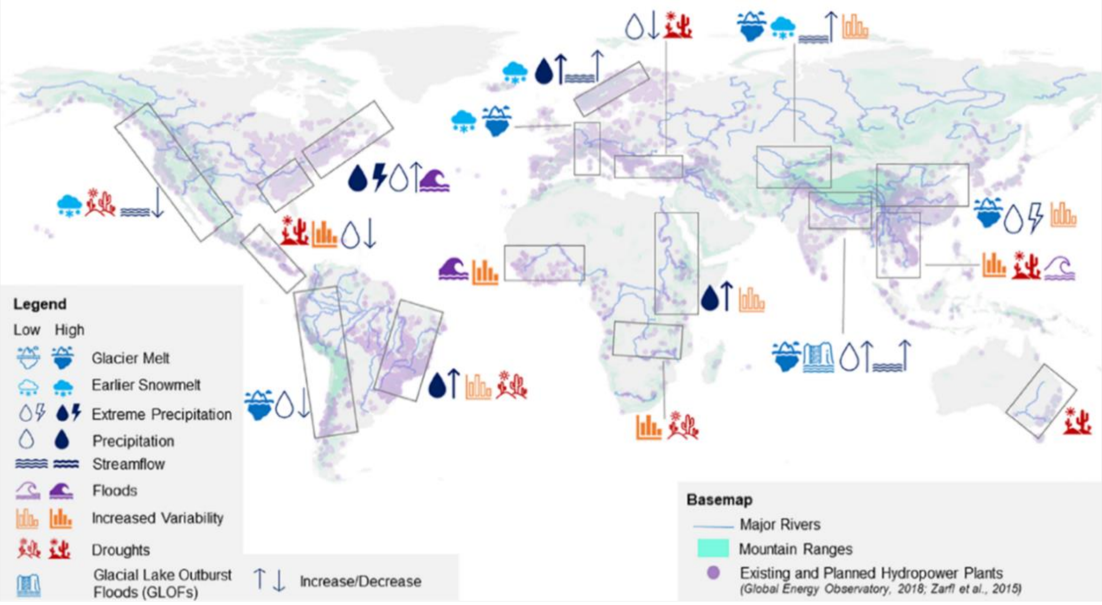


TABLE 2.1 Climate change threats and their potential impacts on hydropower plants

Climate Threats	Controlling Variable	Impacts on Hydropower Plants
CHRONIC STRESSORS (affected by climate change)		
Changes in annual precipitation patterns	Precipitation	• Variations in precipitation modify the hydrological regime, leading to streamflow variations that unavoidably affect the availability and durability of water and, thereby, the energy generation capacity. • Reduced precipitation leads to more intense and longer periods of drought, causing water scarcity and increased competition between different sectors over the deployment of water resources. Such competition may lead to reduction of the water used for energy generation as well as to conflict with local communities and stakeholders. • On the other hand, increased precipitation is associated with higher risk of failure due to flooding (excess hydraulic actions), and may lead to increased scouring and erosion of earthworks and foundations, undermining the stability of infrastructure supported on erodible soils. Furthermore, increased debris flows are expected due to the increased streamflow, which can obstruct the operation of the spillways because of partial or total blockages and amplify sedimentation rates (impacting reservoir serviceability and lifetime). • Either way, climate-change-induced variations in precipitation reduce the predictability of the hydrologic and hydromechanical models employed for the design and assessment of the infrastructure, threatening the safety and operability of certain critical components (e.g., spillways, turbines).
Changes in mean temperature	Temperature	Warming can adversely impact hydropower generation through several interrelated climate phenomena: • In addition to aggravating droughts and the associated water scarcity (discussed above), it leads to increased risk of fire. • The associated vegetation loss can impact the plant infrastructure either directly, through debris flows and accumulation of organic matter in the reservoir, or indirectly, due to the increased surface run-off leading to more frequent and intense flooding during rainfall events. • In high-altitude mountainous regions, additional adverse effects must be considered, discussed in the following in more detail: degradation of permafrost, reduction of seasonal snow storage, and avalanche risk.
Degradation of permanent glacier and ice storage	Temperature	• Glacier degradation leads to increased streamflow and, thus, an opportunity for increased energy production in the short term, but it may reduce streamflow in the long term.

Climate Threats	Controlling Variable	Impacts on Hydropower Plants
		• It is also a multiplier of flood risk and a hazard for hydropower infrastructure, which may be impacted by flowing masses of ice and catastrophic avalanches.
Reduction in seasonal snow storage	Temperature	• Reduced snow storage may occur due to warming of winters, i.e., shift of minimum temperatures and shortening of cold days. It affects the hydrologic regime of rivers and likely reduces the stream flows during springs and summers. • The impact may be severe for RoR projects and projects with relatively small reservoir capacities.
ACUTE HAZARDS (affected by climate change)		
Floods caused by extreme rainfall	Precipitation	• Floods of extreme magnitude may exhaust the design capacity of the infrastructure to accommodate hydraulic loads, causing dam overtopping, followed by erosion and/or scour. • Overtopping is an important failure mode for most dams, in particular for embankment dams where it may result in catastrophic collapses. • Furthermore, erosion and scour lead to differential displacements of foundations and embankments, causing significant damage to the supported infrastructure. • Extreme floods also threaten the energy generation potential of a plant, in addition to its safety, due to the release of water that usually takes place at the beginning of a flood (lowering of the reservoir water table). Inadequate reservoir management strategies or misprediction of incoming flows may result in misuse of the available storage.
Glacial lake outbursts	Temperature	• Warming causes degradation of glaciers, often followed by development of new glacial lakes or enlargement of existing ones. These are precarious formations held in place by debris blockages or unstable barriers (moraines). Abrupt failure of the latter can cause destructive dam-break floods involving excessive discharges of water and torrential flows. The impact can be harsh for any type of infrastructure located downstream.
Landslides	Precipitation	• Landslides are geohazards that are often driven by excess precipitation. As pore pressures accumulate in the masses of sloping grounds, they reduce the capacity of soil or rock to resist the movement/sliding of precariously standing masses. • Failures may be abrupt and lead to the detachment of vast amounts of soil/rock. These movements have the capacity to carry away any type of infrastructure (roads,

Climate Threats	Controlling Variable	Impacts on Hydropower Plants
		pipelines, foundations) that may be partially or fully embedded in them, causing significant failures. • Landslides can cause overtopping or dam breakage if the failure mechanism occurs in the vicinity of a dam or if the detached masses end up in the reservoir.
Avalanches	Temperature	• Similar to landslides, avalanches can impact infrastructure and reservoirs existing in their vicinity. • Warming air temperatures are a driver of avalanche risk due to their impact on the quality and bearing resistance of snow.
Fires	Temperature	• Fires cause physical damage to the power facilities and the equipment of transmission and distribution lines. Wildfires may significantly alter the land cover in the catchment, resulting in increased erosion and sedimentation rates.

TOOL 2.2

ASSESSMENT OF IMPACT ON MAJOR ASSET CATEGORIES

The tool may be used to assess the impact of expected variations in the climatic stressors (as identified using **Tool 2.1**) on the hydropower project. In this assessment, the user should consider the impact in terms of

- **Infrastructure safety:** assess the potential of physical damage to a component of the infrastructure which can result in reduced capacity, in comparison to design, or failure (e.g., deformations due to overtopping).
- **Serviceability loss:** assess the potential of hindered access or blocked use of critical infrastructure components (e.g., spillways blocked by debris).
- **Energy generation:** assess the potential of reduced availability or misuse of the water resource leading to decreased energy production or missed opportunities for higher energy production.

INPUT

1 **Define the ways that the hydropower facility can be impacted by climate stressors**

Use the information provided in **Table 2.1** to identify possible impacts for each one of the hazards identified in **Tool 2.1**.

Shortlist the most relevant impacts according to the regional setting and the characteristics of the project, complementing the list with any additional, case-specific vulnerabilities. The size of the hydropower facility will also have a direct impact on the extent of analysis required.

Whenever possible, highlight critically vulnerable elements (i.e., impacted components/processes that are essential for the operation of the facility) as key points for consideration during the development of adaptation strategies (**Tool 2.5**).

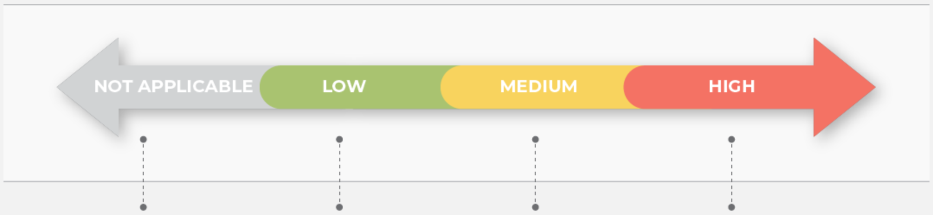
2 Assess the potential losses associated with negative impacts.

Assessments should include:

- Number of days per year that the facility is out of service or is underperforming (e.g., due to reduced streamflow or damage to critical asset components).
- Expected reduction in power generation (e.g., an x% reduction of annual precipitation will result in a y% reduction in power generation capacity).
- Indicative cost of repairs, maintenance, and replacing damaged components (e.g., increased cost due to more frequent need for sediment removal actions).

3 Appraise impact severity

Use the qualitative scale provided in the graphic below to characterize the criticality of each potential impact on the operability and energy generation capacity of the facility.



NOT APPLICABLE	LOW	MEDIUM	HIGH
The project is not impacted by the climate threat.	▪ Components of the facility may be slightly damaged. ▪ Damaged components can be restored quickly and at low cost. ▪ The facility may operate at reduced capacity for a few hours.	▪ Substantial parts of the facility may be moderately damaged. ▪ Damage/service restoration can be costly. ▪ Operational disruptions may last for a few days.	▪ The majority of the facility has been severely damaged, requiring extensive restoration or replacement activities. ▪ The facility may remain out of service (or operate at reduced capacity) for an undetermined period. ▪ Unreliable service and social distrust.

OUTPUT

A comprehensive list of potential climate stressor impacts on the project and its assets, to be input in the subsequent climate risk assessment (**Tool 2.3**).

TOOL 2.3

ASSESSMENT OF CLIMATE RISKS

Following the definitions provided in the Umbrella Toolkit (Modules 1.2 and 2.1), internal climate risks originate from hazards/stressors that directly affect the project; such internal risks describe the **likelihood of a project experiencing an impact of a given severity**. In preliminary climate assessments, the term “likelihood” is schematically used to encapsulate two factors:

- The *frequency of the climate event* (i.e., how often is the facility expected to experience such impacts). This parameter is primarily a function of the intensity of the event, so that the stronger the event, the lower the frequency.
- The *uncertainty of the evolution of climatic factors*.

This tool may be used for a qualitative assessment of *internal* climate-induced risks for hydropower projects. It may be combined with **Tool 2.4**, which estimates external risks (i.e., indirect impacts due to hazards affecting the project’s socioeconomic environment) for an appraisal of the total (internal and external) climate risk.

INPUT

1 **Assign likelihoods to hazards/stressors** potentially affecting the project.
For acute hazards: As a rule of thumb, set likelihood equal to “low” for events that take place once or twice in the life cycle of the project (e.g., a flood that may induce overtopping, if overtopping has been allowed for in the design of the dam), and “high” for events recurring in one to five years.
For chronic stressors: For conservative estimates, consider setting likelihood equal to “high” for all climate projections. Alternatively, set likelihood equal to “low-medium” for climate projections made under the RCP 8.5, and assign “high” likelihood to climate projections that are consistent with RCP 4.5 or 6.0.

Note: Before setting probabilities to RCPs, it is recommended users consult national adaptation documents to guarantee compliance with the prescribed risk assessment framework.

2 **Calculate the climate risk level of each hazard/stressor** as a product of hazard (input from **Tool 2.1**), likelihood (as determined in the previous step), and impact (input from **Tool 2.3**):
[HAZARD x LIKELIHOOD] x IMPACT

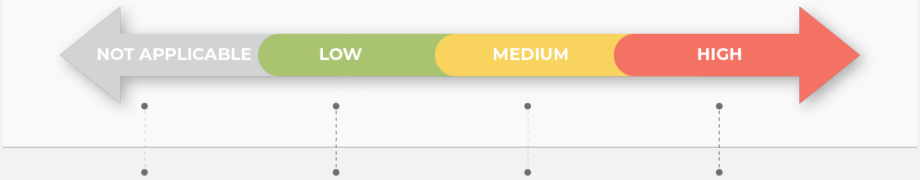
For a qualitative assessment, use the color-coded, two-dimensional matrix provided below. First, combine HAZARD/STRESSOR with LIKELIHOOD to assess the THREAT. Then, combine THREAT with IMPACT to deduce the RISK level.

	Low	Medium	High
Low	LOW	LOW	MEDIUM
Medium	LOW	MEDIUM	HIGH
High	MEDIUM	HIGH	HIGH

In the first iteration, read the hazard severity in the first column (vertical direction of the matrix) and combine it with the likelihood level in the first row of the table (horizontal direction of the matrix). In the second iteration, the threat scales vertically, and the impact scales horizontally.
Example calculation: [low x medium] x high = low x high = medium

3. **Build the risk matrix of the project** combining risks stemming from all potential threats and considering climate scenarios.

4. **Describe consequences and, where possible, provide cost estimates for the level of operational disruption**. As displayed in the graph below low climate risks are associated with minimal disruptions to the facility and the broader community, whereas high climate risks may cause service unavailability for several days and significant revenue loss (that can be catastrophic for the investment). In extreme cases, a prolonged water crisis can create social outrage and distrust.



NOT APPLICABLE

Minor operations disruptions are very rare.

LOW

- The facility may experience (e.g., once per year) minor operational disruptions.
- Major operational disruptions are very rare.
- The increase in maintenance cost is relatively low.
- The energy production of the facility will remain constant (even for the RCP 8.5 projections).

MEDIUM

- Significant operational disruptions may happen on an annual basis or less frequently.
- A moderate increase in the maintenance cost should be expected.
- A slight decrease of energy production for RCP 6.0 or 4.5 projections (and a moderate decrease for the RCP 8.5 projections).

HIGH

- Major operational disruptions may take place frequently.
- Maintenance cost may substantially increase.
- A considerable decrease in energy production is projected in all RCP scenarios.

OUTPUT

A systematic description of all potential climate risks affecting the hydropower project and associated rough cost estimates.

TOOL 2.4

EVALUATION OF CLIMATE-CHANGE-INDUCED EXTERNALITIES AND IMPACTS

External risks originate from hazards/stressors affecting either the infrastructure of the hydropower plant or its broader socioeconomic system, thus indirectly impacting the project's operations and energy generation capacity. As external risks are beyond the control of the project, it is important to identify them early in the project selection process, estimate the severity of their impacts, and plan for contingencies when possible. It may be advisable to restructure or even abandon projects that experience high external risks which cannot be mitigated.

INPUT

This tool may be used to perform a preliminary screening of the broader socioeconomic impacts of climate change and their interactions with the project underway.

1 **Identify external risks that are pertinent to the regional setting of the project.**

A list of commonly encountered climate-induced external risks impacting hydropower projects is provided in **Table 2.2**. The listing is indicative, describing conditions that may introduce positive or negative externalities to the project due to climate change. The user is encouraged to customize the list as appropriate to make it relevant to the project specifics.

Score the "external risk level" as "low," "medium," or "high" (specifying risk sources that are particular to the project under consideration) and add the results to the climate risk matrix of the project (output of **Tool 2.3**).

3

For each externality, estimate potential losses (or gains) and think of ways to remediate their negative consequences. Although in principle external risks lie outside the responsibility of the facility owner, unmitigated risks can negatively impact investor appetite and the bankability of the project. Users should make sure due diligence is practiced when assessing the climate externalities of the project.

Note: Mitigation of external risks is rarely solved through better (or more expensive) adaptation plans. It commonly requires the structuring of adequate risk allocation clauses that specifically describe the responsibility boundaries of the facility owner and provide for the compensation/negotiation mechanics to manage losses. External risk mitigation may also require the addition of contractual provisions that specify strategies/plans to be implemented in parallel with the hydropower project to reduce its vulnerability to external factors. This requires coordination with the local stakeholders and adaptation to the local context.

TABLE 2.2 External climate-induced risks and consequences for hydropower projects

External Factors that Can Be Impacted by Climate Change	Example Consequences for Hydropower Projects
Land use/land cover (LULC) changes, whereby a specific area of land is converted from one use/cover to another	LULC changes can be very consequential for hydropower projects, affecting them in multiple ways. The most significant are related to: • Considerable changes in land use, especially if associated with increasing water demands for irrigation, can increase competition for water use, resulting in policy-enforced limitations that can affect the energy generation capacity of the project. • Changes in the amount of water infiltration across the catchment and hence the surface runoff contribution to the stream flow, which is directly related to the energy generation capacity of the project. • If significant, streamflow changes can have an important effect on flood risk. • Increased erodibility of lands at the periphery of the reservoir causes a greater amount of sedimentation, which diminishes a reservoir’s lifetime. • The sediment and vegetation content of the inflow affects the degree of GHG emissions produced by the reservoir.
Demographic changes to the human population and population segments. These may refer to population distribution, age, marital status, occupation, income, education level, and other statistical measures that may influence the project.	Demographic changes may affect the project through: • Changes in energy demand and prices. • Changes in water demand and competing uses.
Geomorphological and environmental changes: Climate-related hazards may affect the surrounding environment, morphology and/or surrounding infrastructure and, consequently, affect the operation and even the exposure and vulnerability of the project.	Wildfires may pose a significant threat to a project’s operation due to its dependency on power lines. Furthermore, wildfires occurring in a reservoir’s catchment have a very detrimental impact on sedimentation levels and increase long-term GHG emissions.

External Factors that Can Be Impacted by Climate Change	Example Consequences for Hydropower Projects
Associated infrastructure: Climate-change-induced hazards (e.g., permafrost thawing, landslides, mudflows, erosion, and scour) may disrupt the operation of associated infrastructure systems.	Thawing of permafrost ground (due to warming environmental conditions) can cause large-scale settlements along roads that connect the plant to the surrounding communities and external resources. Rainfall-induced slope deformations may cause failures of transmission lines leading to long operational disruptions. Damages to buildings can be disastrous for the safety of the staff and the local community. Particular attention must be paid to enhancing the safety and sustainability of resettlement houses and host communities.
Technological changes: Invention and practice of new technologies and innovative fields that may be impactful for the development and operation of hydropower projects.	Technological advancements may provide opportunities for the project to adopt innovative techniques which may enhance the project's resilience and its potential to operate as a means for adaptation to climate change impacts. Such an example is the incorporation of monitoring and early warning systems that can be installed along the river. In addition to monitoring floods, such systems can be useful for accurate monitoring of environmental flows and water uses.
Policy and regulation changes: Evolution of national and worldwide guidelines and regulations on sustainability and climate change.	Government policy changes, and national or regional actions protecting the use of water in the catchment of interest can have major implications for the project's viability.

OUTPUT

A ranked list of climate externalities for the project, including a description of consequences and possible remediation measures.

Step 2

Screen Possible Adaptation Strategies To Reduce Climate Risks

SCOPE	To identify adaptation measures and compose alternative strategies that build climate resilience into the hydropower project by reducing the project-specific climate risks while maximizing the positive socio-environmental impact of the project. If deemed necessary, the climate adaptation strategies determined here may be combined with climate mitigation measures, as detailed in **Module 3 (Tool 3.2)**, to form a long-term climate plan for the hydropower project.
PROCESS	The process starts with a detailed mapping of all possible adaptation solutions relevant to the project's climate risks (**Tool 2.3**). Users are then asked to build alternative adaptation strategies combining different adaptation measures. The alternative strategies may differ in terms of capital costs and may offer different protections within the multi-hazard environment of the project. Finally, a pre-selection of the preferred adaption strategies will be performed in **Step 3** using a multi-criteria decision framework.
	
TOOLS	**TOOL 2.5** High-level screening of climate adaptation strategies
OUTPUT	A list of possible adaptation strategies for further consideration (in **Step 3**)

TOOL 2.5

HIGH-LEVEL SCREENING OF CLIMATE ADAPTATION STRATEGIES

This tool will guide users through the process of identifying effective climate adaptation strategies that are proportionate to the level of anticipated climate risk. The user is encouraged to become familiar with the concepts of adaptive planning and the relevant existing methodologies, namely adaptive policy making, adaptation pathways, and dynamic policy pathways, as described in the Umbrella Toolkit.

Adaptation strategies are grouped into four categories:

- **Changes in the planning of the project**, including changes in the location or changes in the installed capacity. For example, the agency may wish to consider expanding the intended capacity of the plant to benefit from the projected higher potential for power generation or to consider integrating a potential expansion in the planning process for the future.
- **Changes in the design through hard-engineering solutions** (i.e., structural interventions) aiming at increasing the robustness of the design against identified climate risks (e.g., alter the dam height, type and/or construction material; make allowances for overtopping; modify turbine types/sizes; reinforce banks with anti-erosion protections).
- **Green engineering solutions** aiming to protect the hydropower project and safeguard its operational efficiency without building structural interventions and usually at a significantly lower cost. Such solutions typically simultaneously serve the purpose of climate mitigation and may also offer biodiversity benefits. In this category, we may find nature-based solutions (NbS) that work with natural processes to reduce risks (e.g., the use of vegetation for landslide protection and/or on-site soil stabilization, as discussed in **Box 2.2**).
- **Smart operation solutions** aiming at optimizing the operational costs, maintenance, and risk management strategies at the project scale or, preferably, at a regional scale. This can be accomplished through the installation of a monitoring system (including weather recording stations and instrumentation of rivers and streams to measure discharges and environmental flows) and the development of a customized decision-support platform to optimize water uses/releases, turbine operation, emergency flooding protocols, etc.

INPUT

1 **Select adaptation measures.**

Identify threats that, based on the preceding analysis, introduce medium to high risk to the project. For each considerable threat, identify applicable mitigation actions based on the catalogue of possible solutions provided in **Table 2.3** as well as engineering judgment and local experience.

Note that adaptation measures can be devised for both internal and external risks.

2 **Build an adaptation strategy by combining different adaptation measures**. Define a comfortable level of risk and combine adaptation options that can reduce the risk below this threshold.

It should be noted that comprehensive adaptation strategies usually involve combinations of more than one intervention, including planning, operational, and (hard/green) engineering solutions.

It is likely that different strategies may be appropriate to adapt to different intensities of threats. For example, a certain operational strategy coupled with NbS may be enough to safeguard operation against flooding of medium intensity, but hard-engineering solutions may be required if an event of greater severity is to be expected.

Nevertheless, it is recommended to prioritize practices that have been successfully applied in a project of similar scale (in similar regional settings).

3 **Conceptualize alternative adaptation strategies.** Review adaptation strategies and, where possible, generate alternatives that generate co-benefits (e.g., by also reducing the project's carbon footprint). It is generally considered good practice to come up with more than one strategy to be further evaluated in **Step 3** (**Tool 2.6**).

4 **Provide rough cost estimates for each adaptation strategy.**

Cost estimates should aggregate the capital expenditure required for the implementation of the strategy and the cost of residual risk projected over the lifetime of the facility. Benefits should describe the reduced maintenance/operational cost of the facility after the implementation of the strategy (projected over the facility's lifetime). Where possible, apply benchmarking to validate cost estimates. When benchmarking does not work (e.g., when historic market data are not enough), apply small-scale market testing to corroborate cost estimates.

5 **Repeat the process** for other climate hazards to come up with a complete strategy for the project (or the project alternatives).

OUTPUT

A list of alternative adaptation strategies to be analyzed in the following step (**Tool 2.6**).

TABLE 2.3 Example climate adaptation measures for hydropower projects

Climate Threats	Impacts	Adaptation Measures
Increase in streamflow discharges (due to variations in precipitation or ice storage)	• Increased peak river discharges and water heights • Increased risk of overtopping, which may destabilize the infrastructure • Increased hydraulic and hydrodynamic impacts acting on the plant equipment • Increased erosion rates and scouring of foundations • Increased landslide risk	• Consider future flood risk maps in the design. Apply stringent design considerations for critical assets, especially dams and spillways. • Build flood defenses upstream of the plant to minimize the intensity of flood impacts (flow velocity) on the infrastructure. • Enhance the flood protection of the powerhouse to avoid shortages during flooding. • Design the dam to sustain overtopping impacts during extreme flooding. • Make provisions for increased reservoir storage in the future. • Plan for additional space to facilitate future installation of turbines/generators. • In the case of existing dams: increase height and/or relocate the spillways and, if deemed necessary, increase their capacity. • Monitor foundation scouring of critical structural components, including transmission towers. • Design fish passages and environmental flow capacity for varying discharge rates and water heights.
Decrease in streamflow discharges (due to variations in precipitation or ice storage)	• More intense and longer periods of drought • Water scarcity and increased competition between different sectors over the use of the water resource • Reduction of generated energy	• Prepare drought contingency plans and include relevant provisions in the contract documentation of the PPP. • Engage with local communities and other stakeholders and establish an inclusive, participatory method for decision-making regarding water use. • Monitor the impact of the agreement terms and assess/renegotiate on a regular basis.
Erosion and sedimentation	• Reduced water storage capacity, energy generation potential, and lifetime of the project • Increased operational costs for debris removal works • Failures of equipment due to impact with floating debris	• Employ sediment monitoring and management operations. • Update the flushing plan accordingly. • Implement anti-erosion protection measures in the catchment. • Use barriers upstream of the plant, along river margins, to minimize the ingress of debris. • Monitor the possible deterioration of land cover in the catchment, and preserve or restore vegetated land covers to manage stormwater runoff and reduce soil erosion.

Climate Threats	Impacts	Adaptation Measures
Warming temperatures	• Increased risk of fire • Glacier degradation hazards (impacts, outbursts) • Avalanches	• Develop fire models and set provisions for fire management plans (e.g., controlled burning). • Monitor the condition of glaciers and implement mitigation measures (e.g., controlled breaching, pumping of water) in cases of high risk. • Snow-pack observation and active/passive avalanche risk mitigation (e.g., protection barriers, controlled explosions, etc.)
Landslides	• Failure of infrastructure due to detachment or interaction with moving soil masses • Overtopping • Increased sedimentation	• Carry out a comprehensive geotechnical investigation to evaluate landslide risk. • Monitor movements of precarious slopes. • Implement slope stabilization measures where necessary.
Considerable uses in the region's LULC/ demographic changes	• Changes in water uses • Changes in risk estimates (flooding, sedimentation, drought)	• Prepare contingency plans and include relevant provisions in the contract documentation of the PPP. • Include relevant provisions in the agreement with local stakeholders. • Diversify options in energy supply plans.
Policy and regulation changes	• Changes in water uses • Changes in energy generation capacity • Increase in costs	• Prepare contingency plans and include relevant provisions in the contract documentation of the PPP.

BOX 2.2 VEGETATION CAN REDUCE RISK OF SLOPE FAILURES AND SOIL EROSION

In the context of climate change, landslide risk management faces the challenges of varying rainfall duration and intensity, often causing slope stabilization issues and increased soil erosion. In recent years, there has been an increasing focus on the use of NbS for eco-friendly landslide risk management and control of the run-off mechanisms that lead to erosion. Vegetation (Photo 2.2.1 **2.5**) has become a popular method in areas where ground instability is concentrated on the surface layers of the ground (shallow mechanism).

The stabilizing effect of vegetation is thanks to the plant roots acting as soil reinforcement that binds soil layers together and increases the confinement of loose soil masses. What is more, plants provide a partial relief against excessive water pressures, which constitute a common failure factor. Nevertheless, research findings[8] point out that the effect of vegetation can be detrimental if involving tall trees subjected to lateral loading due to high wind speeds (storm surges).

It is recommended that the effect of vegetation as a climate adaptation measure be investigated and quantified by use of numerical modelling (expert geotechnical analysis) that can capture the physical, mechanical, and hydraulic properties of the soil and soil-root interaction.

PHOTO 2.2.1 Shrubs and other vegetation can provide slope stabilization and anti-erosion protection

Source: World Bank. 2018. "Can Nature Help Us Manage Risk in a Time of Growing Climate Extremes?."

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[8] Kondrup, C., P. Mercogliano, F. Bosello, and J. Mysiak. 2022. *Climate Adaptation Modelling*. https://link.springer.com/10.1007/978-3-030-86211-4.

Step 3

Integrate Climate Risks Into The Planning Of Hydropower Projects

SCOPE	To describe a multi-criteria analytical framework that will support users incorporating climate decisions into the planning of hydropower projects.
PROCESS	Once the user has completed the previous steps of this toolkit, there will be a dizzying array of data/requirements that need to be mainstreamed into strategic decisions. Comparing alternative installations with respect to their power generation potential, cost of energy, and efficiency is just one side of the coin. On the other side, there are climate-related risks, vulnerabilities, and opportunities that can also influence planning decisions. Balancing competing objectives requires a multi-criteria approach that can best work within a participatory decision-making environment. The methodological framework of such an approach—called a multi-criteria decision-making framework—is described in **Tool 2.6**. The process starts with the selection of important variables, the establishment of a stakeholder council, and the definition of objectives. Following a scoring and weighting procedure, the preferred strategy is derived, which will be subsequently forwarded for a preliminary economic analysis (conducted in **Module 3**).
	
TOOLS	**TOOL 2.6** Multi-criteria decision-making framework
OUTPUT	A climate-informed planning decision for a new hydropower project

TOOL 2.6

A MULTI-CRITERIA DECISION-MAKING (MCDM) METHOD

The MCDM method offers a scientifically sound decision framework, which can provide a comprehensive and transparent basis for any kind of assessment, including decisions on the planning of new hydropower projects. In the context of this guide, the MCDM method aims to assist users in planning for projects that, in addition to other objectives, are:

- Climate resilient (i.e., can sustain extreme climate hazards with minimal disruption).
- Climate insensitive (i.e., are minimally impacted by the variability of climate stressors).

Users are referred to the Umbrella Toolkit (Module 2.1) for insights on how climate decisions may benefit from empirically based multi-criteria analysis (and other equivalent approaches).

It must be acknowledged that MCDM-based methods rely on empirical, linear correlations. They do not model the actual physical processes. Although they can be very efficient in analyzing complex problems, they are prone to erroneous judgment. Therefore, it is recommended to carry out a validation of the MCDM framework against a known problem (e.g., another hydropower energy project in a similar environment, preferably in the same country).

INPUT

This tool describes the general framework for conducting an MCDM analysis to assist the preliminary planning decisions of a hydropower project (see example in **Box 2.3**). Depending on the input parameters and the specific objectives of the assessment, the MCDM can support any other type of decision, from risk assessments (where the aim is to minimize the climate-induced impacts) to operational decisions of power plants. Instances of MCDM may also vary in complexity, from purely qualitative formulations to mathematical formulations using fuzzy-logic theories for optimization.

1 **Define the objective of the decision-making** (i.e., the assessed variable), e.g., identification of optimum project location, identification of optimum hydropower scheme, estimation of climate risk.

2 **Engage a council of experts** (e.g., hydrologists, environmental scientists, dam engineers, community engagement experts) that will provide elicitation regarding the effect of different parameters on the output of the decision-making process. In preliminary assessments, elicitation is based on empirical evidence and involves qualitative comparison among parameters of relative importance (described below).

3 **Collect input parameters (as traditionally done)**

Input variables should describe the general project set-up and reflect the dependence of the project's energy potential on local environmental factors and constraints. Users are referred to IHA's Hydropower Sector Climate Resilience Guide for a preliminary screening of key input parameters.

Typical parameters to be considered:

- Hydropower generation potential (e.g., precipitation, catchment hydrology, boundaries, fluctuation of stream discharges).
- Geomorphology (e.g., topography, known geohazards and landslide zones, altitude, ice/snow cover seasonal variations).
- Energy demand (e.g., demographic data, socioeconomic factors, national/regional policies).
- Water and land uses (e.g., competitive uses, environmental factors, areas of conservation).
- Operational factors (e.g., availability of road network, transmission lines).
- Technical design parameters (e.g., hydropower scheme, reservoir size, power capacity).

4 **Collect climate parameters** affecting the power generation capacity, operations, and safety of the project. Information can be selected from the preceding tools and may involve:

- Climate risks, including loss estimates (output of **Tool 2.3**).
- Climate adaptation strategies and associated capital cost (as per **Tool 2.5**).
- Benefits from undertaking a specific climate adaptation strategy (e.g., loss reduction, reduction of operational/maintenance cost, and broader socioeconomic benefits).

5 **Ranking, classification, and rating of criteria**

Ask the council of experts to rank the criteria based on their importance in influencing the assessed variable. Ranking (i.e., weighting) of the criteria can be achieved through a pair-wise comparison of relative importance. Several approaches of varying sophistication can be employed at this step,[9] however, the analytical hierarchy process (AHP) is the most widely adopted and easiest to navigate. It relies upon the construction of a paired comparison matrix, where the relative importance of one parameter in comparison to another is evaluated on a scale of 1 to 5. Synthesis

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[9] See a detailed review written for water sector practitioners in: Bertule, M., L.R. Appelquist, J. Spensley, S.L.M. Trærup, and P. Naswa. 2018. *Climate change adaptation technologies for water: A practitioner's guide to adaptation technologies for increased water sector resilience*. UNEP DTU Partnership.

of experts' responses in one AHP matrix results in the identification of a weighting factor for each criterion.

6 Synthesis of criteria and consistency checks

Perform a weighted linear combination of the criteria to produce a qualitative map of the assessed variable. Calculate the consistency index[10] and make sure it is lower than a predetermined threshold (e.g., 10 percent). The winning solution is the solution that receives the higher score on the assessed variable.

Users may also wish to repeat the process by changing the objective of the assessment to acquire a more holistic overview of the pros and cons of the different solutions.

OUTPUT

A decision for a new hydropower project that meets climate objectives and achieves stakeholders' consensus.

BOX 2.3 EXAMPLE OF MCDM ANALYSIS USED FOR PIORITIZATION OF HYDROPOWER DEVELOPMENT SITES IN THAILAND

Researchers[11] employed MCDM analysis to assist policy making for hydropower development in the Ping River Basin (**Figure B2.3.1**) in Thailand. Focusing on potential projects with electric power potential greater than 100 kilowatts (kW), they developed a set of criteria and sub-criteria, as summarized in **Figure B2.3.1** and in the table below, to comparatively evaluate a total of 64 potential sites in the Ping River basin.

Criteria weights for the purpose of the MCDM analysis were discussed and assigned by expert groups assembled to identify the controlling parameters and discuss their influence on hydropower development, considering the local contexts. A set of main criteria, comprised of several sub-criteria, were identified, and evaluated as summarized in the table below. According to the experts' opinions, in this area the primary concern is the environment (weight: 0.355), which encompasses parameters relevant to flow patterns, loss of habitat and land, riverbank deterioration, and sedimentation. The experts also considered the social component very significant (0.234), followed by the electricity generation potential (0.181), the technical feasibility (0.141), and finally, stakeholder engagement (0.089).

It should be highlighted that the comparative importance of the different parameters may vary significantly from one region to another. Therefore the weighting process must be carried out in view of the specific local context.

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[10] The consistency ratio is defined as $CR = \frac{\lambda - n}{n-1}$, where λ is the principal eigenvector of the pairwise matrix and n is the number of the considered criteria.

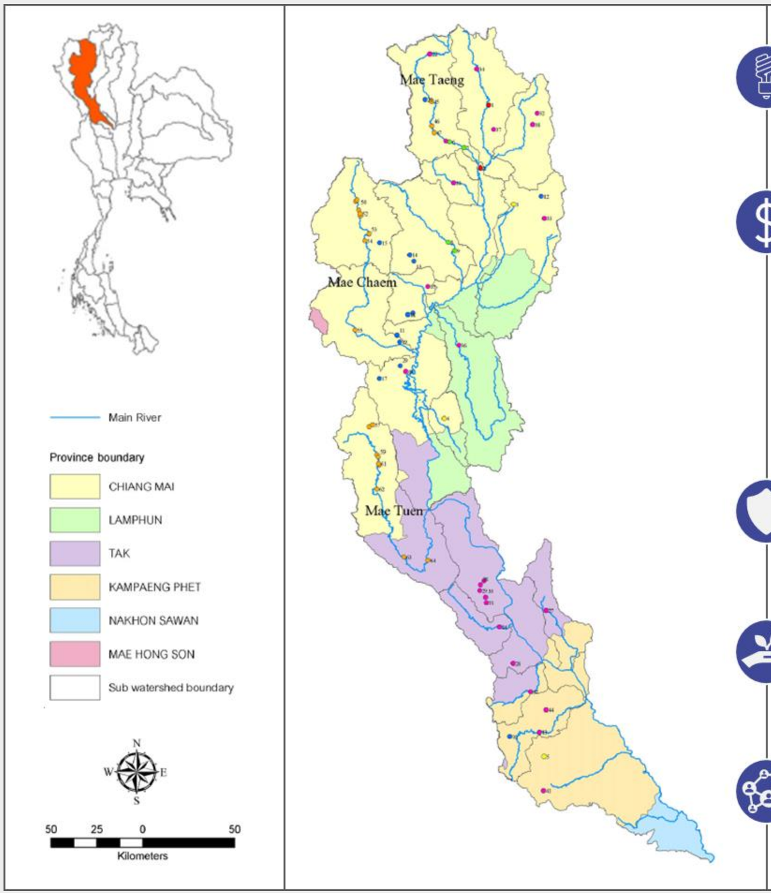
[11] Supriyasilp, T., K. Pongput, and T. Boonyasirikul. 2009. "Hydropower development priority using MCDM method." *Energy Policy* 37 (5), 1866–1875. https://doi.org/10.1016/j.enpol.2009.01.023.

Table 2.3.1. Decision criteria for the prioritization of hydropower development sites

Main Criteria	Subcriteria		Expert Weight
Electricity generation (A) (0.181)	A1	Installed capacity	0.288
	A2	Annual energy production	0.421
	A3	Load firm supply	0.121
	A4	Length of transmission line	0.170
Engineering and economics (B) (0.141)	B1	Technology, engineering feasibility, and difficulty of construction	0.033
	B2	Channel alignment	0.039
	B3	Slope of channel	0.081
	B4	Annual flow	0.062
	B5	Accessibility to project site	0.039
	B6	Expected development period	0.052
	B7	Benefit/sharing/multipurpose	0.044
	B8	Project cost	0.154
	B9	Internal rate of return (IRR)	0.101
	B10	Net present value (NPV)	0.080
	B11	Electricity generating cost	0.315
Socioeconomics (C) (0.234)	C1	Safety in area	0.499
	C2	Social conflict	0.165
	C3	Water resource problems	0.126
	C4	Land use problems	0.084
	C5	Legal obstacles	0.071
	C6	Available infrastructure and services	0.055
Environment (D) (0.355)	D1	Flow pattern and amount of flow	0.626
	D2	Loss of habitat and land utilization	0.125
	D3	Collapse of river bank	0.090
	D4	Sedimentation	0.090
	D5	Dust and noise during site construction	0.069
Stakeholder involvement (E) (0.089)	E1	Shortage in electricity	0.380
	E2	Understanding level	0.290
	E3	Acceptance level	0.190
	E4	Informant	0.140

Note that the numbers in brackets refer to the weights of the main criteria (primary weights).
Source: Supriyasilp et al. 2009.

FIGURE B2.3.1 Location of 64 potential hydropower plant sites in the Ping River basin and summary of the criteria used in the MCDM analysis (adapted from Supriyasilp et al. 2009)



CRITERIA

ELECTRICITY GENERATION
- Installed capacity
- Annual energy production
- Load firm supply
- Length of transmission line

TECHNICAL AND COST
- Construction feasibility (on site size and existing infrastructure)
- Channel alignment and slope
- Annual flow
- Site accessibility
- Expected development period
- Benefit/sharing/multipurpose
- Project cost
- Internal rate of return
- Net present value
- Electricity generation cost

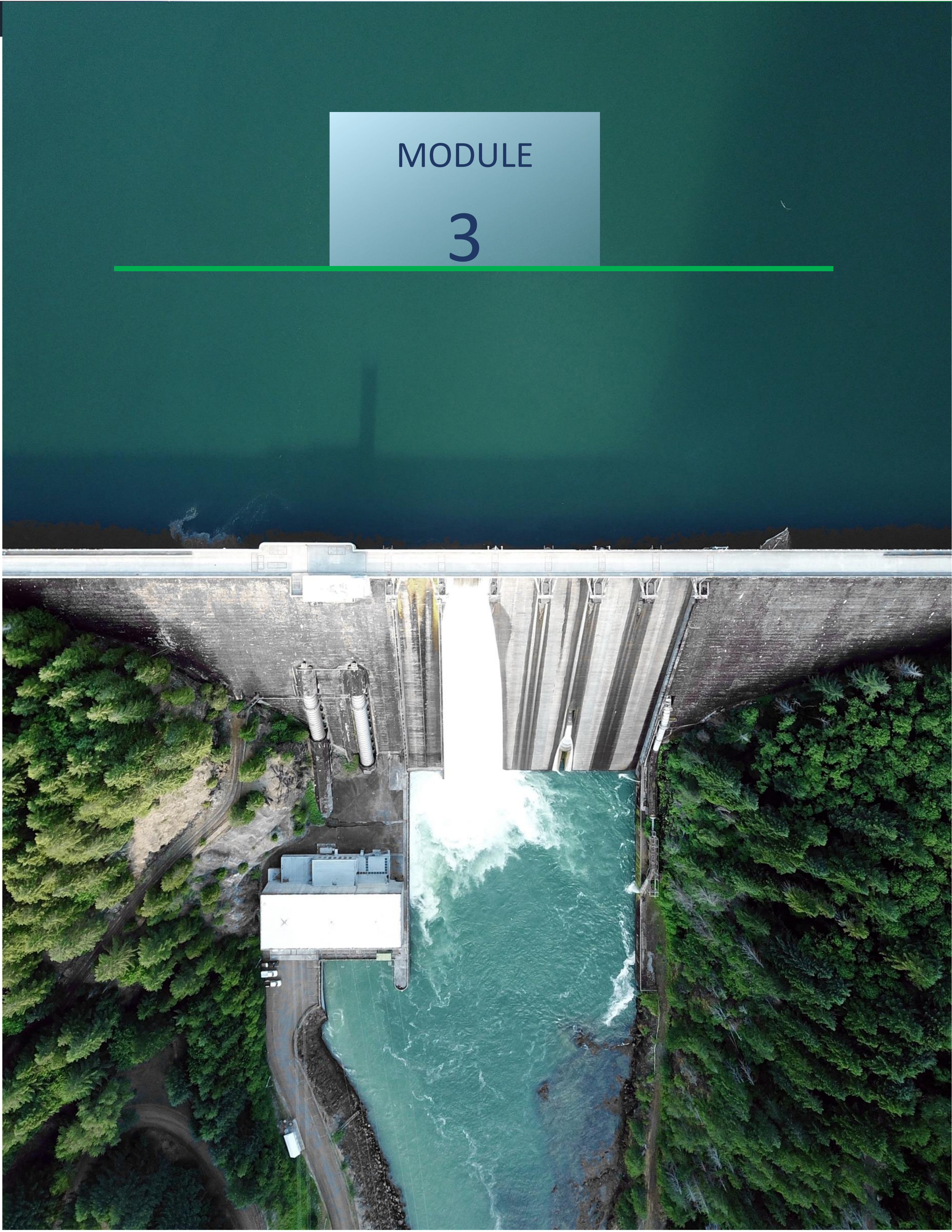
SOCIAL
- Safety in the area
- Social conflict
- Water resource problem
- Land use problem

ENVIRONMENTAL
- Flow pattern characteristics
- Loss of habitat/ land utilization
- River exploitation level
- Construction noise/dust

STAKEHOLDER INVOLVEMENT
- Energy needs
- Acceptance levels
- Communication/ information

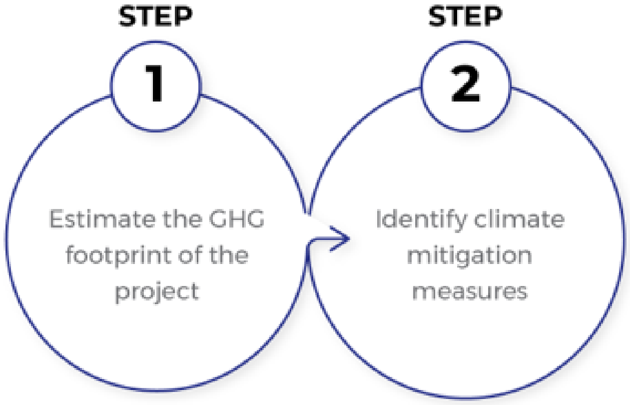
MODULE

3



Module 3

ASSESS GHG EMISSIONS AND PLAN CLIMATE MITIGATION STRATEGIES



Certain reservoir systems may be an important source of GHG emissions.[12] This module intends to assist users in reliably evaluating the GHG emissions of a hydropower project in relation to its energy output and identify appropriate actions toward the climate mitigation of projects that are likely to have a high carbon footprint.

The module includes two steps:

Step 1 describes procedures and available online resources for conducting a life-cycle GHG emissions estimation of hydropower facilities.

Step 2 identifies opportunities for GHG reductions and helps users pre-assess the benefits (reduced GHG emissions and reduced carbon pricing) of alternative mitigation strategies.

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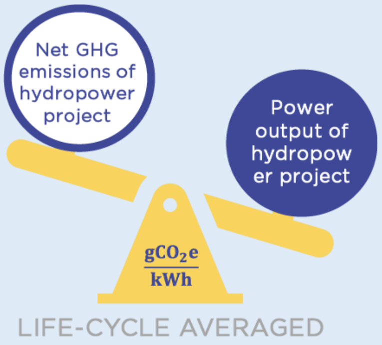
[12] Prairie, Y.T., J. Alm, A. Harby, S. Mercier-Blais, and R. Nahas. 2017. *The GHG Reservoir Tool (G-res) User Guide: UNESCO/IHA research project on the GHG status of freshwater reservoirs*. Updated version 3.0 (27-10-2021). UNESCO Chair in Global Environmental Change and the International Hydropower Association.

Step 1

Estimate The GHG Footprint Of The Project

SCOPE	This step will assist users in assessing the GHG emissions of the project (or the project alternatives) to inform decisions towards their minimization throughout the entire life cycle of the project. The exercise can be performed to (i) compare alternative schemes and designs (e.g., reservoir-based dams usually have much higher GHG emission rates than diversion dams); (ii) compare emissions due to different construction methods and materials (in run-of-river projects, the highest portion of the project's GHG emissions is often due to the construction process and the footprint of materials); (iii) investigate the carbon footprint of operational decisions (e.g., the impact of water retention times); and (iv) guide decisions for mitigation measures.
PROCESS	The process follows the outline for GHG emissions accounting described in the Umbrella Toolkit (Module 2.1), starting with the estimation of the GHG footprint before any mitigation measures are implemented (upper-bound estimate). Widely established GHG emission intensity thresholds are indicated as references for the assessment of a project's carbon footprint.
	 ⚙ Tool 3.1
TOOLS	**TOOL 3.1** A procedure for the life-cycle assessment (LCA) of net GHG emissions
OUTPUT	Assessment of the project's carbon footprint

TOOL 3.1

A PROCEDURE FOR THE LIFE-CYCLE ASSESSMENT (LCA) OF NET GHG EMISSIONS

This tool can be used to assess the GHG emissions of the baseline project (i.e., assuming the complete absence of mitigation measures). It may then be combined with **Tool 3.2** to evaluate the benefit of different mitigation strategies in terms of GHG reduction to enable their comparative assessment. Following global good practice, it is suggested to base the assessment on the estimation/measurement of **net** GHG emissions. In multi-purpose projects, this is an estimate of emissions that can be allocated to hydropower only. A life-cycle (LC) averaged approach is adopted for estimating both emissions and power capacity. The recommended LC duration is 100 years. Due to this timeframe, the reservoir, which under certain circumstances can be a significant source of GHG emissions, is the primary concern. This tool focuses on GHG emissions by reservoirs, assuming negligible LC emission intensities in the case of diversion plants (in agreement with guidelines and the international literature).

Calculation sub-modules of this tool make reference to the use of available predictive tools endorsed by the Intergovernmental Panel on Climate Change (IPCC). These are: (i) the GHG Reservoir Tool (also known as the G-res Tool),[13] developed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and IHA; and (ii) the IEA Hydro,[14] a data-collection and modelling approach developed by the International Energy Agency (IEA).

INPUT

1 **Review GHG emissions targets** for the country’s hydropower projects in the national context (e.g., NDCs) and/or in the global good practice (e.g., criteria set by the Climate Bonds Initiative[15]).

2 **Review available tools/methodologies for the estimation of GHG emissions in hydropower projects**. Tools and guidelines to be advised may include:

- World Bank, 2018: “Greenhouse Gases from Reservoirs Caused by Biogeochemical Processes.”
- The G-res Tool.
- IEA Hydro, 2012: International Energy Agency, Hydropower Annex XII: Guidelines for Quantitative Analysis of Net GHG Emissions from Reservoirs Volumes 1 - 3.
- Climate Bonds Standards, 2021: “Hydropower Criteria: Background Paper.”

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[13] GHG Reservoir Tool. https://g-res.hydropower.org/.

[14] IEA Hydro. https://www.ieahydro.org/annex-xii-hydropower-and-the-environment.

[15] Climate Bonds Initiative. “The Hydropower Criteria.” https://www.climatebonds.net/standard/hydropower.

3 **Predict the GHG emissions of the reservoir** following the three-step approach summarized in **Figure 3.1**.

The first step is qualitative, intended to screen out projects that may safely be assumed to have a low carbon footprint. The main criteria for this screening are listed in **Table 3.1**.

The second step is quantitative, employing the G-res tool for a measurable estimation of GHG emissions. A third step, using IEA's more detailed procedure, is foreseen for cases where the assessor lacks confidence in the result of the second step.

4 **Assess emission intensity.**

A fair assessment of GHG emissions must consider them in comparison to the amount of the produced energy in the same time frame. A well-established assessment protocol has been issued in the framework of the certification scheme developed by the Climate Bonds Initiative (CBI) and is summarized in **Figure 3.2**. It adopts stricter criteria for the newer hydropower projects (those beginning operation after 2020) and relies in the calculation of two indexes:

- **The power density (PD)** is defined as the area of the reservoir divided by its power capacity.
- **The emission intensity (EI)** is defined as the average LC GHG emissions divided by the average LC power capacity. The framework suggests that the numerator be estimated using the G-res tool.

New projects are expected to demonstrate a PD > 10 Watt per square meter W/m^2 and/or an EI < 100 grams of CO2 equivalent per kilowatt-hour gCO2e/kWh to be certified by the Climate Bonds Initiative (CBI.) An additional requirement is in effect for pump storage facilities, which should be able to demonstrate their role in supporting grid decarbonization (e.g., through connection to intermittent renewables).

OUTPUT

The net LC GHG emissions of the "do nothing" case assessed as negligible, or compliant/non-compliant with the emissions thresholds.

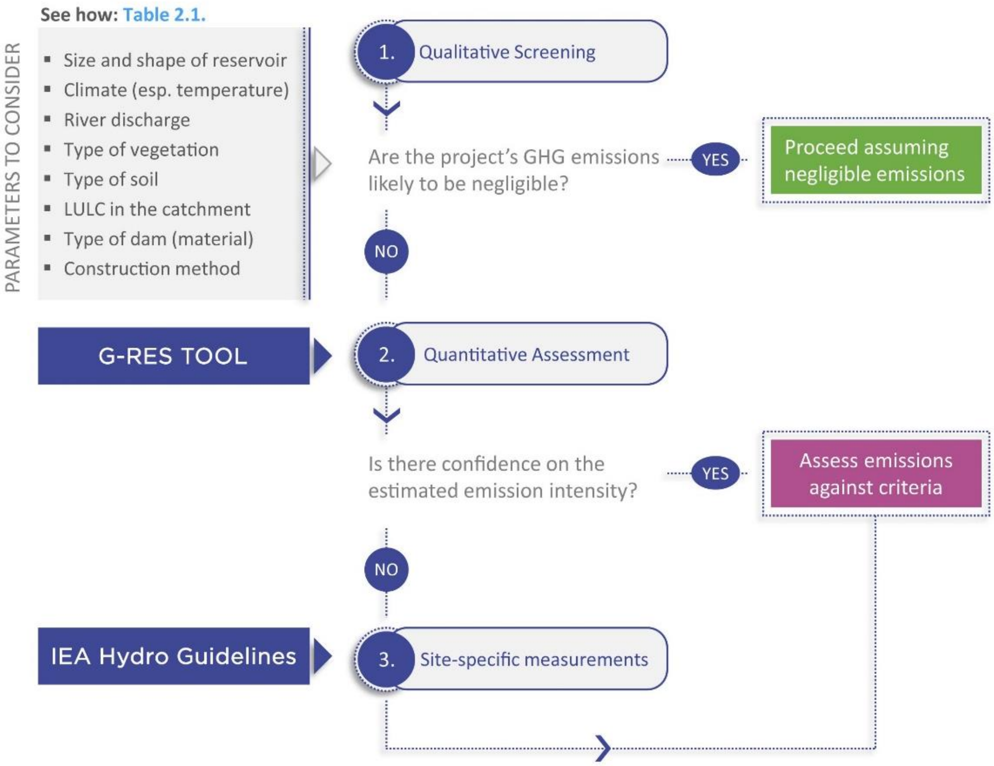

FIGURE 3.1 Flow-chart of the GHG emissions prediction process

TABLE 3.1. Conditions allowing assumption of negligible GHG emissions in the screening process

Parameter	Impact on GHG Emissions
Type of facility	Run-of-river facilities can be assumed to be low-emissions projects. Global data indicate that they are characterized by high PD (exceeding 100 W/m2) and low EI (typically lower than 1gCO_2e/kWh).
Climate	Cold climate disfavors the creation of GHG emissions. By contrast, recent research data indicate that tropical reservoir-based hydropower plants can have a high emission rate, potentially exceeding that of fossil fuel.[16] In cold regions, facilities with PD < 20 W/m^2 can be assumed to be negligible sources of GHG.
Carbon stock (vegetation/ depth)	In cases of sparse vegetation in the catchment and/or deep reservoirs, the threshold PD may be, as previously, taken as equal to 20 W/m^2.

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[16] Song, C., K. Gardner, S. Klein, S. Pereira Souza, and W. Mo. 2018. "Cradle-to-grave greenhouse gas emissions from dams in the United States of America." *Renewable and Sustainable Energy Reviews* 90 (July): 945-956.

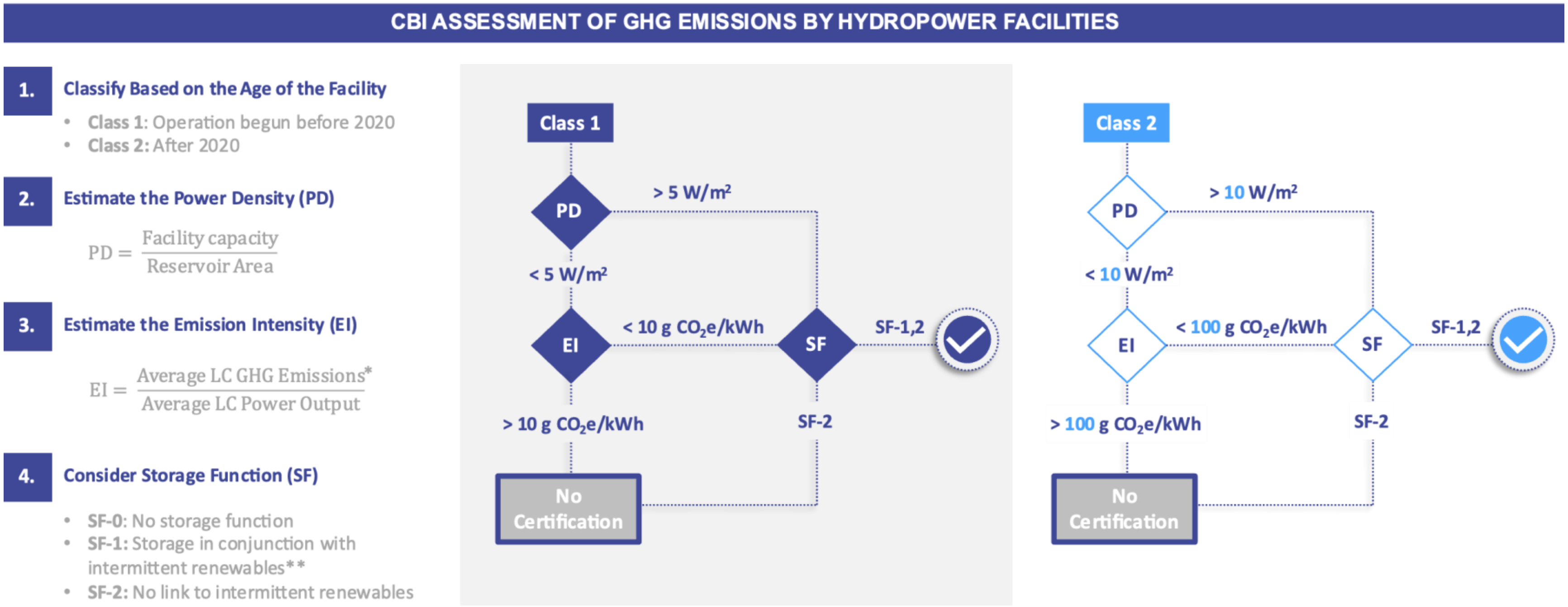

FIGURE 3.2 GHG emissions assessment protocol issued by the Climate Bonds standard and certification scheme, adapted from the Climate Bonds Standard

* Average net LC emissions estimated using the G-Res tool.

** Pumped storage facilities must also meet one of the following criteria:
(i) The facility is demonstrably purposefully built in conjunction with intermittent renewables; and/or (ii) the facility is contributing to a grid which already has a share of intermittent renewables deployment of at least 20 percent or has credible evidence of programs in place that increase the share of intermittent renewables to this level within the next 10 years; and/or (iii) the facility can credibly demonstrate that the pumped storage will not be charged with an off-peak grid intensity that is higher than the intensity of the electricity that it will displace when it is discharged. For example, demonstrating that there is no combination of the following in the merit order: (i) mid-merit coal and (ii) gas used at times of peak demand.

Step 2

Identify Mitigation Measures

SCOPE	To identify entry points for mitigation measures and highlight their corresponding co-benefits and trade-offs. The cost-effectiveness of alternative mitigation strategies will be assessed in **Module 3,** considering the overall project economics and financial plan.
PROCESS	The output of **Tool 3.2** can be used to identify entry points for possible GHG emissions reduction in hydropower projects. Reduction of emissions can be achieved in several ways, the most effective probably being the appropriate screening of locations for the development of the reservoir, but also through the adoption of eco-friendly construction methods, the management of the catchment area, and the targeted reforestation of the surrounding lands. The effectiveness of alternative climate mitigation strategies can be assessed through iterative running of the assessment process shown in **Figure 3.2**.
	
TOOLS	**TOOL 3.2** High-level screening of GHG reduction strategies applicable to hydropower projects
OUTPUT	▪ Alternative climate mitigation strategies and their associated costs and benefits ▪ (Optional) A ranking/prioritization of the different climate mitigation strategies based on the estimated reduction in EI

TOOL 3.2

GHG REDUCTION STRATEGIES APPLICABLE TO HYDROPOWER PROJECTS

The IEA documents detail strategies for the reduction of GHG emissions from hydropower reservoirs, addressing all the different stages of a project's life: planning, design, construction, operation and maintenance, and catchment management. This tool includes a brief checklist (**Figure 3.3**). For more details, the user is advised to look into Volume 3 of IEA Hydro (2012).

INPUT

1. Retrieve the **GHG emissions reduction goals** reviewed within **Tool 3.1**
2. **Consult** the **Figure 3.3** checklist to identify applicable mitigation strategies.
3. **Synthesize** as many as possible of the strategies identified in (2) to achieve the maximum possible reduction in GHG emissions throughout the project's LC.
4. Provide a rough estimate for the **cost of climate mitigation.** If necessary, advise local construction contractors and/or engineers with experience in sustainable construction. Include land acquisition and resettlement costs if the envisaged mitigation strategies have additional space requirements.
5. **Assess the GHG emissions** of the project after the implementation of the climate mitigation strategies using the quantitative steps of **Tool 3.1**.
6. **Confirm** that the updated estimate of GHG emissions is below the set threshold.

OUTPUT

Re-evaluated estimation of the project's emission intensity and cost-effectiveness of the selected GHG emissions reduction strategies.

Planning and Design

- ✓ Consider GHG emissions in the selection and optimization of the dam site location.
- ✓ Remove and dispose of organic matter existing in the area that will be inundated.
- ✓ Accommodate multi-level discharge (power intake from different depths) to minimize degassing.
- ✓ Plan an optimal symbiotic relationship with cascade reservoir systems, to best exploit the water resource (water use allocation).

Construction

- ✓ Rational management of diesel fuel and electricity consumption by onsite equipment installation and usage, which is the main source of GHG emissions during the construction phase.
- ✓ Consider GHG emissions in the design of the dam and, if possible, prefer a rockfill dam against conventional concrete dams.
- ✓ Design erosion protection measures that will limit sediment transport in the reservoir.

Operation & Management

- ✓ Catchment management using forested barriers along susceptible river margins to minimize the ingress of debris and other organics to the river.
- ✓ Land-cover management: Forestation of arable land and reforestation of destroyed forests, to mitigate emissions without significantly affecting agricultural production.
- ✓ Upstream flood regulation to moderate flood peaks and debris flows.
- ✓ Upstream wastewater treatment, if applicable.

FIGURE 3.3 Checklist of climate mitigation strategies to reduce GHG emissions in hydropower projects

MODULE

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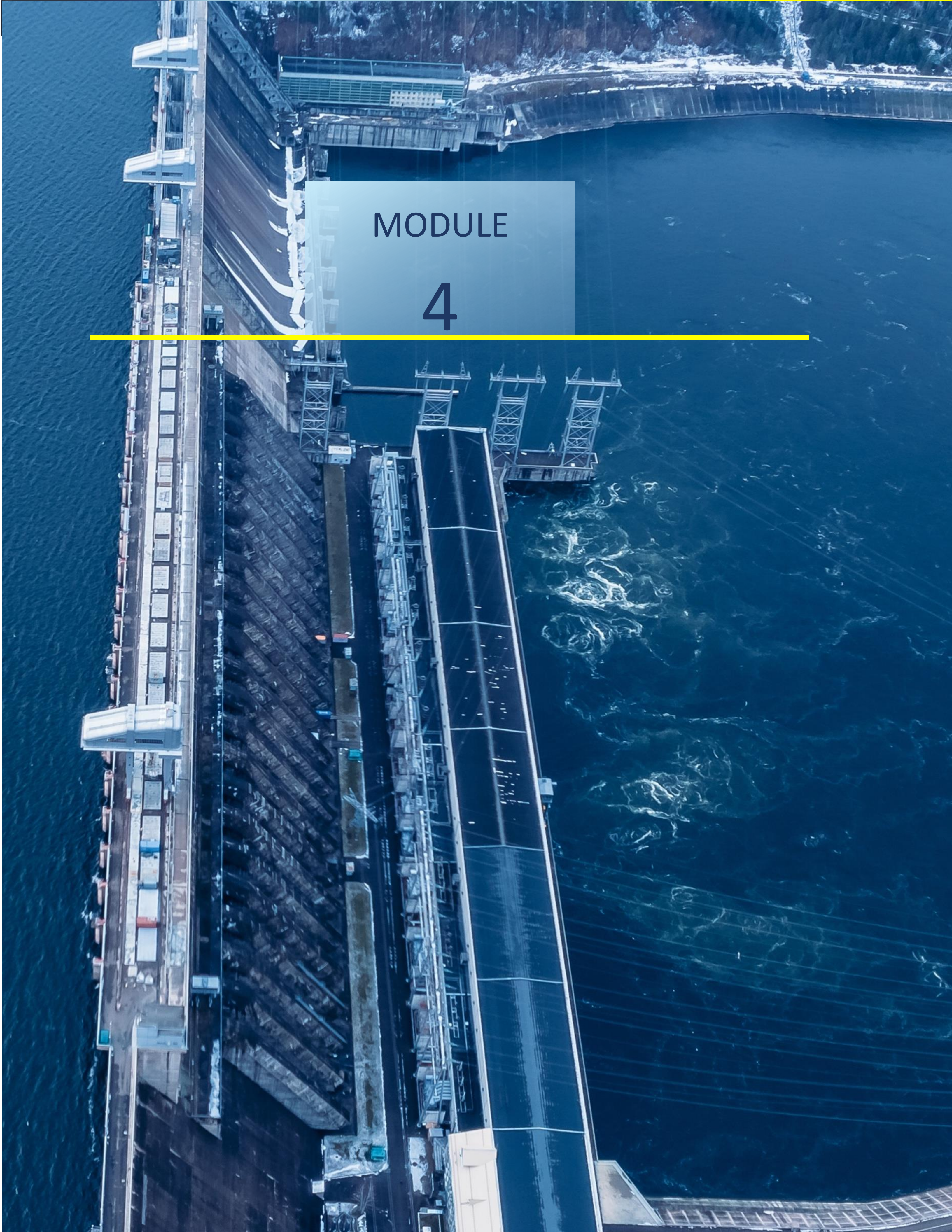


Module 4

CLIMATE CONSIDERATIONS IN ASSESSING PROJECT’S ECONOMICS AND FINANCES

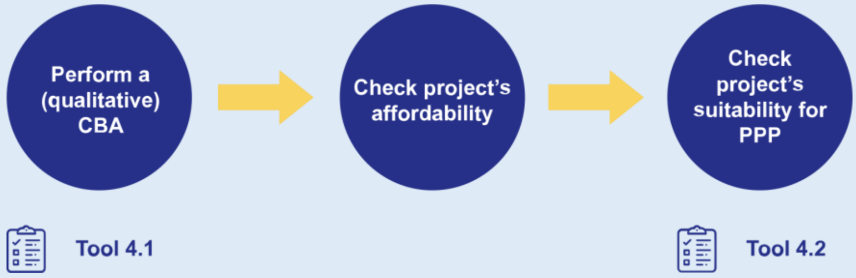
This module is meant to support entities’ inclusion of the previous climate considerations in their traditional economic assessments of Phase 1 “Project Identification and PPP Screening” in the PPP project cycle. To this end, this module consists of a single step that provides tools and examples for:

- Identifying all climate-related costs/benefits that should be integrated with an enhanced cost-benefit analysis (CBA) (**Tool 3.1**).
- Performing a VfM assessment to determine whether the PPP should be preferred over traditional procurement after incorporation of climate considerations (**Tool 3.2**).

Step 1

Check Economic Soundness of Alternative Climate Strategies

SCOPE	To compare the climate strategies identified in the previous module in terms of cost-effectiveness, affordability, and suitability for a PPP. The output will be a project that has been successfully screened from an economic perspective and can therefore be considered suitable for proceeding to a full technical and economic appraisal.
PROCESS	Following the screening process presented in the Umbrella Toolkit, the economic analysis is performed in stages, starting with a preliminary CBA (**Tool 4.1**) to identify the project that maximizes the benefit-over-cost ratio. For best results, all important climate-related costs (e.g., additional climate capital expenditures (CAPEX), costs of disruptions caused by extreme weather events) and benefits (e.g., risk reduction benefits, protection of human settlements, and biodiversity) should be synthesized and compared after monetary evaluation. Once the project has been identified, the affordability of the project is tested in view of the budgetary limits, constraints, and other concurrent investment plans of the public authority, following the general considerations described in the Umbrella Toolkit. The final check is to assess how climate-induced risks, costs, and opportunities may affect the suitability of a project as a PPP (**Tool 4.2**). The project that successfully passes all tests receives the green light to proceed to the Appraisal Phase.



TOOLS	**TOOL 4.1** Climate entry points for CBA (specific for hydropower projects) **TOOL 4.2** Climate value drivers for VfM analysis

OUTPUT	A hydropower project with climate adaptation and mitigation measures that can be moved forward for appraisal

TOOL 4.1

CLIMATE ENTRY POINTS FOR HYDROPOWER-SPECIFIC CBA

The tool describes entry points for climate-related CBA analysis considerations that are relevant to hydropower projects. CBA analyses are customarily conducted for different scenarios accounting for changes in the financing scheme, electric prices, and downstream power generated. Prior to applying the tool, users are advised to review methodologies for estimating the monetary value of social-environmental benefits and the CBA Primer (2017)[17] and consult the Umbrella Toolkit (Modules 1.3 and 2.3), where climate-related considerations for CBA (applicable to all sectors) are described in greater detail.

INPUT

TABLE 4.1 Hydropower-specific climate entry points for CBA

CBA Process Outline*	CBA Sub-Steps*	Climate Entry Point
Projecting financial data with conversion/ adjustment	Tax adjustment	• If applicable in the country, include tax incentives that promote climate mitigation and adaptation actions (e.g., use of the hydropower infrastructure for flood protection within the catchment, installation of early warning systems). • If applicable, include levies and environmental taxes in the "do nothing" option.
	Shadow prices and opportunity costs adjustment	• Adjust costs and benefits as would otherwise be done following the 2017 WB Guidance Note on the shadow price of carbon.[18]
	Construction of the model	• Include the cost of **implementing adaptation measures** (e.g., cost of multi-level discharge system, cost of constructing flood protection measures upstream, cost of anti-erosion measures). • For nature-based solutions, the total cost should also include the cost of maintenance (which may be a significant portion of the initial investment).

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[17] Guzman, A., and F. Estrázulas. 2012. "Full Speed Ahead: Economic Cost-Benefit Analyses Pave the Way for Decision-Making." *Handshake* (IFC quarterly journal of public-private partnership) 7 (October).

[18] World Bank. 2017. "Shadow Price of Carbon in Economic Analysis." Guidance Note, November 12, 2017. https://thedocs.worldbank.org/en/doc/911381516303509498-0020022018/original/2017ShadowPriceofCarbonGuidanceNoteFINALCLEARED.pdf.

CBA Process Outline*	CBA Sub-Steps*	Climate Entry Point
		• Consider the cost of sustainable construction (e.g., cost of recycling demolition materials, investment in electrical construction machinery).
	Operational and maintenance cost	• Consider the increase in the cost of operation (e.g., due to possible need to reduce water retention time, need to install additional turbines for operation during seasonally reduced water use, cost of possibly necessary repairs after intense storms and flood events). • Consider increase in maintenance costs (e.g., sediment management techniques, maintenance of vegetated slopes, fire-smart landscaping actions, cost of monitoring).
	Term and residual value	• Residual value estimates should be adjusted to include climate-change impacts, for example: ▪ Reductions related to frequently failing slopes. ▪ Reductions caused by reduced power generation.
Adding externalities	List of externalities	• The cost of externalities may include: • Cost of indirect damage caused by power generation loss due to damage to transmission lines, broken supply chains due to damage in the road network yielding to limited accessibility to the plant, increased travel times. • Cost of emergency services (e.g., use of aerial means to extinguish fire or evacuate personnel). • Permanent or temporary changes in LULC (see **Table 2.2**). • Disruption during construction (introduced by unfavorable weather conditions, e.g., extreme heat, frequent and intense rainfalls, cyclones). • The quality/reliability of the transmission grid. • Long-term effects on environmental flows in the watershed. • External benefits arising from the installation of monitoring systems and weather stations along the river, useful for early warning and protection of nearby communities.
Adding (other) socioeconomic benefits	Monetizing/inferring value for relevant benefits	• Include an increase in private investment confidence (business, entrepreneurship, property). • Increase power generation downstream.
	Considering/ qualifying other unvalued benefits	• Include resilience benefits such as: • Avoided loss to the network adjusted over the probability of the event. • Avoided disaster to the broader ecosystem (e.g., if the plant infrastructure acts as anti-flood protection). • Environmental benefits of nature-based solutions (e.g., quality of air, better aesthetics). • Alignment with strategic climate objectives. • Increased agricultural productivity.
Relative price adjustments and bias/risk adjustments	Market imperfection	• Apply as would otherwise have been done.
	Other opportunity cost adjustments	• Consider alternative uses of the land and space that climate measures cover, if any, and apply such costs.
	Taxes	• Same as above, apply only to the extent that tax advantages are applicable when a project exceeds its purpose in social benefits. • Consider the tax income gained from steady uninterrupted operations.
Defining base case, defining and	Discount rate definition and	• Consider adjusting discount rate for valuation depending on levels of certainty of cash flows (applies to projects that include climate measures) and uncertainty of cash flows (applies to "do nothing"

CBA Process Outline*	CBA Sub-Steps*	Climate Entry Point
calculating economic internal rate of return (EIRR)	calculation of NPV and EIRR	alternatives). This needs to be aligned with the probabilistic analysis of events occurring to avoid “hurting” a project with uncertainty twice (one with a high probability of costs occurring and one with a high discount rate because of uncertainty of cash flows).
Incorporating uncertainty: sensitivities	Test the strength of the proposed business plan and present the effect of variations	• As would otherwise be conducted.

*per APMG PPP Certfication guide

OUTPUT

The results of the analysis of climate entry points in the project’s CBA may be summarized in a screening report highlighting which climate mitigation and adaptation aspects have been considered and ensuring these have been adequately evaluated. A comparison of the project costs and benefits with and without climate mitigation and adaptation measures will ideally inform the decision-makers to support better project outcomes.

IMPORTANT NOTE

Choosing a Discount Rate

The discount rate used in the economic analysis is particularly important when evaluating and comparing adaptation options because the associated benefits (or avoided costs) are unlikely to be realized for many decades. There is no consensus on the appropriate discount rate to use for resilience strategies. As a good practice, study teams may choose to explore the sensitivity of economic analysis findings to different discount rates or the possibility of applying a non-constant discount rate over the horizon of the assessment.

TOOL 4.2

CLIMATE VALUE DRIVERS FOR VFM ANALYSIS

A VfM analysis is performed to identify whether (and to what extent) climate-related risks, opportunities, and uncertainties may affect the suitability of a project for PPP and non-PPP delivery. The tool describes entry points for climate-related considerations for VfM analysis that are relevant to hydropower projects. It explains the rationale of these considerations; identifies conditions of positive, negative, or conditional performance; and, where applicable, provides specific references and examples.

INPUT

TABLE 4.2 Impacts of climate change on PPP suitability for hydropower projects

VfM Driver	PPP Suitability: Climate Considerations	Conditions	Impact on PPP Suitability
Project size	Is the project too big for the market? Or is the project too complex to be delivered as a PPP?	Consideration of climate-change impacts in their full range of possibilities may result in a need for implementation in exhaustive climate adaptation measures. Such a condition may be particularly problematic when the construction of the adaptation measures requires the cooperation of different PPP units, different government units outside of the PPP unit, or even authorities from different countries, e.g., in transboundary projects. Such conditions could impact the appetite of potential bidders or hinder the project's financing.	**Negative**
Market appetite	Would there be private investor appetite?	The identification of previously unknown climate risks (e.g., the potentially increasing effect of droughts) could hamper investor appetite.	**Negative**
		A thorough CBA of climate adaptation/mitigation works would provide visibility and hence increase private sector appetite.	**Positive**
		Engagement with local communities and other stakeholders, and establishment of an inclusive, participatory method for decision-making regarding water use will provide confidence that possible water scarcity periods will not impact the project disproportionately.	**Positive**
Precedent projects	Are precedent transactions already developed as PPPs for this type of project in the country/region/similar countries?	Climate risks are better understood in a catchment where there is a legacy of hydropower development. The involved stakeholders are better informed, and the local communities are familiar with the services and benefits provided.	**Positive**
Risk allocation	Are there any significant climate risks within the project that are not manageable by a private partner?	Extreme weather events may under certain circumstances cause extended losses to hydropower projects. The risk of sustaining such losses may be reduced by proper design of climate adaptation works and insurance against any excess risks. In case costs for climate adaptation works are high or insurance is unavailable, the risk may not be manageable by the private partner (e.g., risk of dam failure due to extreme	**Negative**

VfM Driver	PPP Suitability: Climate Considerations	Conditions	Impact on PPP Suitability
		hydraulic actions during flooding implies excessive restoration/replacement costs).	
		Uncertainty in estimating climate risks costs (i.e., CAPEX and/or operation and maintenance [O&M] costs) impact the PPP suitability of hydropower projects.	**Mostly negative** (unless specific measures to increase certainty are taken)
	Are there circumstances where climate risks can be better assumed by the private party?	Private sector capital and innovation bring higher efficiency in disaster preparedness, response, and recovery. Also, insurance coverage increases the capability of the private party to assume a certain level of climate risk.	**Positive**
	Is there a risk of non-availability of the land/right of way and land acquisition cost overrun?	Geophysical hazards (e.g., landslides, subsidence) may be intensified by climate change; hence hydropower projects interfering with landslide-prone areas, thawing permafrost zones, or areas impacted by coastal erosion could experience higher risks.	**Mostly negative** (unless recognized and proper measures are structured)
Certainty of offtake/supply	Is it possible that the project will experience a change in demand due to climate change?	Interdependencies between climate, land use, and population render the hydropower development vulnerable to external factors that may not be under the control of the PPP and may have a negative impact on the demand for electricity and hence energy prices, thus compromising investment certainty.	**Mostly negative**
		Increased growth of a region (partially affected by milder climate conditions) may positively impact the energy demand.	**Mostly positive**
Project quality	Will the project quality increase if the project is developed through a PPP scheme?	In several cases, the private party may bring innovation and high standards. Examples of such innovation applicable to hydropower could indicatively include contractors with experience in the development of integrated monitoring systems for adaptive management of hydropower generation, flood risk management, and early warning.	**Mostly positive** (provided that the methods used are tested)
		As commercial lenders become more informed on the climate change risk, they will demand higher climate-resilience standards to stimulate high performance in order to ensure repayment/returns.	**Positive**
Output-based contracting	Is it possible to define clear output-based indictors describing the	The power purchase agreement could be linked with financial incentives or penalties, thereby enhancing faster as	**Mostly positive**

VfM Driver	PPP Suitability: Climate Considerations	Conditions	Impact on PPP Suitability
	performance of the plant to weather events?	well as better responses to climate-related disruptions.	
Finance availability	Are there any significant climate risks that may harm the availability of financing?	Climate-related events may be responsible for external risks (e.g., permanent or temporary changes in LULC, water demand changes, geomorphological changes), which could be non-mitigable. Such risks may test the willingness of financiers to participate or could raise requests for higher guarantees.	**Negative** (unless recognized and proper measures are structured)
Legal or regulatory framework	Has the country adopted national legislation on climate change?	Prior existence of a national framework promoting green investments (defining other subsidies and incentives for private sector participation) would definitely boost the project. For example, existing legislation describing beneficial provisions for low-emissions hydropower would positively impact the development of RoR hydropower schemes.	**Mostly positive**

OUTPUT

The results of the VfM may be summarized in a screening report highlighting which climate mitigation and resilience aspects have been considered and how they are impacting the suitability of the project as a PPP.

MODULE

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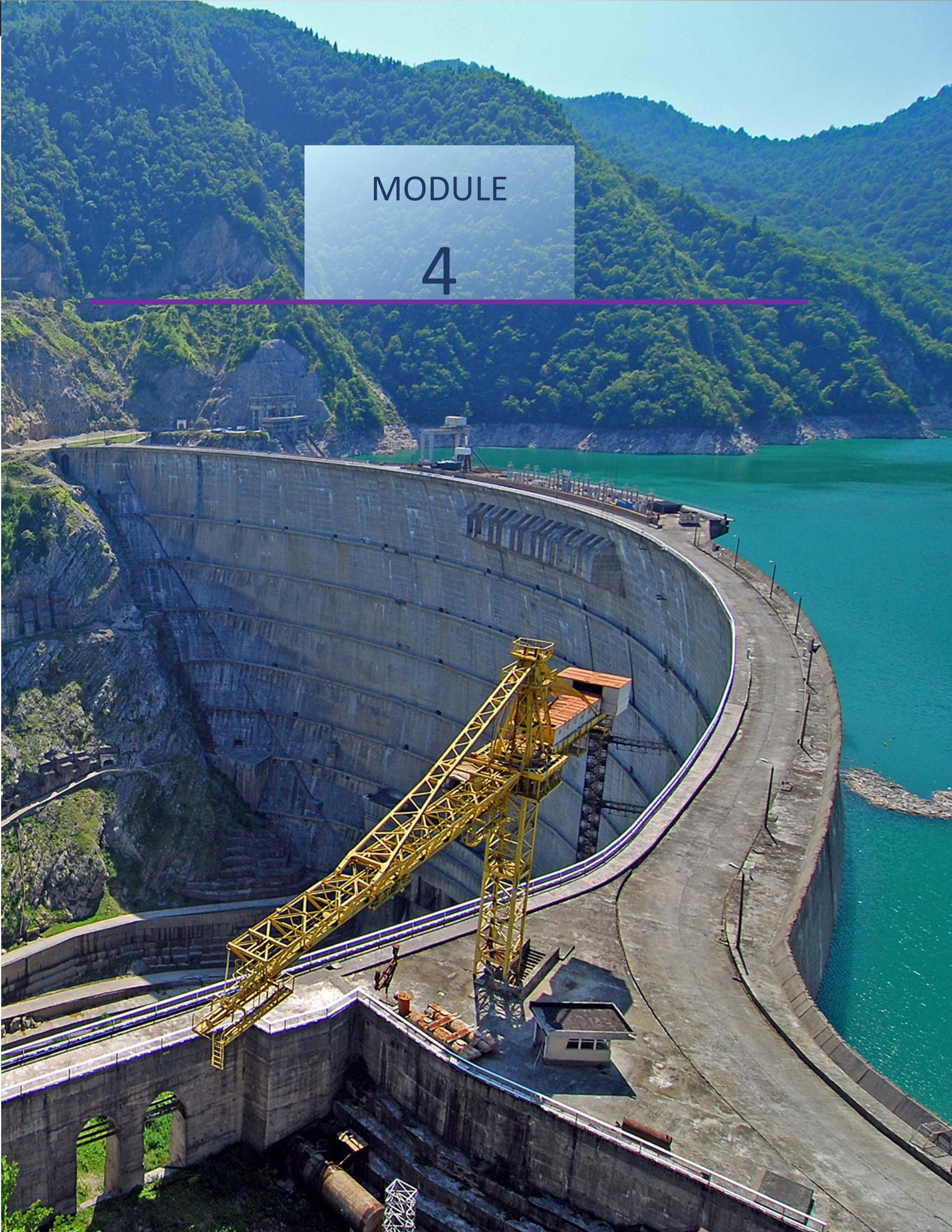

Module 5

KPIS FOR CLIMATE-RESILIENT AND SUSTAINABLE HYDROPOWER

KPIs are customarily used in PPP hydropower projects to assess and evaluate a project's performance during design, construction, and operation. KPIs are developed around specific government objectives, and the private partner will either be entitled to additional payments for good performance or to reduced payments for poor performance. Expanding this general notion to PPPs containing climate actions, the relevant KPIs can be used to measure: (i) the hydropower project's alignment with specific climate mitigation objectives, and (ii) its climate resilience, i.e., the ability to prepare, respond to, and quickly recover from climatic hazards.

The tools described in the ensuing provide indicative high-level examples of climate KPIs soliciting forward-looking information to be included in performance-based contracts.

Based on the understanding that there is no one-size-fits-all for KPIs, the tools describe climate indicators that may be applicable to a broad range of hydropower projects. It is then the obligation of the entity in charge, with the assistance of experienced consultants, to derive project-specific KPIs that best describe the technical/operational challenges of the project and to take advantage of the expertise and innovation skills of the private sector.

TOOL 5.1

KPIS MEASURING CLIMATE ADAPTATION OBJECTIVES

Multi-purpose hydropower reservoirs often deliver several services relevant to climate adaptation, mainly through flood regulation and water storage. The relevant KPIs included in this section have a dual purpose: (i) to facilitate assessments of a project's resilience to climate change (resilience of the project) and (ii) to track the effectiveness of the project's contributions to climate change adaptation (resilience through the project).

Table 5.1 provides a **non-exhaustive list of climate-adaptation KPIs** that can assist the public authorities and their advisors when structuring and preparing performance-based contracts for hydropower projects. As previously, this tool does not recommend specific threshold values for either the event intensity or the performance level of the hydropower project. These should be derived in consultation with the technical advisor in due consideration of the project's risk profile, the frequency of the event, and the importance of the project for the management of risk at the broader catchment/regional scale.

IMPORTANT NOTE
Climate Thresholds and Performance Level

One KPI may be related to one or more hazards. However, the climate thresholds that apply to different hazards will differ. Moreover, depending on the severity of the event, different performance levels will apply for the same hazard (e.g., longer response time will be tolerated for extreme versus normal-intensity events).

TABLE 5.1 Indicative climate adaptation KPIs

Performance Objective	Example Indicators
Project sustainability	Existence and application of the Hydropower Sustainability ESG Gap analysis tool, addressing all three phases: preparation, implementation, and operation
	Existence of an environmental and social action plan
	Time period during which the identified gaps must be addressed and mitigated (*months*)
Resilience *of* the project	Number of climate-related incidents causing disruptions or requiring significant capital mobilization (*number/year*)
	Reaction time after a severe event (*hours*); time to complete adaptation actions following measurement of specific indicators characterizing chronic stresses such as river discharge or wind speed (*months*)
	Plant availability factor
	Unit forced outage rate

Performance Objective	Example Indicators
	Existence of a flood storage buffer; time to discharge and time required to reduce reservoir level in order to achieve it (*hours*)
	Existence of redundancies for powerhouse (drainage, spillway relocation, redundancies)
	Frequency of serious dam safety violations (*number of incidents/year*) and time required to completely address them (*hours*)
	Time to repair damage due to climatic stressors (*days*) or to receive spare parts for damaged equipment (*days*)
	Frequency of benchmarking of emergency response plans against best practices
	Emergency response fleet (*number of vehicles and operators*) and emergency management exercises (*number/year*)
	Ratio of maintenance work completed/maintenance work planned *(%)*
	Frequency of anti-erosion maintenance actions (*number of actions/year*)
Resilience *through* the project	Emergency response plans communicated to local communities and organization of engagement and training workshops with informative material in the local language (considering also illiterate populations, if applicable).
	Assessment of the project's impact on land uses at regional scale and likelihood of resettlement and its implications undertaken early in the project preparation stage.

TOOL 5.2

KPIS MEASURING CLIMATE MITIGATION OBJECTIVES

This tool is designed to assist public authorities and their advisors in structuring and preparing performance-based contracts for hydropower. **Table 5.2** provides a non-exhaustive list of climate mitigation KPIs that can be widely adaptable to hydropower projects and that have been recommended by internationally recognized frameworks.

The KPIs are divided into themes representing core elements of a PPP contract: design, construction, and operation and maintenance. KPIs are described by a performance objective and an example measurement (i.e., how to measure compliance with the objective). It should be noted that the tool does not provide threshold values for the suggested KPIs. This is country- and project-specific information that the public authority should provide based on good-practice examples and applicable norms/rules. Typically, it is considered good practice to define two levels of achievement: a *conserving level* is one that has no negative impacts and an *improved level* is one that will benefit the overall project performance. Performance below the conserving level will usually lead to the application of penalties, whereas performance above the improved level may be tied to specific rewards/incentives for the private partner.

TABLE 5.2 Indicative climate mitigation KPIs

DESIGN-RELATED KPIs

Performance Objective	Example Indicators
Reduction of reservoir emissions	Existence of a plan for measuring emissions during the project's operation.
	Design requirements for power intake structures based on GHG emissions calculations.
	Existence and application of a specific plan for sediment management and anti-erosion protection including sediment treatment specifications.
	Existence of a concise plan for removal and disposal of organic matter existing in the area that will be inundated (applicable to reservoirs) specifying the process and frequency of removal/disposal operations.
Improvement of energy efficiency	Estimation of the energy efficiency of the project and assessment of its fit with national/regional policies and plans on mitigation.
Optimization of water use	Existence of a plan for water use allocation considering both competing water demands on cascading reservoir systems and also future climate projections for the intensity and duration of dry seasons.
Minimize impact on biodiversity	Existence of environmental impact assessment including assessment of biodiversity, plans for environmental flows, and particularly the passage of aquatic species and loss of habitat due to disruption of river connectivity.

CONSTRUCTION-RELATED KPIs

Performance Objective	Example Indicators
Reduce emissions in construction	Total amount of embodied tons of carbon dioxide (*CO2*) and other GHG emissions of the construction materials: CO2 equivalent (*CO2e*).
	Net CO2 equivalent emissions of construction equipment per usage (tons *tn of CO2e per kilometer (km) or cubic meter (m3)*.
Promoting sustainable resource management and circular economy	Percentage of materials used for construction/maintenance works that come from local and/or recycled or reclaimed sources (e.g., earthworks using local soil) compared to percentage of total materials used.
	Primary and secondary suppliers of plant machinery/equipment that have sustainable sourcing/procurement/management certification (*%* or *number*).

OPERATION AND MAINTENANCE-RELATED KPIs

Performance Objective	Example Indicators
Reduction of reservoir emissions	Site-specific assessment of GHG emissions considering catchment management practices. Numerical targets for GHG emissions (*CO2e/year*).
	Sedimentation (*tons/year*); sediment removal operations (*number/year* and *tons/year*).
	Erosion monitoring (*number of operations/year*).
	Annual water retention (e.g., in *m3/years*).
Reduction of GHG emissions from transmission lines	Percentage of non-emissive gas insulated equipment *(%).*
Efficiency of maintenance operations	Preventive loss indicator (PLIplan)—the ratio between estimated energy loss caused by planned interruptions and the maximum energy that can be produced during the reported period *(%).*

Summary and Conclusions

CLIMATE ENTRY POINTS IN THE EARLY STAGES OF A HYDROPOWER PPP PROJECT PREPARATION

After completion of all the steps described in this toolkit, users are expected to have shaped a clear view of how to incorporate climate considerations in the early stages of project preparation for a hydropower PPP project, using a set of practical tools that allow:

- **Identification and mapping of the national and international climate-related frameworks** and commitments relevant to the hydropower project under consideration. To this end, the toolkit navigates users through the main documents defining such policies, while guiding them as to the specific focus areas that are important for a hydropower PPP project.
- **Screening of the hydropower PPP project's alignment with the Paris Agreement** and the regulations stemming from it. Screening is performed by means of four sets of questionnaires—each one referring to one pillar of the relevant considerations—through which users are able to identify areas where improvements may be necessary, recalling that all WBG-supported projects must be fully aligned with the Paris Agreement by 2025.
- **Estimation of the hydropower project's carbon footprint,** by performing a preliminary assessment of the GHG emissions associated with its construction and operation. The relevant tools provide step-by-step instructions on how to provide a preliminary life-cycle assessment (LCA) of such emissions, supported by a list of international resources for assessing emissions associated with each (construction- or operation-related) activity.
- **Appraisal of the climate-related risks that the specific project is exposed to,** which are defined as the potential losses that could be either internal to the project (in the form of physical damage and loss of revenues due to a climate event immediately impacting the operability of the infrastructure) or external (in the form of economic losses due to an acute event or chronic hazard impacting the operation of the hydropower plant, which may remain physically intact). To this end, a set of readily available online resources are provided that allow users to understand which hazards may affect the project, given its location and the components of the plant. Based on such data, the potential effects of each hazard on specific assets of the hydropower project may be assessed. Hence, users will be able to form a preliminary opinion as to the vulnerability of each asset type, its appropriateness for the project/region, and the associated needs for risk reduction measures.
- **Preliminary exploration of climate adaptation and resilience strategies** aimed at reducing the risks identified above and enhancing the project's bankability. Users are guided through the relevant tools enabling identification of adaptation measures for their hydropower project, while at the same time providing a high-level indication regarding the costs and benefits of each option, so that users are able to design different resilience strategies, each with distinct costs and benefits.
- **Preliminary identification of climate entry points in the cost-benefit analysis of the project,** using a step-by-step approach that supports users in understanding how climate risks, as well as adaptation and resilience plans, may reflect in the project economics by presenting the tradeoffs between climate-related risks and investments.
- **Preliminary appraisal of the project's VfM and suitability as a PPP,** using a set of tabulated instructions explaining the effects of various potential climate actions identified above, on parameters

such as project bankability, investor appetite, and project risk profile. It is also shown how failure to act—or invest—may negatively impact the project if investor risks remain unmitigated or if insufficient measures hamper the eligibility of the project to receive funding from multiple sources.

- **Preliminary identification of climate (mitigation or adaptation related) KPIs** that could be used to trigger climate-related clauses of the payment mechanism in PPP contracts. It is shown that climate considerations are meant to be present in all phases of the PPP project—from project selection, design, and construction through project implementation. To this end, a non-exhaustive set of essential climate-related KPIs is presented as part of the relevant tools that describe hydropower-specific actions and quantifiers to allow them to be monitored.

The present hydropower-specific toolkit, when used in conjunction with the WBG's Umbrella Toolkit, is meant to support PPP agencies operating in EMDE countries to incorporate climate risks and opportunities in hydropower PPP projects, by providing detailed guidance applicable to the early stages of such projects' preparation. Given the importance and complexity of incorporating climate change in PPP projects, all appraisals performed at the preliminary stages with the help of this toolkit will need to be reassessed in detail with the help of expert consultants on the basis of project-specific data that will become available in subsequent stages of the project.

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