Screening Hydropower Facilities for Climate Change Risks to Business Performance

A Framework

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About the Author

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Dr. Hellmuth received her Ph.D. in Environmental and Civil Engineering from the University of Colorado, Boulder, in 2002; her M.S. in Environmental and Civil Engineering from the University of Colorado, Boulder, in 1997; and a B.S. in Environmental/Water Resources Studies and French, (Double Major), from the University of Minnesota, Minneapolis, in 1995

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1. Introduction

This framework for screening hydropower facilities for climate change risks to business performance is designed to help

- Hydropower plant managers and operators identify vulnerabilities of existing facilities; and
- Hydropower project developers or investors screen planned hydropower projects for climate vulnerabilities at the conceptualization stage.

The framework and associated tool are designed to be accessible to these users, without requiring specialized knowledge of climate change. Guidance is provided throughout the tool to explain climate change concepts and provide links to resources for users to better understand expected climate changes in their location.

The framework is designed to identify climate-related risks to a specific hydropower plant's environmental, financial, and social performance. This framework covers three different types of hydropower plants: storage, pumped storage (both closed loop and open loop systems), and run-of-river. Understanding the environmental, financial, and social effects of climate change is critical to ensuring sustainable implementation and operation of hydropower plants. Exploring and anticipating these effects early in planning for new hydropower projects allows for consideration of appropriate steps to avoid, mitigate, or compensate for effects. Despite being less flexible to adapt and change, existing hydropower plants can benefit from a better understanding and anticipation of the effects of climate risks, which can result in improved operational decisions or investments to reduce or manage these risks.

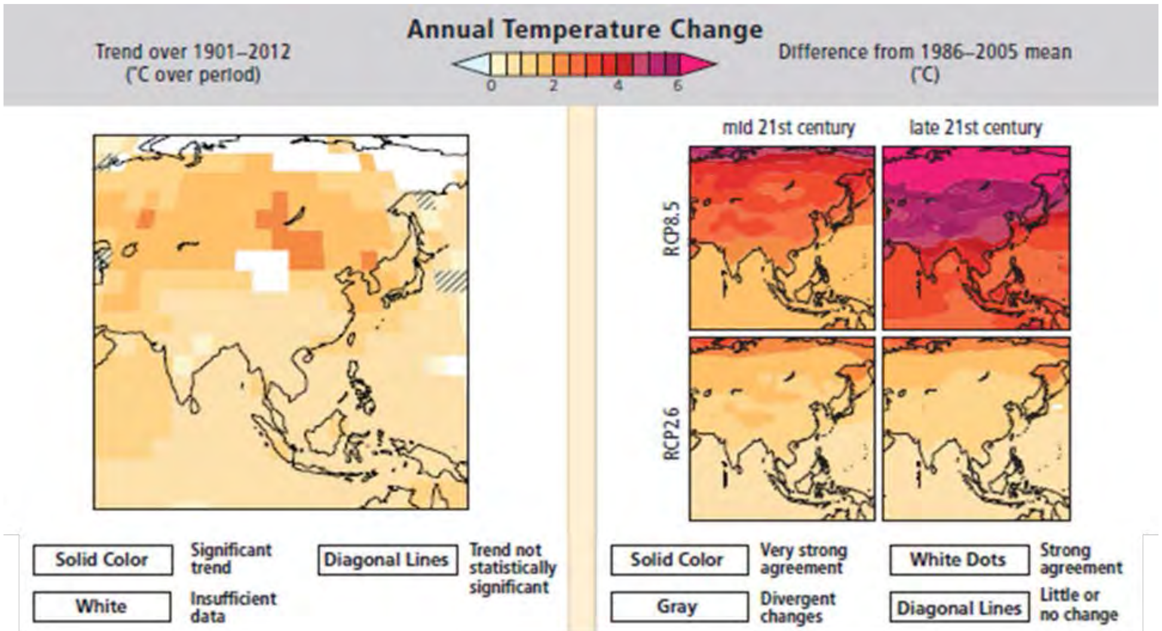
Southeast Asia is already experiencing the effects of climate change. Average temperature has increased at a rate of 0.14–0.2°C per decade since 1960, and there has been an increase in the number of hot days and warm nights. Precipitation trends are characterized by strong variability across the region and between seasons. These trends are projected to continue into the future with climate change. Average and extreme temperatures are projected to continue to increase (see Figure 1-1). Projected changes in precipitation are less certain and projections for average annual precipitation vary within the region (see Figure 1-2). Regarding extreme events, climate models project increases in precipitation extremes from the monsoon and tropical cyclones in Southeast Asia (Hijioka et al. 2014).

Moreover, the timing, duration, and rainfall of the monsoon season are also projected to change (Loo et al. 2014. By the end of the 21st century, the annual flow of the Red River is projected to decline by 13 percent to 19 percent, and that of the Mekong River by 16 percent to 24 percent

(Asian Development Bank 2009). The potential effects on water resources, such as irregular stream flows and greater sedimentation, threaten sustainable development in a region highly dependent on water resources for livelihoods.

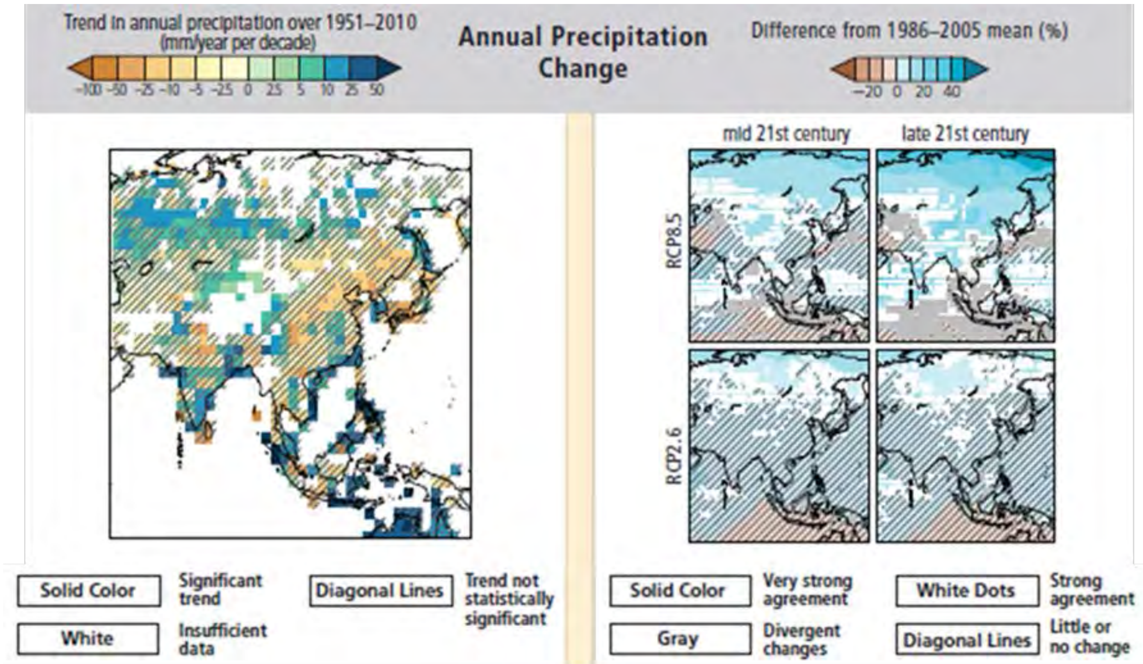
Figure 1-1

Trends and Projections for Annual Temperature Change in Asia



SOURCE: Hijioka et al. 2014.

Figure 1-2
Trends and Projections for Annual Precipitation Change in Asia



SOURCE: Hijioka et al. 2014.

Major Climate Events in Southeast Asia

- In Indonesia, floods in 2003–2005 caused US$205 million in infrastructure damage to roads, dams, houses, and other water resource management structures.
- Drought in the Philippines during El Niño years has caused severe water shortages at Angat dam, which supplies the metropolitan Manila region. Water rationing reduced daily service by about four hours in some areas and affected hydropower production.
- In Vietnam, deaths and injuries from flash floods and landslides in mountainous areas have become more frequent over the last decade—about 9.3 people per million die each year because of climate-related disasters.
- Source: Asian Development Bank, 2009. The Economics of Climate Change in Southeast Asia: A Regional Review.

This document outlines the risks to hydropower performance and reliability given climate-related stressors, the framework methodology for assessing business risks to hydropower facilities, and the accompanying screening tool. The climate-related stressors include temperature changes, changes in hydrology (flow timing and amount), extremes (heat waves, drought, floods), and associated sedimentation.[1] The methodology explains the conceptual basis for the tool. The tool, an interactive Excel spreadsheet, facilitates a structured application of the methodology to identify important risks to the hydropower facility. However, the tool is not intended to provide a detailed risk analysis. Rather, it is intended to help users determine the appropriate level of effort for further studies, consultation, and dialogue during project design or modification.

With support from USAID's ASEAN Connectivity through Trade and Investment (ACTI) Project, the framework was applied to three hydropower plants: one each in Laos PDR, Vietnam, and the Philippines. The application to the hydropower plants was followed up by a full-day workshop on the framework application in Myanmar during the 3rd ASEAN Renewable Energy Week (AREW), 23-27 March 2015. The workshop engaged over 30 representatives from government, nongovernmental organizations, academia, bilateral donors, the private sector, and ASEAN regional institutions. Results from the AREW workshop and the case study application were presented at a high-level session at the Renewable Energy–Sub Sector Network (RE–SSN) of the ASEAN Energy Cooperation. The results of the application of the framework tool and the AREW workshop are provided in Appendix A.

[1] These climate-related stressors were derived from IPCC SRREN: http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch05.pdf.

2. Risks to Hydropower Performance from Climate Change Stressors

Climate-related stressors can affect different parts of the hydropower supply chain from primary electricity generation and production, to secondary transmission and distribution, and finally to energy demand. Impact will vary depending on the type of facility but can include direct effects on the timing and availability of water for generation, as well as indirect effects such as air temperature changes on energy demands and usage patterns. These in turn affect hydropower performance and reliability, including for example, on the plant's ability to meet regulatory constraints, or peak energy demands during weather extremes.

Here we briefly describe climate-related stressors and their potential effects on hydropower reliability. Notice that climate change and climate effects vary by context, and some of the descriptions below may not apply to your hydropower plant. Figure 2-1 provides a high level snapshot of the relative effects of each climate stressor on the different types of hydropower plants. Run-of-river plants are more sensitive to changes in flow volume and timing than storage plants, for example.

What are the business risks to hydropower facilities from climate variability and change?

Climate variability and change can affect a hydropower facility's revenue, costs, reputation, and ability to meet regulatory requirements. For example:

- Changes in precipitation patterns can lead to longer dry seasons that make it more difficult to meet environmental regulations, such as in-stream flow requirements and ramping rate restrictions.
- Higher temperatures can increase peak demand and lower the efficiency of transmission and distribution, rendering generation insufficient.
- Maintenance costs may increase as turbines suffer from higher sediment loads.

Figure 2-1

Summary of Climate Stressor Applicability by Project Type

Climate Stressor	Change	Project Type			
		Storage	Pumped Storage		Run-of-River
			Open Loop	Closed Loop	
Temperature	Increase	Smaller decrease	Smaller decrease	N/A	Smaller decrease
	Decrease	Smaller increase	Smaller increase	N/A	Smaller increase
Flow volume and timing	Increase	Larger increase	Larger increase	N/A	Larger increase
	Decrease	Bigger decrease	Bigger decrease	N/A	Bigger decrease
Sedimentation	Increase	Bigger decrease	Bigger decrease	N/A	Bigger decrease
	Decrease	Larger increase	Larger increase	N/A	Larger increase
Drought	Increase	Bigger decrease	Bigger decrease	N/A	Bigger decrease
	Decrease	Larger increase	Larger increase	N/A	Larger increase
Flood extremes*	Increase	Bigger decrease	Bigger decrease	Smaller decrease	Bigger decrease
	Decrease	Larger increase	Larger increase	N/A	Larger increase

Legend: Shading indicates relative effect on generating capacity. *N/A* | *Bigger decrease* | *Smaller decrease* | *Smaller increase* | *Larger increase*

**Increased flow is included under "Flow volume and timing", flood extremes represent extreme events that pose safety risks*
SOURCE: Modified from: http://www.middlebury.edu/media/view/352071/original.

FLOW VOLUME AND TIMING

Flow volume and timing includes changes in hydrology as a result of changes in rainfall, temperature, and wind. These changes include seasonal shifts and changes in flow magnitudes due to changes in monsoon (e.g., timing, duration, rainfall amount), changes in glacier melt (e.g., timing), and longer-term changes in total rainfall amount. Southeast Asia is broadly projected to become drier due to climate change in the future; by the end of the 21st century, the annual flow of the Red River is projected to decline by 13 percent to 19 percent, and that of the Mekong River by 16 percent to 24 percent. Due to temperature increases, the extent of snowpack and glaciers is also projected to decrease. Understanding the local climate change projections and their impact on the water resources that your plant relies on is important, as regional changes may not accurately capture local projections.

Water availability as a result of flow volume and timing has extensive implications for hydropower. Reduced water availability may result in difficulties meeting competing environmental, financial, and social demands. From an environmental perspective, lower flows may complicate meeting in-stream flow requirements and conserving sensitive ecosystems. Low flows or changes in timing also affect generating capacity, affecting the plant's ability to deliver reliable supply. Lastly, a facility must also ensure that enough water is available for irrigation and other local uses to minimize negative effects on the local community. Shifts in seasonal runoff can result in greater electricity generation during periods of high flow, but can also lead to reduced generation during periods of low flow and high energy demand. In the long term, expected reductions in snowpack will likely reduce generating capacity.

AVERAGE TEMPERATURE

Temperate changes here include increasing average temperatures, but do not including extremes (such as heat waves, which are covered below). Temperature effects on snowmelt are covered above. Here we cover changes in water availability as a result of increasing evaporation of surface water storage supplies, as well as temperature effects on transmission and demand.

The average temperature in Southeast Asia has increased at a rate of 0.1–0.3°C a decade since 1960. For high surface area reservoirs, such increases can mean significant losses of water supply. Reduced storage can hurt financial performance because the facility has less flexibility to buffer variable flow rates and less capacity to meet peak demands. At the same time, higher temperatures can increase electricity demand, which is already rising due to population increases and industrialization. The increased possibility of blackouts or brownouts translates to reputational risk for the business. Lastly, transmission also suffers from lower efficiencies during periods of high temperatures.

EXTREME EVENTS

The term “extreme events” refers to heat waves, droughts, floods, and typhoons. Due to increasing climate variability, such extreme weather events are likely to become more frequent and severe. For example, the number of tropical depressions, tropical storms, and typhoons reported in Southeast Asia reached an all-time high in 2004. In the past 15 years, the Philippines has been struck by the strongest typhoon ever recorded, the most destructive typhoon, the deadliest storm, and the typhoon registering the highest recorded 24-hour rainfall. Meanwhile, droughts and floods continue to plague Indonesia, Lao PDR, Myanmar, and Vietnam, particularly in El Niño years.

As mentioned in the flow volume and timing section above, low water availability threatens all dimensions of business performance. Droughts exacerbate these difficulties. Managing competing water demands becomes even more complex, as there are tradeoffs between preserving flows for environmental regulations, allocating water to agriculture and water supply, and using water to generate electricity. Drought can also significantly affect other forms of energy generation that require water for cooling (e.g., thermal), compounding strain on the grid.

Heat waves are projected to become more intense and more frequent around the world. Such events increase demand for electricity, so hydro facilities that provide peak power may struggle to produce adequate electricity and may suffer financial and reputational consequences. Transmission infrastructure can experience line sag that reduces the mechanical integrity of overhead transmission and distribution systems. As mentioned above, high temperatures, including heat waves, can also reduce the ability of the transmission lines to carry power due to lower efficiency at higher temperatures.

Typhoons, floods, and landslides all present physical risks to a facility’s infrastructure and surrounding communities. Infrastructure damage and plant shutdowns can reduce financial performance. At the same time, lack of adequate protection for the community from events such as dam overtopping can harm the plant’s reputation. Beyond the facility, the larger energy system can also suffer from such extreme weather events: pipelines and production infrastructure for energy resources and transmission and distribution systems may be disrupted, increasing reliance on the hydro facility.

SEDIMENTATION

This stressor refers to sedimentation effects as a result of increasing intensity and frequency of rainfall events and flooding. Sedimentation from upstream erosion and deposition is already a major issue for many facilities because it can reduce the capacity of dams and reservoirs and can damage turbines. At the moment, insufficient data exist on trends in landslide-inducing storms to infer that these types of disturbance events are changing.

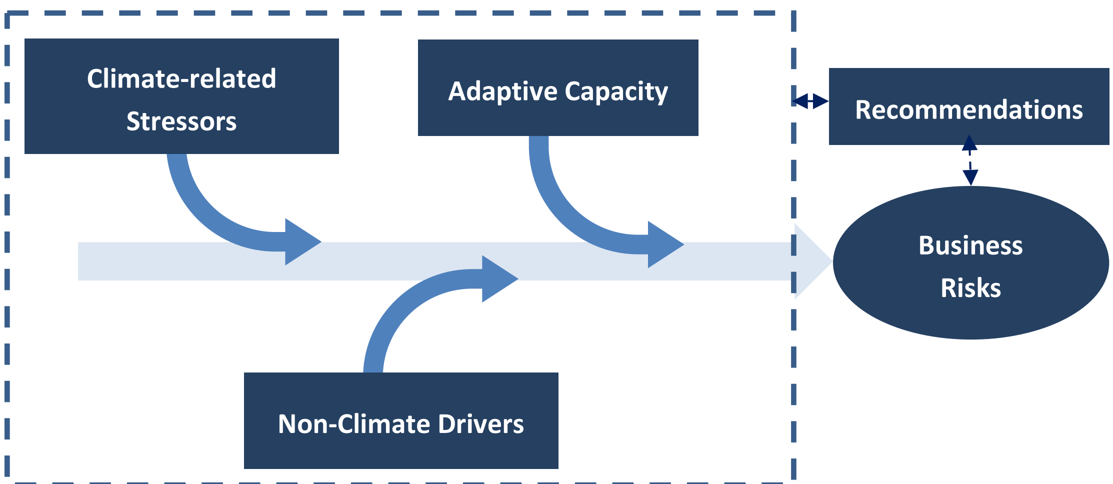
Sedimentation in reservoirs can harm financial performance by reducing water storage and the associated flexibility to cope with variable flows and meet peak demands. Such effects impede the reliability and adequacy of generation. Another financial concern associated with sediment loading (in particular, suspended solids) is maintenance costs, which can increase significantly due to wear and tear on turbines. Such cost increases can raise energy prices and reduce affordability for consumers.

3. The Framework

The framework helps users assess business risks to hydropower performance by breaking climate risk down into three components (Figure 3-1): potential impact from climate-related stressors, potential impact from non-climate drivers, and adaptive capacity (USAID, forthcoming). Once the risks have been assessed and identified, the framework provides users with a set of recommendations to help manage or mitigate the identified risks.

Figure 3-1

Conceptual Framework for the Tool



Potential effects from climate-related stressors include such things as direct damage to infrastructure from floods or landslides and reduced generation from variable precipitation patterns. Energy demand can also be affected by higher temperatures. Climate-related stressors can indirectly influence the facility as well; for instance, drought may aggravate conflict between the hydropower facility and local water users, leading to a damaged reputation for the plant and, possibly, unrest.

These climate effects are frequently exacerbated by non-climate drivers, such as changes in land use and land cover and increases in energy demand. The combined impact of climate-related stressors and non-climate drivers is particularly important to consider in areas of rapid change, such as Southeast Asia. For instance, upstream land conversion to cropland can increase erosion while heavy downpours become more frequent, both of which escalate sedimentation and can increase wear on turbines.

Adaptive capacity represents what the facility has done and can do to counter and manage the potential effects from climate-related stressors and non-climate drivers. Adaptive capacity can take many forms, such as financial flexibility that can tailor operations to optimize performance in real time, insurance to limit financial risk from extreme events, and early warning systems to safeguard the facility and surrounding community.

Finally, a set of recommended options is provided for the facility to consider as it takes further action to reduce or manage the identified climate risks. For example, for a new project where the identified climate risks are moderate to high, one recommendation may be to conduct more detailed design studies to better understand the implications of climate change for key hydropower infrastructure. Because of the high-level nature of the screening, the recommendations are typically suggestions for further exploration; the appropriateness of different measures depends strongly on the specific context.

4. The Tool

The tool can be used for screening in order to flag climate risks at an early stage of project development, or it can be used on existing facilities to identify existing or future risks. The tool is not intended to provide a detailed risk analysis. Rather, it provides a set of high-level, practical recommendations based on identified risks but not tailored to the specific project context. Recognizing that each facility is different, the tool is customizable to allow the user to maximize its usefulness. The basic structure of the tool is illustrated in Figure 4-1.

In the tool, the facility's performance is organized into three categories: environmental, financial, and social. These categories were chosen to capture the numerous objectives of the facility as well as the importance of environmental regulations, social cohesion with the surrounding community, and reputation.

A brief description of each individual steps follows.

STEP 1: DESCRIBE THE FACILITY

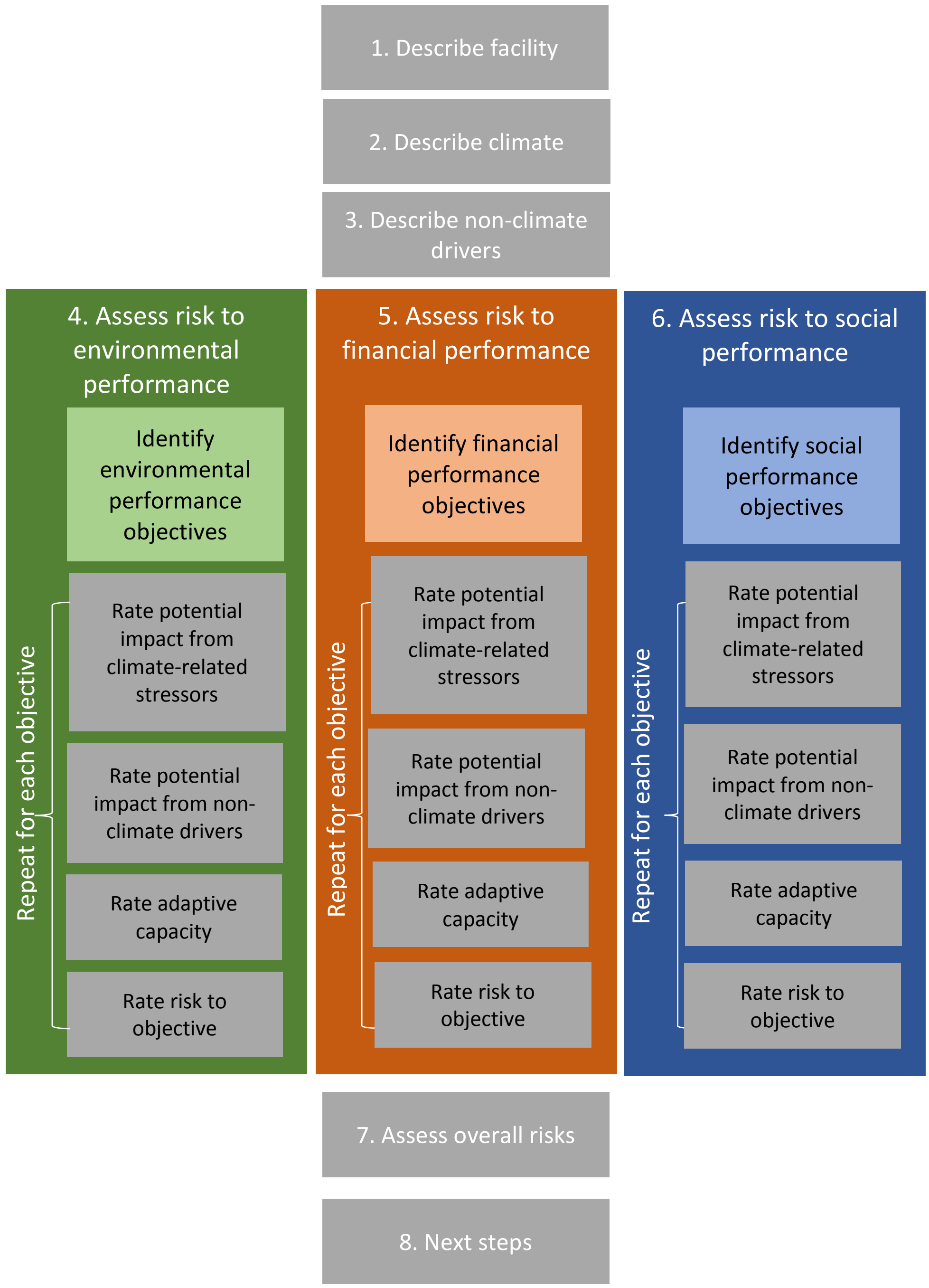
This step is intended to obtain basic information about the plant that lets the tool provide tailored guidance to the user on salient risks for a facility. The user begins by entering details specific to the type of hydropower plant, which in turn affects the questions and content provided downstream. The tool allows for consideration of three different types of hydropower plants: storage, pumped storage (both closed loop and open loop systems), and run-of-river. The user enters information surrounding the generating capacity, type of power provided (e.g., peak operation, firm power, or a combination), the annual runoff, whether it is an operational plant or planned project, and other characteristics.

STEP 2: DESCRIBE CLIMATE

In this step, users populate the tool with information on climate in two timeframes: recent and future. This information will be used in later steps in conjunction with knowledge of the facility to guide the user's selection of impact and risk ratings. Documenting the information here lets users refer back to this page to refresh their memories and share findings with others reviewing or contributing to the screening.

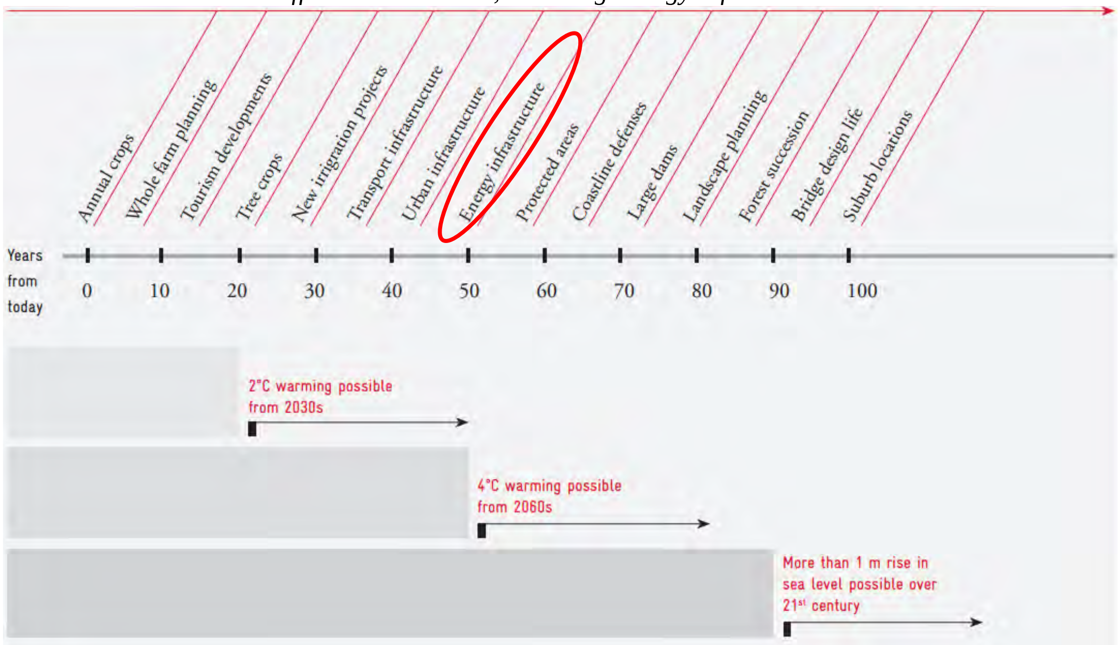
Figure 4-1

Structure of the Vulnerability Assessment Framework



The timeframe relevant for the hydropower project depends on the nature of the project and varies for different infrastructure assets associated with the plant (e.g., transmission, generation, and impoundment). Figure 4-2 illustrates the concept of the time scale of climate change and project lifetimes as it applies to a range of investments.

Figure 4-2
Time Scales Relevant to Different Investments, including Energy Infrastructure



SOURCE: *Modified from Smith et.al 2011.*

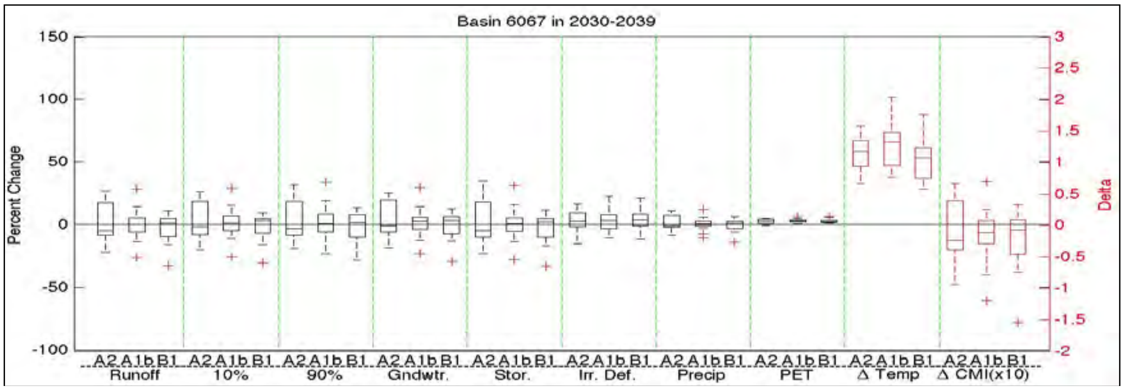
The tool includes four climate-related stressors: average and extreme temperature, flow volume and timing, extreme events, and sedimentation.[2] Whenever possible, local climate information should be used as inputs to this step. However, the tool also directs users to sources such as the World Bank's Climate Change Knowledge Portal (CCKP), which provides historical and future data on climate and hydrological variables. See Figure 4-3 for an example of output from the CCKP.

STEP 3: DESCRIBE NON-CLIMATE DRIVERS

In addition to changing climate conditions, hydropower facilities must cope with evolving non-Climate drivers, such as population growth and deforestation. Energy, water, and land systems interact in many ways. Climate change affects the individual sectors and their interactions; the combination of these factors affects the climate change vulnerability of hydropower systems. For example, hydropower generation, transmission, and distribution depend upon land use and water supplies, which will be affected by climate change, which ultimately changes the vulnerability of hydropower systems to climate change. Jointly considering risks, vulnerabilities, and opportunities associated with energy, water, and land use is challenging but can improve the identification and evaluation of options for reducing the harm from climate change.

[2] These climate-related stressors were derived from the 2011 Intergovernmental Panel on Climate Change (IPCC) IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Chapter 5: Hydropower (Kumar, et al., 2011)

Figure 4-3
Excerpt from World Bank Climate Change Knowledge Portal



Like with the previous step, users will document their understanding of these non-climate drivers to guide their ratings later in the tool. The recording of this information ensures that all team members are operating under similar assumptions as they proceed through the screening.

Examples of Non-Climate Drivers

Land use and land cover: Land use change in Southeast Asia, such as increased conversion of nonagricultural land to cropland and deforestation, dramatically affects water resources. Unsustainable harvesting and logging increase exposure to extreme events such as typhoons, landslides, floods, and drought.

Upstream-Downstream hydro development: In the Mekong Upper Basin, China is developing a cascade of up to eight hydropower projects (and 17 under consideration). In the Lower Basin, 136 hydropower projects exist, are under construction, or are under consideration. (ICEM, 2013)

STEPS 4–6: SELECT AND RATE RISK TO PERFORMANCE OBJECTIVES

With the preparatory steps complete, the user now proceeds through a series of steps to rate risk to each performance objective. This process also provides insight into the key forces driving the chosen risk rating. There are three categories of performance: environmental, financial, and social. For each category, there are several predefined objectives for each plant type (Table 4-1), though users can also enter their own objectives.

Table 4-1
Predefined Objectives by Facility Type

Performance Category	Objective	Storage	Pumped Storage		Run-of-River
			Open	Closed	
Environmental	Meeting in-stream flow and reservoir elevation requirements	x	x		x
	Minimizing ecosystem damage (e.g., maintain dissolved oxygen levels, minimize fish mortality)	x	x		x
	Respecting water ramping rate restrictions	x	x		
Financial	Maximizing revenue from power generation and ancillary services	x	x	X	x
	Minimizing infrastructure maintenance, upgrade, and retrofit costs	x	x	X	x
	Maintaining high operating efficiency	x	x	X	x
	Meeting firm energy	x	x	X	x
	Meeting peak electricity demands	x	x	X	
Social	Providing affordable and reliable electricity to consumers	x	x	X	x
	Benefiting the surrounding community (e.g., quality of life, livelihoods)	x	x	X	x
	Ensuring safety of nearby communities	x	x		x

For each performance category (environmental, financial, social), the user completes the following steps:

Select priority performance objectives for the facility

The objective of this step is to establish the priority performance objectives for the facility, such as meeting in-stream flow regulations or ensuring the safety of the nearby community. Selection of these objectives is a critical step because it enables users to tailor the tool to their priorities and streamline screening by avoiding irrelevant or less important objectives.

A number of objectives are preloaded into the tool; users may also write in their own objectives. Selection is limited to five objectives per category in order to ensure the screening is not inordinately long. The preloaded objectives were chosen for their broad applicability to the different types of hydropower facilities.

Rate potential impact from climate-related stressors

For each of the priority objectives, users apply climate information and their knowledge of the facility to rate the potential impact from climate-related stressors on the achievement of the objective. For preloaded objectives (those suggested by the tool), the climate-related stressors are selected based on relevance, and guidance is provided that further explains the relationship between the objective and the stressor. For custom objectives, all four stressors (average and extreme temperature, flow volume and timing, extreme events, and sedimentation) are included.

In light of potential future changes in climate, ratings are selected for two timeframes: recent and future.

Rate potential impact from non-climate drivers

Non-climate drivers interact with climate-related stressors to worsen effects on the facility. In this step, users rate the potential impact from non-climate drivers that are relevant to the performance objective. As with the climate-related stressors, for preloaded objectives the non-climate drivers are selected based on relevance to the objective, and ratings are determined for two timeframes. This allows users to differentiate between, for instance, limited upstream and downstream hydro development in the past, and aggressive plans to develop hydro in the future.

Rate adaptive capacity

All hydropower facilities already cope with some degree of climate variability. This adaptive capacity can take many forms, such as contingency plans, financial flexibility, and flood insurance. Users account for existing adaptive capacity in this step by rating how these factors permit the facility to cope with or avoid the potential effects outlined in the previous steps. The tool filters the adaptive capacity factors based on the objective and offers guidance to the user for preloaded objectives.

Rate risk to the objective

In this step, users sum up their previous ratings to determine the level of risk posed to the performance objective. This risk rating requires an integrated consideration of adaptive capacity and the potential effects of climate-related stressors and non-climate drivers. For example, the potential impact from changes in flow volume and timing may be so severe that despite financial flexibility and a reservoir to buffer the effects, risk of being unable to meet firm power is high. See Figure 4-4, for an example of the tool's rating page for environmental performance.

STEP 7: ASSESS OVERALL RISKS

The objective of this step is to summarize the risks to individual objectives into three ratings of overall risk to environmental performance, financial performance, and social performance (Figure 4-5). This involves a relative weighting of different objectives and their risk ratings. This step puts individual objectives into a broader context and lets the user compare the different performance categories with one another.

Figure 4-4
Screenshot of Environmental Performance Rating Page

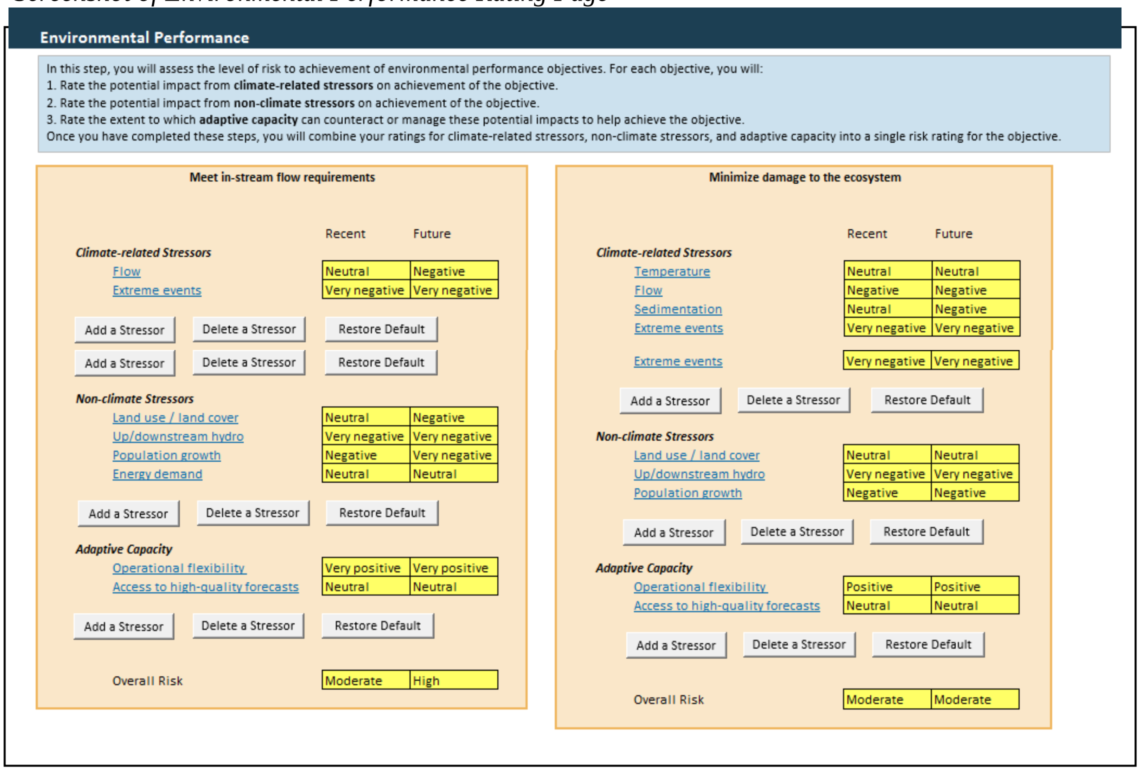
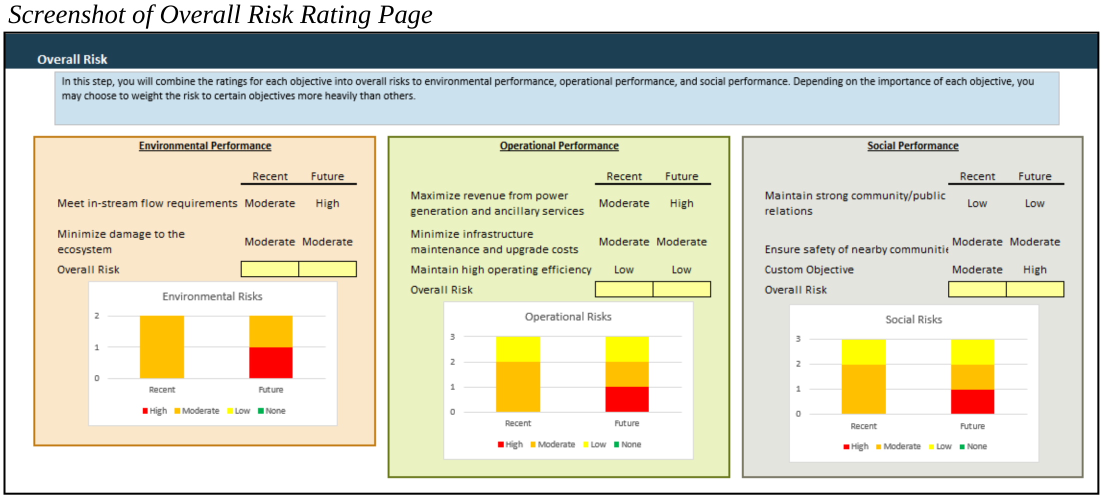


Figure 4-5
Screenshot of Overall Risk Rating Page



STEP 8: NEXT STEPS

In this step, users review suggested next steps selected based on their overall risk ratings in Step 7. These recommendations are options for the facility to consider as they take further action to reduce or manage their climate risks. Because of the high level nature of the screening, the recommendations are suggestions for further exploration; the appropriateness of different measures depends strongly on the specific context. Not all of these recommendations are under the control of the plant operator or developer—some are higher level policy recommendations. We suggest holding discussions with relevant stakeholders to identify the most appropriate options to pursue, and using the recommendations and resources provided here as a starting point. The full list of recommendations and resources is provided below.

Recommendations for Plant Operators or Developers

Engineering and Technology

Integrate climate change considerations into design studies for new or existing hydropower infrastructure. Detailed design studies can build on the results of this screening and provide a better understanding of the risks posed to the business. A detailed assessment can be tailored to the specific project context with local climate and hydrological information. Potential changes in design to be considered include modifying design of the reservoir to take into consideration expected higher or lower flows, changing the number and capacity of turbines, employing sediment expulsion technology, and changing the design of flood control measures. New studies may be required to evaluate whether design changes are necessary for existing infrastructure.

Build flexibility into the plant design. A flexible plant design enables the facility to adjust to changing conditions in the future. For example, a dam can be constructed in a way that allows for heightening in the future to increase flood protection. Flexibility must be incorporated into the original plant design.

Retrofit existing facilities to prepare for flood or drought conditions. Retrofitting existing facilities can be necessary depending on projected changes in climate conditions.

Relocate or reinforce key infrastructure from floods, storms, and other extreme weather events. Fortifying the facility's infrastructure reduces damage from floods, heavy rainfall, strong winds, and landslides. This limits repair and replacement costs and can shorten disruptions. Projects have several fortification options, including but not limited to adding drainage, changing land use, and implementing flood protection.

Implement erosion control measures to reduce siltation and sedimentation. Erosion control measures such as slope stabilization, planting vegetation, or installing drainage pipes in hillsides can improve operations by managing sedimentation, because sedimentation decreases plant efficiency and increases damage to turbines. Erosion control can also enhance environmental performance.

Review maintenance programs in light of climate change. Reviewing maintenance programs in light of potential climate change effects ensures that timing and frequency of maintenance are compatible with potential increases in wear and tear and unpredictable rainfall. For example, sometimes major repairs are only done during the dry season, and shortened dry seasons may disrupt that schedule. In addition, installing additional turbines can allow more frequent maintenance.

Policy and Planning Recommendations

Improve or acquire data for flood risk mapping. Data on elevation, local hydro meteorology, local terrain, built environment, and populations can improve modeling and operational decision-making, particularly in mountainous areas with complex topography. Flood risk maps can be enhanced by weighing taking into consideration projected changes in return period rates of the 1:100 year flood, for example.

Implement or improve monitoring systems. Monitoring increases knowledge and understanding of changing flood risk over time, providing critical information on flow rates and plant performance. These data can then be used to make operational improvements, trigger early warning systems, and ensure that environmental regulations are met.

Develop drought- and flood-management plans that incorporate climate change. The main purpose of developing drought- and flood-management plans is to prevent catastrophic and costly damage to the facility, or to have a plan in place in case of drought. These plans determine key thresholds, stages, and responses. They minimize the environmental, operational, and social impact of droughts and floods. Plants could become ineffective or noncompliant with regulations if their plans do not adequately consider the possibility of more intense or frequent floods or droughts. For example, rule curves for reservoir surface levels in the flood season could be revised to reflect climate change.

Modify emergency preparedness and response plans to incorporate climate change. In light of projected climate changes, utilities can update emergency preparedness and response plans—including emergency drills, training activities, and early warning systems—to ensure that plant operators and nearby communities are prepared for floods or landslides, minimizing damage to the facility and livelihoods.

Improve coordination between competing water users, and raise awareness of climate change implications. In areas where water availability is projected to decrease, it will be increasingly important for multipurpose dam operators to coordinate with competing water users, dialogue on the implication of climate change, and maximize water use efficiencies.

Recommendations for Plant Operators or Developers and Policymakers

Implement public outreach activities to raise awareness of water scarcity in light of climate change and increasing water demand. Outreach by both the government and the project developer can help the public understand water as a shared resource, opportunities to improve water efficiency use, and the effects of climate change. This benefits the facility by increasing water available for the ecosystem and plant, and minimizing conflict over water resources. Communication with local communities should be done before developing a facility in order to establish a plan for resource sharing, possibly to include provision of potable water to local villages by the project developer.

Support water use efficiency and demand-side management in other water uses, such as agriculture. Maximizing water use efficiency in other water uses is a no-regrets practice that can help the facility's performance in many ways. With more water available to the facility, it can improve environmental performance, increase generation, and reduce conflict between competing users.

Promote end-use energy efficiency. Reducing energy demand through energy efficiency can help ensure that the facility has adequate generating capacity and reduce the risk of blackouts or brownouts. Energy efficiency also reduces climate change.

Coordinate with upstream and downstream hydro power projects that may be developed in light of climate change. Coordinating with operators and planners of upstream and downstream plants can help manage flows and water releases to maximize productivity, minimize environmental damage, and reduce the risk of extreme events, given projected climate change. This coordination should take place through higher level coordinating bodies (e.g., associations), if appropriate.

Recommendations for Policymakers and Regulators

Integrate water management approaches in the basin and develop water regulations that reflect climate change. A water resource management plan and accompanying regulations can help manage growing demand for water and balance water use for food security, hydropower operations, and other needs.

Implement or improve land use management planning and regulations in light of climate change. Optimizing water use in other sectors through effective land use management can ensure that there is water available for hydropower operations. In addition, some land use management strategies can help prevent siltation.

Improve reliability through back-up supply, smart-grid technology, and distributed generation. Flexibility and redundancy in the grid minimize the impact of unexpected reductions in generation from the hydro plant. For example, distributed generation reduces reliance on a central grid and provides backup supply during brownouts or blackouts.

5. References

Asian Development Bank. 2009. The Economics of Climate Change in Southeast Asia: a Regional Review. http://www.adb.org/sites/default/files/publication/29657/economics-climate-change-se-asia.pdf.

Asian Development Bank. 2013. Guidelines for climate proofing investment in the energy sector. Asian Development Bank.

Hijioka, Y., E. Lin, J.J. Pereira, R.T. Corlett, X. Cui, G.E. Insarov, R.D. Lasco, E. Lindgren, and A. Surjan. 2014. Asia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1327–1370.

Hong Troung et al. 2013. Basin Profile of the Upper Sesan River. Project report: Challenge Program on Water & Food Mekong project MK3 Optimizing the management of a cascade of reservoirs at the catchment level. ICEM—International Centre for Environmental Management, Hanoi Vietnam, 2013.

ICEM. 2013. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin: Main Report. USAID.

IEA (International Energy Agency). 2013. Southeast Asia Energy Outlook. World Energy Outlook Special Report.

IPCC. 2014. Climate Change 2014: Effects, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/report/ar5/wg2/.

Kumar, A., T. Schei, A. Ahenkorah, R. Caceres Rodriguez, J.-M. Devernay, M. Freitas, D. Hall, Å. Killingtveit, Z. Liu, 2011: Hydropower. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch05.pdf.

Loo, Y., et al. 2014. Effect of climate change on season monsoon in Asia and its effects on the variability of monsoon rainfall in Southeast Asia. http://www.sciencedirect.com/science/article/pii/S167498711400036X.

Smith, M.S., Horrocks, L., Harvey, A., and Hamilton, C. 2011. Rethinking adaptation for a 4◦C world

Strzepek and McClusky. 2010. Modeling the Impact of Climate Change on Global Hydrology and Water availability. Environment Department of the World Bank.

Traerup, S. and Olhoff, A. 2011. Climate risk screening tools and their application: a guide to the guidance. Roskilde, DK: UNEP Risoe Centre.

USAID. Forthcoming. Climate Change Vulnerability Assessment: An Annex to the USAID Climate-Resilient Development Framework.

U.S. Global Change Research Program. 2014. Climate Change Impacts in the United States: the Third National Climate Assessment. http://nca2014.globalchange.gov/report.

VWMC (Vietnam National Mekong Committee) and Institute of Water Resources Planning (IWARP). 2003. Analysis of Sub-Area 7V Basin Development Plan.

Wild, T. and Loucks, D. (2014). "Managing flow, sediment, and hydropower regimes in the Sre Pok, Se San, and Se Kong Rivers of the Mekong basin." Water Resources Research, 10.1002/2014WR015457, 5141-5157.

World Bank. 2015. Climate and Disaster Risk Screening Tools: http://climatescreeningtools.worldbank.org/

6. Selected Resources

Asian Development Bank. 2009. The Economics of Climate Change in Southeast Asia: a Regional Review. http://www.adb.org/sites/default/files/publication/29657/economics-climate-change-se-asia.pdf.

This regional study reviews the economics of climate action, both adaptation and mitigation, for Southeast Asia. On adaptation, it recounts major climate effects facing the region and how they may detract from development progress, focusing on the water resources, agriculture, forestry, and health sectors. It suggests adaptation options as well as policy options.

BC Hydro. 2012. Potential Effects of Climate Change on BC Hydro's Water Resources. https://www.bchydro.com/content/dam/hydro/medialib/internet/documents/about/climate_change_report_2012.pdf.

This study from BC Hydro focuses specifically on modeling climate change effects on the water supply and the seasonal timing of reservoir inflows. It recounts observed effects and their consequences for hydro generation and projects future changes.

Future Water. 2009. Climate Change and Hydropower, Impact and Adaptation Costs: Kenya. http://www.futurewater.nl/downloads/2009_Droogers_FW85.pdf.

This report employs the Water Evaluation and Planning (WEAP) approach to model the effects of climate change on hydro generation in Tana basin in Kenya. It simulates numerous climate change scenarios as well as different portfolios of adaptation options. The outputs cover not only the impact on hydro generation but also shortages in irrigation water, rain fed agriculture, and urban water.

Hijioka, Y., E. Lin, J.J. Pereira, R.T. Corlett, X. Cui, G.E. Insarov, R.D. Lasco, E. Lindgren, and A. Surjan. 2014. “Asia” in Climate Change 2014: Effects, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1327–1370.

The IPCC Fifth Assessment Report chapter on Asia details observed and projected climate change in Asia, including temperature, precipitation and monsoons, tropical and extratropical cyclones, surface wind speeds, and oceans. The chapter also outlines anticipated effects on several sectors (including freshwater resources, terrestrial and inland water systems, and human settlements and infrastructure) and strategies for managing risks.

International Finance Corporation. 2011. Climate Risk and Business - Hydropower. Kafue Gorge, Zambia. http://www.ifc.org/wps/wcm/connect/54595f004a830c6885dcff551f5e606b/ClimaetRisk_HYdro_Zambia_Full.pdf?MOD=AJPERES.

This case study focuses on the climate-related risks to a storage hydro facility in Lower Kafue Gorge, Zambia. The report documents detailed hydrological, reservoir energy, and financial modeling approaches for the risk assessment. It concludes with a discussion of adaptation options and recommendations.

International Finance Corporation. 2011. Climate Risk Case Study–Khimti 1 Hydropower Scheme. http://www.ifc.org/wps/wcm/connect/af11c8804a830dd88614ff551f5e606b/ClimateRisk_Hydro_Nepal_Full.pdf?MOD=AJPERES.

This case study examines the Khimti 1 hydropower scheme in Nepal, which is a 60MW run-of-river plant. The risk analyses examine both direct risks, such as a glacial lake outburst flood, and indirect risks, where climate effects on the local community may have consequences for the facility. It provides adaptation options as well as a discussion of lessons learned for the broader hydropower sector.

Kumar, A., et al. 2011. Hydropower. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch05.pdf.

This report focuses more broadly on the status of hydropower as a climate change mitigation option, examining the technical potential worldwide and opportunities for growth and improvement. One section of the report discusses the implications of climate change for the resource base and viability of hydropower deployment in the future.

Smith, M.S., Horrocks, L., Harvey, A., and Hamilton, C. 2011. Rethinking adaptation for a 4◦C world Phil. Trans. R. Soc. A (2011) 369, 196–216 doi:10.1098/rsta.2010.0277

U.S. Global Change Research Program. 2014. Climate Change Effects in the United States: the Third National Climate Assessment. http://nca2014.globalchange.gov/report.

The chapter on energy in the U.S. National Climate Assessment reviews how climate may affect energy supply and demand, including hydropower production. It provides recommendations for the broader energy system regarding smart-grid technology and other options to manage climate risks to the grid.

Appendix A: Case Study and Workshop

APPLICATION OF FRAMEWORK TOOLS AND AREW WORKSHOP

With support from USAID's ASEAN Connectivity through Trade and Investment (ACTI) Project, a framework for screening hydropower facilities for climate change risks to business performance was developed and applied to three hydropower plants: one each in Lao PDR,[1] Vietnam, and the Philippines. This framework consists of a guidance document and a practical, Excel-based tool that was designed to be easily used by plant investors and managers to identify specific risks from climate change associated with individual plants. The framework was applied by hydropower plant managers and government representatives in a full-day working session held in each country.

The working sessions (March, 18, 20, and 24, 2015) were followed up by a full-day workshop on the framework application held in Myanmar during the 3rd ASEAN Renewable Energy Week (AREW), 23-27 March 2015. The workshop engaged over 30 ASEAN Member State (AMS) representatives from government, non-governmental organizations, academia, bilateral donors, the private sector, and ASEAN regional institutions. Results from the AREW workshop and the case study application were presented at a high level session at the Renewable Energy–Sub Sector Network (RE-SSN).

This report reviews the climate and non-climate challenges for hydropower plants, describes the framework methodology case study applications and workshop, and provides a set of outcomes and next steps.

CASE STUDY SELECTION

A solicitation of interest was distributed by the ASEAN Center for Energy (ACE) to hydropower plant companies operating within the respective countries. The plants had the opportunity to better understand and characterize climate risk to business performance. Case-study plants were expected to proactively engage in the effort, including providing existing information and data on hydropower plant assets, as well as actively participating in the test of the hydropower risk assessment framework, and providing feedback on the framework.

Several plants expressed interest, including in Lao PDR, Thailand, the Philippines, and Vietnam. The pilot facilities that were chosen broadly reflected a representative range of geographies and countries, climates, hydropower technologies, and existing vulnerabilities, so that results would be relevant and useful to the wider industry. Selection criteria included:

[1] Note that the results of the Lao PDR application are confidential, and as such, are omitted from this appendix.

- Country interest, project or facility interest, and staff availability
- Importance of hydropower to the country or community
- Availability of climate information and information on the project or facility
- Willingness to share information
- Existing vulnerability to climate-related hazards
- Presence of knowledge centers
- Size, technology, and status of facility (planned vs. existing)

Based on these criteria, the Theun Hinboun hydropower plant in Lao PDR, the Tudaya-2 hydropower plant in the Philippines, and the Pleikrong hydropower plant in Vietnam were chosen as representative cases of run-of-river and conventional storage facilities. The results from Tudaya-2, and the Pleikrong are shared here.[2]

TUDAYA-2 CASE STUDY

The framework was applied with representatives from Hedcor Inc. (responsible for the management and operation of Tudaya-2) and the Philippines Department of Energy (DOE). The Tudaya-2 hydropower plant is a 7 MW capacity run-of-river hydropower plant on the Sibulan River in Davao del Sur. Tudaya-2 comprises an intake weir, desander, conveyance line, surge tank, high-pressure surface penstock, powerhouse, and transmission line. Two Francis turbines (with an expected lifetime of about 25 years) are coupled to generators suitable for local and remote control. The power produced is supplied to the Mindanao grid, one of the three main grids of the Philippines. Tudaya-2 is a registered United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM) Project, and has been operating since 2014.

Information on existing and potential future climate at the location of the facility was obtained from the World Bank Climate Change Knowledge Portal (CCKP), including Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A2 and B1[3] scenarios, with a focus on a mid-century timeframe; from the Philippines meteorological agency (PAGASA); and from discussions with stakeholders during the framework application. The data sources show that mean temperatures across the South Pacific have increased by approximately 1°C since 1970, at an average rate of 0.3°C per decade, with more rapid increases observed in the southern reach of the archipelago where the Tudaya-2 is located (CCKP). Average temperatures are projected to increase by 1–2°C by 2050–2059 in the Sibulan River Basin, and hot days are expected to become more frequent (CCKP).

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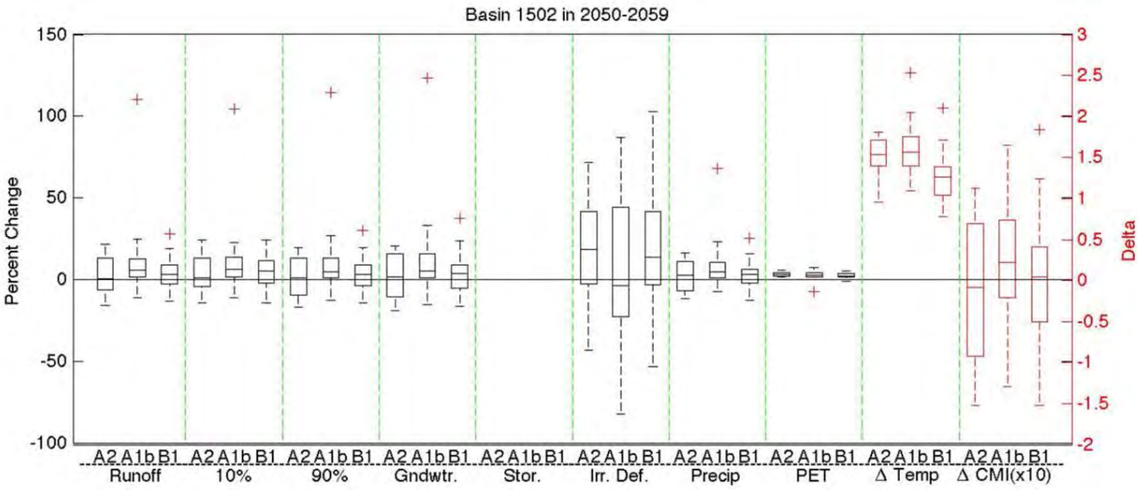
[2] Note that results from the Theun Hinboun are proprietary and cannot be shared.

[3] The SRESs were used as a basis for climate projections in the IPCC Fourth Assessment Report (2007). A2 assumes very high population growth and slower economic growth and technological development, representing a high-emissions scenario. B1 assumes the same population levels as A1, but with more clean technologies (and the lowest CO_2 emissions).

Figure A-1. Box-whisker plots for Basin 1502 (where Tudaya-2 is) in 2050–2059 (CCKP)



Note: This figure, for the A2, A1b, and B1 model ensembles, shows the percentage change in mean annual runoff, 10% (flood indicator (annual high flow)), 90% (drought indicator (annual low flow)), Gndwtr (groundwater baseflow), Stor (water available to basin (basin yield)), Irr. Def (irrigation deficit (crop water deficit for crops)), Precip (mean annual precipitation), PET (annual potential evapotranspiration), and the change (Delta) in Temp (average change of mean temperature), and Delta CMIX x10 (climate moisture index) SOURCE: (Strzepek and McCluskey, 2010).

The number of rainy days in the Philippines has increased since 1990 (CCKP), and according to PAGASA[4] the intensity of rainfall in Davao del Sur has been increasing from 1951 to 2008. The historical frequency of tropical cyclones making landfall in Davao del Sur is low. Future rainfall patterns remain unclear, though projections indicate precipitation increases, particularly in the wetter seasons (June–November) (CCKP). At the basin level, the uncertainty in changes in runoff closely mirrors precipitation projections. Days with extreme rainfall are projected to increase in both frequency and intensity under a changing climate (CCKP). Recent evidence also points to a more frequent occurrence of El Niño, bringing an increase in drought conditions along this region (CCKP). According to Hedcor Inc. representatives, sedimentation occurs in the river basin, though much of the sedimentation is trapped upstream by the infrastructure of the Sibulan A hydropower plant (also run-of-river) upstream.

The watershed is a protected area that supports some villages along with their crops and cattle. The forests are protected by government regulation, though some deforestation occurs. Energy demand is increasing, as population and industry grow. Tudaya-2 is the farthest downstream of four run-of-river plants in a cascading hydropower system, after Sibulan A and B and Tudaya 1. Due to limited storage and control, the upstream hydropower plants do not regulate flow for Tudaya-2, but they do help to reduce downstream trash and sedimentation.

Hedcor Inc. representatives identified two priority objectives for environmental performance: (1) protecting low flows, and (2) minimizing ecosystem damage. The Tudaya-2's environmental water permit[5] stipulates that a 20% streamflow level must be maintained during operations.[6] This could be challenging during the dry season if drought frequency and intensity should increase because of climate change. Given that Tudaya-2 is a run-of-river plant with no storage, it has very little effect on

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[4] Climate Data Section, Climatology and Agrometeology Branch, DOST, PAGASA.

[5] Comply with the Minimum Compensation Flow requirements set by the Philippine Water Code.

[6] Sluice gates can be closed during low-flow periods, to stop water diversion.

downstream flow aside from the stretch of river just below the diversion. In order to minimize ecosystem damage, the project has spent on reforestation to reduce erosion and siltation and maintain watershed integrity.

Hedcor Inc. identified three priority financial performance objectives: (1) maximize revenue from power generation, (2) minimize maintenance, upgrade, and retrofit costs, and (3) maintain a high operating efficiency. By contract, the price per kilowatt hour of energy is fixed for the next 20 years. The Tudaya-2 benefits from the Philippines' renewable energy law, which prioritizes the dispatch of renewable energy over other energy sources during periods of low demand.

Finally, Hedcor Inc. identified three priority social performance objectives: (1) provide reliable energy to consumers, (2) benefit communities, and (3) ensure safety of nearby communities. Tudaya-2 has provided scholarships for education of local villagers and built a new water supply system closer to the village nearby the hydropower plant; it has also educated locals about safe behavior around the hydropower plant (particularly during high flows).

Results of the risk analysis are presented in Table A-1 below. For now, stakeholders indicated the hydropower plant faces little to no risk of not meeting its environmental, financial, and social performance objectives. For the future, potential increases in intensity and frequency of flash floods and droughts, and deforestation (that may contribute to sedimentation), were identified as a potential climate and non-climate effects that may threaten several of these performance objectives.

In particular, increasing drought may compromise the plant's ability to meet low flow and generation targets in the dry season. Hedcor Inc. said that flows in the past two years are lower than those that the design and operations were based upon. Engineers had only 15 years of data on which to calculate design flow. In addition, a 500-year flood event in 2011 inundated the Sibulan A powerhouse upstream of the Tudaya-2, which damaged the Sibulan A powerhouse, disrupted power production, and led to the construction of a wall around the powerhouse to protect it from future flooding. The Tudaya-2 is designed to withstand the 100-year flood event, and the powerhouse is not protected by a wall or other measures. Projected increasing intensity and frequency of flood events may place Tudaya-2 at risk of flood damages, and raises safety concerns for surrounding communities.

Based on the identified risks, the tool provided structural, policy, and planning measures that could be taken. These include developing flood risk maps that include climate change, improving monitoring systems, and potentially relocating or reinforcing key infrastructure from floods, storms, and other extreme weather. In addition, reviewing maintenance programs in light of climate change could help to ensure that timing and frequency of maintenance are compatible with potential increases in sedimentation or debris. Finally, raising awareness at the government and community level is recommended to better ensure compliance, and enforcement of regulations meant to safeguard forests in the protected area.

Table A-1.
Assessment of current (C) and future (F=year 2050) risks to achieving performance objectives at Tudaya-2

	Environmental				Financial						Social					
	Protect Low Flows		Maintain Integrity		Maximize Revenue		Minimize Maintenance		Maintain Efficiency		Reliable Energy		Positive Impact		Ensure Safety	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
CLIMATE STRESSORS																
Temperature																
Flow volume & timing		-														
Sedimentation																
Extreme events		-		-												
NON-CLIMATE DRIVERS																
Land use/land cover				-												
Up/downstream hydro																
Population growth		-		-												
Energy demand																
ADAPTIVE CAPACITY																
Insurance																
Early warning system																
Operational flexibility																
Storage																
Access to quality forecasts																
Climate sensitivity of grid																
Community education																

	Environmental				Financial						Social					
	Protect Low Flows		Maintain Integrity		Maximize Revenue		Minimize Maintenance		Maintain Efficiency		Reliable Energy		Positive Impact		Ensure Safety	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
Overall risk	N	M	N	L	N	M	N	M	N	M	N	M	N	L	N	M

Notes: gray=neutral, orange=negative, red=very negative, light green=positive, dark green=very positive (not shown here). Overall risk is indicated by None (N), Low (L), Moderate (M), and High (H).

PLEIKRONG CASE STUDY

The Pleikrong is a conventional storage hydropower plant with 100 MW capacity in the Se San River Basin in the central highlands of Vietnam. The Pleikrong hydropower plant contributes electricity to the national grid and regulates water flow to a series of downstream hydropower plants of Yaly, Se San 3, and Se San 4.

Mean annual temperature has increased by 0.4°C since 1960, with the rate of increase more rapid in the dry season (December–April) and in the southern parts of Vietnam (CCKP). Average maximum daily temperature is projected to increase 3.5°C during 2055–2080 in the Se San River Basin (International Centre for Environmental Management (ICEM 2013).[9] The frequency of relatively hot days and nights is projected to increase, while the number of relatively cold days and nights is projected to decrease at mid-century (CCKP).

Application of the Framework with stakeholders at Electricity Vietnam, Hanoi. Photo credit: Molly Hellmuth.

Mean rainfall over Vietnam has not shown any increase or decrease since 1960 (CCKP). The proportion of rainfall falling in heavy events has not changed significantly since 1960; nor has the maximum amount falling in 1-day or 5-day events (CCKP). Dry season precipitation and mean runoff are projected to decline, while wet season rainfall and runoff are projected to increase for the A2 scenario during 2060–2079 (CCKP). The proportion of total rainfall that falls in heavy events is projected to increase by 2%–4% by the 2090s (CCKP). The probability of extreme rainfall and flooding is projected to increase, with increased risk of flash floods, mudslides, and landslides in mountainous areas (CCKP). The high current variability of inter-annual rainfall poses drought risk; projected increasing variability is likely to exacerbate this risk. Drought frequency has been increasing in the Se San River basin (Hong Troung et al. 2013).

The Krong Po Ko River, where the Pleikrong is located, is influenced by the west Truong Son Range, where the flood season starts in June and ends in November. Severe floods have been increasing in recent years, including those in 1996 and 2000, that caused extensive loss of life and production, and damage to infrastructure. Tropical cyclones in the East Sea have become less frequent over the past several decades, although the frequency of tropical cyclones affecting Vietnam has increased by 0.43 event per decade in the past 50 years (ICEM 2013). Climate change is likely to increase cyclone-related rainfall rates near the centers of tropical cyclones making landfall in West, East, South, and Southeast Asia (Hijioka et al. 2014). Projected increases in precipitation could be compounded by increasing cyclone intensities.

Erosion and soil runoff currently cause sedimentation of the Pleikrong reservoir; while deforestation to allow for planting coffee and pepper has resulted in soil erosion and flash floods (Hong Troung et al. 2013). Population is growing, and the deforestation rate is high. Dry-season energy is highly valuable given the lower flows and increases in basin temperature during this time. In general,

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[9] The ICEM study uses IPCC Scenario A1b—a moderate emissions scenario—for all climate projections.

reducing energy production in the wet season and increasing it in the dry season represents increased firm power, which can be more profitable than maximizing annual energy production.

The Pleikrong's environmental performance objectives include meeting instream flow requirements and respecting water ramping restrictions. Financial performance objectives include maximizing revenue from power generation and ancillary services, maintaining high operating efficiency, and meeting peak electricity demands. Social performance objectives include providing affordable and reliable electricity to consumers and benefiting the community.

The results of the risk analysis are presented in Table A-2 below. For now, stakeholders indicated the hydropower plant faces very little risk of not meeting its performance objectives. However, achieving some of these objectives can be particularly challenging in the dry season, where the simultaneous effects of high water demands for agriculture, low flow, and high energy demands require plant operators to meet competing water needs and adhere to instream water regulations. Projected reductions in rainfall and increases in temperature during the dry season may portend higher evaporation, lower water availability, and higher agricultural water demands, downstream salinity, and energy demands. This could diminish Pleikrong's ability to maintain reliable energy generation and meeting competing water demands for agriculture and ecological flows.

Based on the identified risks, a series of structural, policy, and planning measures were provided by the tool, including recommendations to build resilience to potential dry season challenges, including:

- Developing drought management plans that incorporate climate change;
- Improving coordination between competing water users (e.g., agriculture and hydro);
- Implementing public outreach activities to raise awareness of water scarcity; and
- Supporting water-use efficiency and demand-side management in other water uses, such as agriculture.

The government could promote end use energy efficiency, and better enforce and raise awareness of land use regulations that would reduce erosion and sedimentation effects. Finally, the hydropower plant could implement or improve monitoring systems in light of climate change, in order to better understand changes in the basin, and to be better prepared to implement operational and structural changes.

Table A-2.
Assessment of current (C) and future (F=year 2050) risks to achieving performance objectives at Pleikrong

	Environmental				Financial						Social			
	Meet Instream Flow		Respect Water Ramping		Maximize Revenue		Maintain Efficient Operations		Meet Peak Demands		Positive Impact		Ensure Safety	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F
CLIMATE STRESSORS														
Temperature														
Flow volume and timing														
Sedimentation														
Extreme events														
Salinity														
NON-CLIMATE DRIVERS														
Land use/land cover														
Up/downstream hydro														
Population growth														
Energy demand														
ADAPTIVE CAPACITY														
Insurance														
Early warning system														
Operational flexibility														
Storage														
Access to quality forecasts														
Climate-sensitivity of grid														
Overall Risk	M	H	M	M	L	L	L	M	L	L	L	M	L	M

Notes: gray=neutral, orange=negative, red=very negative, light green=positive, dark green=very positive (not shown here). Overall risk is indicated by None (N), Low (L), Moderate (M), and High (H).

WORKSHOP ON SCREENING HYDROPOWER FACILITIES FOR CLIMATE CHANGE RISKS, MARCH 25, 2015 AND PRESENTATION TO THE RE-SSN, MARCH 26, 2015, YANGON, MYANMAR

A full-day workshop on the framework, engaging 30 representatives of ASEAN Member States (AMS), was held during the Third ASEAN Renewable Energy Week (AREW) on March 25, 2015, in Yangon, Myanmar. The objectives of the workshop were to familiarize participants with the framework; to present results of the case studies; and to better understand the potential utility of the framework. The results of the workshop and case studies were presented to the members of the Renewable Energy Sub-Sector Network (RE-SSN) on March 26, 2015.

Workshop participants were presented an overview of the framework, followed by an in-depth presentation and discussion of each step of the framework application to the case studies in Vietnam and Laos, including the case study results and the feedback from the participants in applying the case study.

Workshop participants were supportive of the framework, and agreed with the case study application feedback. In addition, some workshop participants indicated interest in applying the framework to their own hydropower plant investments. Some government participants wanted to explore the idea of training their staff on the framework, and of potentially requiring a due diligence screen for climate risks by all new hydropower plant projects.

Finally, the results of the ACTI Hydropower workshop and case study applications were presented to the members of the RE-SSN. The presentation included a brief overview of the purpose of the framework, its case study application, the workshop, and the resulting feedback. The ASEAN Center for Energy (ACE) indicated it would be considering ways to continue the work that had been started.

OUTCOMES AND NEXT STEPS

The framework was developed to allow hydropower plant operators, investors, and other stakeholders to better screen for and understand risks to achieving objectives for business performance. The framework was developed to be able to be applied by accessing publicly available information, avoiding the need for large amounts of data or prior knowledge of climate change. The framework also provides high level recommendations on how to manage the identified risks. Application represents a first-stage risk screening process, to raise awareness of the risks among key stakeholders.

Outcomes

The tool was applied by hydropower plant and government stakeholders to a small scale, run-of-river hydropower plant (Tudaya-2), and a larger scale conventional storage hydropower plant (Pleikrong). The application of the framework generated lively discussion among participants, achieving the goal of raising their awareness of a broad range of potential effects. Participants articulated a number of challenges—both climate- and non-climate-related—that must be addressed in order to meet their social, environmental, and financial performance objectives. The challenges highlighted by the owners and managers of hydropower plants include:

- Flooding (including from cyclones), droughts (including those associated with El Niño events), and low flows in the dry season.
- Lack of hydrologic data, due to a lack of existing gauging stations that would provide reliable and long time series of information on which to base investment decisions.
- Rapid population growth, a result of natural population growth and internal migration.
- Lack of regulated land use planning and enforcement, and lack of compliance with conservation measures for natural areas, leading to deforestation (despite afforestation programs), land degradation, and increasing sedimentation.
- Lack of solid waste management, leading to debris collection that can exacerbate flooding and public health concerns.
- Increasing competing water needs, particularly for agriculture, during low flow (dry season) periods.

Hedcor Inc., Tudaya-2's operator, expressed interest in applying the screen to other existing and planned hydropower plants in different regions of the Philippines, to better understand the differentiated risks to the company's plants and ways to manage those risks. Participants in the Pleikrong application case study noted that the tool may be usefully applied at project conceptualization, given that building large scale hydropower plants requires significant investment, intensive hydrologic modeling, and consultations that ultimately result in large fixed infrastructure assets that can be costly to modify once built.

During the framework applications, hydropower plant managers also suggested that government representatives would benefit by applying the tool because they would better understand how government actions can improve the performance and sustainability of hydropower plants. These actions include enforcing land and water use regulations and managing flood risk. Also, in some cases hydropower plant ownership may be transferred to the government after concessions run out in 25–30 years; in those cases, governments need to be aware of and plan for potential effects on hydropower plant performance.

During the AREW workshop on the framework, government representatives indicated their interest in being trained on the framework, in order to raise their own awareness of climate risks. Some government and government-affiliated representatives also indicated that the framework might be usefully applied by new investors to demonstrate that those investors have identified potential risks from climate change and ways to manage those risks.

Hydropower investments are expected to increase significantly over the next two decades to meet increasing energy demand and renewable energy objectives. At the same time, climate change poses risks to the ability of hydropower plants to meet environmental, social, and financial objectives. With that in mind, it will be imperative for sustainable, environmentally responsible, and safe operation of hydropower plants to take into account how changing climate and hydrological regimes may affect performance, within a broader context of changing demographics and land use and of growing competing water demands.

Next Steps

A number of key takeaways and next steps that were highlighted by the working sessions and workshop are described below.

A more detailed risk assessment would enhance the usefulness of the framework. While the results of the risk screening process provided a useful starting point for understanding risks, many participants expressed interest in a more detailed risk assessment. To improve on the current model, some simple yet robust indicators could be developed to better quantify the relationship between projected changes in water availability, sedimentation, temperature, and extremes, and their impact on hydropower business objectives. For example, potential hydropower output depends in part upon the flow rate,[10] so information on how the flow rate is expected to change as a result of climate change could be quantified (with uncertainty bands) in order to indicate the potential impact of climate change on hydropower output. Additional indicators may include the change in sedimentation rates as a result of changes in land use and rainfall intensity, or approximations of the extent of flood risk, based on projections of the frequency and intensity of flooding.

The economic costs and benefits of climate change effects and of adaptation investments should be quantified. Hydropower plant representatives indicated that hydro investments typically have high capital costs, increasing the difficulties in justifying further upfront expenses (e.g., implementing flood protection measures). The framework could be expanded to quantify the potential economic effects of climate change given, for example, projected annualized and seasonal reductions or increases in generation capacity, direct cost of damages and service disruptions due to flooding, or increased maintenance costs as a result of higher sedimentation. Costing of adaptation measures (low cost to higher cost options), combined with developing quantitative relationships between implementation of adaptation measures and avoided damages, can help investors better understand the tradeoffs associated with adaptation investments.

The framework should be widely disseminated, in local ASEAN country languages. Participants in the AREW workshop are eager to apply the framework to build their understanding of the climate risks to hydropower, and to apply the framework to planned and existing hydropower plants. Many have expressed an interest in receiving support from the technical staff assigned to these initiatives and, in the absence of opportunities for direct engagement, are eager to receive materials and tools they can adopt and apply to their own climate resilience efforts.

Needs for technical and institutional support. These needs are articulated above and include more reliable and accurate climate data, and greater coordination with government agencies regarding the types of interventions that government can support to improve sustainability of hydropower plants, and improved coordination on flood risk management. Adaptation finance could be sought out to fill these needs.

[10] Power (P)=Flow rate (Q) x Head (H) x Gravity (G) x Efficiency (E).

In addition, ACE confirmed the interest of ASEAN Member States in further applying and developing the framework. As an outcome of the RE-SSN meeting, ACE has formally requested further support and cooperation from ACTI for the following activities:

1. Conduct additional studies with the framework in other Member States;
2. Update the screening framework to incorporate the lessons learned from the case studies;
3. Share the framework methodology and tool with ACE; and
4. Organize similar seminars on climate change effects to hydropower plants in Member States.

APPENDIX A REFERENCES

Hijioka, Y., E. Lin, J.J. Pereira, R.T. Corlett, X. Cui, G.E. Insarov, R.D. Lasco, E. Lindgren, and A. Surjan. 2014. Asia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1327–1370.

Hong Troung et al. 2013. Basin Profile of the Upper Sesan River. Project report: Challenge Program on Water & Food Mekong project MK3 Optimizing the management of a cascade of reservoirs at the catchment level. ICEM—International Centre for Environmental Management, Hanoi Vietnam, 2013.

ICEM. 2013. USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin: Main Report. USAID.

Strzepek and McClusky. 2010. Modeling the Impact of Climate Change on Global Hydrology and Water availability. Environment Department of the World Bank.

Appendix B: Tudaya-2 Working Sessions

Working sessions to apply the framework for screening hydropower facilities for climate change risks, Department of Energy, Manila, Philippines, March 18, 2015. Purpose: provide an overview of the climate vulnerability screen framework.

Time	Activity	Materials
8:00 AM	Overview of Working Sessions and Vulnerability Screening Framework • Overview of the project activities • Overview and objectives of the vulnerability and adaptation screen tool • Goals of these working sessions • Go over tool, including steps, and the performance objectives • Discussion throughout presentation for clarification of approach	Participant(s) please bring laptop computer. Projector
9:00 AM	Application of tool with Participant(s): Steps 1 and 2: Focus on–Climate Stressors • Participant(s) will work with Dr. Hellmuth to test the tool on their hydropower plant. • Dr. Hellmuth will present the information gathered on climate variability and change, including the process used to gather the information, and the limitations of the information. • Discuss with participant(s) climate effects the hydropower plant has experienced in the past. • Fill in tool steps 1 and 2.	Participant(s) should come prepared with some information/studies on climate effects related to: drought, flood, sedimentation, changing flow.
10:00 AM	Break	
10:15 AM	Application of the Tool with Participant(s): Step 3 • Dr. Hellmuth will discuss with participant(s) non climate related drivers that currently affect the hydropower plant, and how expected changes in these drivers may affect the hydropower plant in the future. • Participant(s) will work to apply the tool and fill in Step 3 based on the information presented, but also their own understanding of the context.	Participant(s) should come prepared with some information/studies on non-climate drivers: land use/land cover, upstream/downstream hydropower plant investments, demographic characteristics, and energy demand.
11:00 AM	Application of the Tool with the Participant(s), Steps 4–6: Identify Environmental, Financial, and Social Performance Objectives, and Rate Risks to each Objective • Participant(s) will identify the performance objectives in each performance category. • Participant(s) will refer to information in steps 1–3, to assess the level of risk to achievement of the performance objectives.	Participant(s) should come prepared to identify the plant's environmental, social, and economic performance objectives (review defaults on page 10 of the framework).

Time	Activity	Materials
	Each performance category is allotted 1 hour to complete	
12M	Break	
1:00–3:00 PM	Application of the Tool with the Participant(s), Steps 4–6, continued • Participant(s) will refer to information in steps 1–3, to assess the level of risk to achievement of the performance objectives.	
3:00–3:30 PM	Application of the Tool with Participant(s), Step 7: Overall Risk • Participant(s) will work with each other to assess the overall level of risk to achievement of each performance objective.	
3:30–4:30	Application of the Tool with Participant(s), Step 8: Next Steps • Based on the overall ratings for Environmental Risk, Financial Risk, and Social Risk, high level recommendations are provided in the framework. • Participant(s) will discuss the recommendations, their applicability and utility, and other measures that may be missing.	
4:30–5:00 PM	Overview of Results • Review and discuss outputs from the tool • Are there additional considerations that should be factored in to the framework? • Provide feedback on the framework approach; identify areas for further refinement that may add value to hydropower plant planners and investors	

Tudaya-2 Working Session Participants		
First Name	**Last Name**	**Organization**
Rolando	Vergara, Jr.	Hedcor Inc.
Leslie	Cornelio	Hedcor Inc.
Angeles	Roval	Philippines Department of Energy
Michael	Velsaco	Philippines Department of Energy

Appendix C: Pleikrong Working Sessions

Working Sessions to apply the framework for screening hydropower facilities for climate change risks, Vietnam Electricity (EVN), Hanoi, Vietnam, March 20, 2015. Purpose: provide an overview of the climate vulnerability screen framework.

Time	Activity	Materials
8:00 AM	Overview of Working Sessions and Vulnerability Screening Framework • Overview of the project activities • Overview and objectives of the vulnerability and adaptation screen tool • Goals of these working sessions • Go over tool, including steps, and the performance objectives • Discussion throughout presentation for clarification of approach	Participant(s) please bring laptop computer. Projector
9:00 AM	Application of tool with Participant(s): Steps 1 and 2: Focus on–Climate Stressors • Participant(s) will work with Dr. Hellmuth to test the tool on their hydropower plant. • Dr. Hellmuth will present the information gathered on climate variability and change, including the process used to gather the information, and the limitations of the information. • Discuss with participant(s) climate effects the hydropower plant has experienced in the past. • Fill in tool steps 1 and 2.	Participant(s) should come prepared with some information/studies on climate effects related to: drought, flood, sedimentation, changing flow
10:00 AM	Break	
10:15 AM	Application of the Tool with Participant(s): Step 3 • Dr. Hellmuth will discuss with participant(s) non-climate related drivers that currently affect the hydropower plant, and how expected changes in these drivers may affect the hydropower plant in the future. • Participant(s) will work to apply the tool and fill in Step 3 based on the information presented, but also their own understanding of the context.	Participant(s) should come prepared with some information/studies on non-climate drivers: land use/land cover, upstream/downstream hydropower plant investments, demographic characteristics, and energy demand.
11:00 AM	Application of the Tool with the Participant(s), Steps 4–6: Identify Environmental, Financial, and Social Performance Objectives and Rate Risks to each Objective • Participant(s) will identify the performance objectives in each performance category • Participant(s) will refer to information in steps 1–3, to assess the level of risk to achievement of the performance objectives	Participant(s) should come prepared to identify the plant's environmental, social, and economic performance objectives (review defaults on page 10 of the framework).

Time	Activity	Materials
	Each performance category is allotted 1 hour to complete	
12:00M	Break	
1:00–3:00 PM	Application of the Tool with the Participant(s), Steps 4–6, continued • Participant(s) will refer to information in steps 1–3, to assess the level of risk to achievement of the performance objectives.	
3:00–3:30 PM	Application of the Tool with Participant(s), Step 7: Overall Risk • Participant(s) will work with each other to assess the overall level of risk to achievement of each performance objective.	
3:30–4:30	Application of the Tool with Participant(s), Step 8: Next Steps • Based on the overall ratings for Environmental Risk, Financial Risk, and Social Risk, high level recommendations are provided in the framework. • Participant(s) will discuss the recommendations, their applicability and utility, and other measures that may be missing.	
4:30–5:00 PM	Overview of Results • Review and discuss outputs from the tool • Are there additional considerations that should be factored in to the framework? • Provide feedback on the framework approach; identify areas for further refinement that may add value to hydropower plant planners and investors	

Participants		
First Name	**Last Name**	**Affiliation**
Pham Ngoc	Phu	
Li Npgis	Fry	
Truong Viet	Truong	KTAT, MTCN, BCT
Dao Phi	Hin	EVN
Doan Tun	Cuong	Ialy, EVN
Tnil Hong	Cy	MT
Nguyen Minh	Hau	Pho VTm Vu NLTT, TCM
Lo Thi Ngoe	Quynh	Pho TB KHCN, MT, EVN
Pham Thi Thu	Hwong	CV, Cong ty To Ialy, EVN
Hrang Van	Loi	CV Ban KHCN, MT, EVN
Hrang Suk	Thao	CV Ban KHCN, MT
Bui Van	Minh	CV Ban KHCN, MT

Appendix D: ASEAN-U.S. Workshop

Workshop on screening hydropower facilities for climate change risks, March 25, 2015, Yangon, Myanmar.

Time	Activity
8:30 AM	Registration
9:00 AM	Opening Session • Welcoming Remarks—Noordin Azhari, Deputy Chief of Party, ACTI • Opening Remarks—Dr. Sanjayan Velautham, Executive Director, ASEAN Centre for Energy
9:20 AM	Session 1: Overview of ACTI and Climate Change Vulnerability Screening Framework • Overview of the project activities • Overview and objectives of the vulnerability and adaptation screen tool • Questions/discussion Speaker: Dr. Molly Hellmuth Facilitator: Noordin Azhari
10:20 AM	Coffee Break
10:35 AM	Session 2: Demonstration of Application of tool on Case Study Hydropower plants: Types of hydropower plant, Climate Stressors • Overview of the types of hydropower plant the tool was tested on • Description of climate variability and change and relevancy to hydropower plant; including the process used to gather the information, and the limitations of the information • Discussion with participant(s): what types of climate effects have their hydropower plants experienced in the past? Speaker: Dr. Molly Hellmuth Facilitator: Dr. Sanjayan Velautham (TBC)
12M	Lunch
1:00 PM	Session 3: Demonstration of Application of the Tool on Case Study Hydropower plants: Non-climate Drivers • Description of the types of non-climate related drivers that currently affect the hydropower plants, and how expected changes in these drivers may affect the hydropower plant in the future. • Discussion with participants: what types of non-climate stressors are they concerned about in their regions? Speaker: Dr. Molly Hellmuth Facilitator: Chris Zamora

Time	Activity
2:00 PM	Session 4: Demonstration of Application of the Tool on Case Study Hydropower plants: Environmental, Financial, and Social Performance Objectives and Risk Ratings • Description of the performance objectives chosen by the case study Hydropower plants. for each performance category • Description of identified risks, and risk ratings • Discussion with Participants after each performance category: What are the critical performance objectives of hydropower plant in your region? How might these be affected by climate change? Speaker: Dr. Molly Hellmuth Facilitator: Chris Zamora
3:30 PM	Networking Coffee Break
4:00 PM	Session 5: Demonstration of Application on Case Study Hydropower plants: Overall Risk and Next Steps • Presentation of the overall risk, and high level recommendations • Discussion of Results Speaker: Dr. Molly Hellmuth Facilitator: Noordin Azhari
	Closing Remarks - TBC

Participants	
Name	Affiliation
Sovanna Toch	Director of New and Renewable Energy Department Ministry of Mines and Energy, Cambodia
Chhim Chhunn	Head of Renewable Energy Office Ministry of Mines and Energy, Cambodia
Azah Ahmad	Director, RE & Technology SEDA Malaysia
Moe Kyaw Oo	Assistant Director, Energy Planning Department, Ministry of Energy, Myanmar
Tin Htut	Director, Energy Planning Department, Ministry of Energy, Myanmar
Khin Than Nwe	Head of Department, Energy Planning Department, Ministry of Energy, Myanmar
Aung Htay	Assistant Geologists, Energy Planning Department, Ministry of Energy, Myanmar
Phone Myint Ag	Assistant Material Officer
Htun Naing Aung	Chairman, Energy & Environment Group (EEnG)
Dr. Hla Myo Aung	Deputy Director
Dr. Nan Sandar Lwin	Deputy Director
Dr. Thi Thi Soe	Principal Scientist
Aung Ko Oo	Principal Scientiest (MSTRD) Ministry of Science & Technology
Marissa Cerezo	Director - III Department of Energy (DOE)
Brandon Lon	Principal Analyst Energy Market Authority (EMA), Singapore

Participants	
Yaowateera Achawangkul	Mechanical Engineer, Professional Level Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy, Thailand
Nguyen Ninh Hai	Deputy Director Ministry of Industry & Trade
Quach Quang Dong	Deputy Director Ministry of Industry & Trade
Dr. Sanjayan Velautham	ASEAN Centre for Energy (ACE)
Christopher G. Zamora	ASEAN Centre for Energy (ACE)
Junianto M	ASEAN Centre for Energy (ACE)
Susy Marisi Simarangkir	Senior Advisor (ASEAN RESP) ASEAN Centre for Energy (ACE), Indonesia
Badariah Yosiyana	Project Officer (ASEAN RESP) ASEAN Centre for Energy (ACE), Indonesia
Lisa Tjandra	Administration Officer (ASEAN RESP) ASEAN Centre for Energy (ACE), Indonesia

Attachments

- Attachment:1: Application of the hydropower plant Tool to Pleikrong
- Attachment 2: Application of the hydropower plant Tool to Tudaya-2