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Promoting Resilience in the Energy Sector

Final Report

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Background

Project Motivation & Description

There is an urgent need in the APEC region to enhance the resilience of energy infrastructure to reduce the impact from natural and man-made disasters, and climate change. APEC economies face 70 percent of all global natural disasters. Energy systems are further stressed by exploding growth and urbanization across the APEC region.

This project supported a three-day workshop focusing on capacity-building training on the methodology for evaluating and addressing climate change risks to the power sector, with guidance on Integrated Resource and Resilience Planning, hydropower risk screening, and provided guidance for identifying and evaluating measures for addressing a range of climate risks across power sector components. The workshop was designed to help participants build capacity through presentations and interactive exercises, and share experiences and best practices from power sector practitioners engaged in climate resilient planning. This report describes the workshop proceedings and outcomes.

Objectives

The project workshop aimed build an understanding of:

1. Methodologies for evaluation climate change risks to power system resources, infrastructure, and demand;
2. Integrated resource and resilience planning (IRRP), and how IRRP can incorporate climate risk screening and support climate-resilient planning and decision-making; and
3. Climate risk screening for hydropower resources.

Workshop participants & structure

Seven expert speakers and 29 delegates representing nine APEC economies attended the workshop, with an additional 54 Participants attending from the host economy. Expert speakers came from the Philippines, the United States, and Australia. The APEC economies represented include Malaysia, Thailand, Viet Nam, Indonesia, the Philippines, Chile, China, and the United States.

Workshop Summary

The workshop took place over three days, from 31 July 2018 through 2 August 2018, and was hosted in Cebu, Philippines. The following sections describe the content of each day, including summaries of presentations as well as the best practices shared by presenters and identified through interactive sessions. The full agenda can be found in Appendix A. Workshop Agenda.

Day 1: Introduction to the Workshop and Climate Resilience

The first day provided an introduction to climate risks facing the power sector and resilience options to mitigate these risks. The day began with opening remarks, welcomes, and participant introductions, and was followed by a series of presentations, exercises, and discussions, as described below.

Opening Remarks from Philippines DOE

Director Patrick Aquino welcomed the distinguished guests and participants, indicating his support for the workshop on climate resilient energy planning. Director Aquino noted that the intent of the workshop was to provide basic frameworks, lessons learned, best practices, and case studies in improving energy resiliency, including in APEC member countries.

Three years ago, the Philippines hosted an APEC Energy Ministers Meeting under the theme: Towards an Energy Resilient APEC Community. This was a momentous event as the Energy Resiliency Task Force (ERTF) was established, with the Philippines and the United Stated were selected to be Co-Chairs. Director Aquino noted that attaining energy resiliency is an action agenda for APEC member economies, as defined by the APEC Energy Ministers in the Cebu Declaration, energy resiliency is the ability or quality of energy infrastructure to withstand natural and man-made disasters, to recover and return to normal conditions in a timely and efficient manner and to build back better.

Various initiatives have been undertaken at regional and national levels to drum up support and awareness on the critical importance of energy resilient infrastructure and facilities in the rehabilitation efforts of devastated communities, including:

- The Summit on Energy Resiliency (New Zealand, 2016) where the challenges on Financing and Investment on energy resiliency programs was discussed
- The inaugural first Meeting of the Energy Resiliency Task Force at the 51st meeting of the Energy Working Group (EWG), (Australia, 2015). Since then, ERTF meetings have become a regular side event during the regular EWG meetings.

Director Aquino reiterated the targeted outcomes of the workshop, to build the participants understanding of:

- Methodologies for evaluating climate change risks to power system resources, infrastructure, and demand
- Integrated resource and resiliency planning (IRRP), and how IRRP can incorporate climate risk screening and support climate-resilient planning and decision-making
- Climate risk screening for hydropower resources

He noted that there are two key actors in building energy resilience. The Government Sector, as key actor, should create enabling frameworks to encourage resilience-building actions by developing stimulating and supportive policies, and by setting an example in managing its own energy assets and even in the giving of emergency response support to its affected stakeholders. While the Private Sector which owns and operates a majority of the energy systems, and serves as the front liners in building energy resilience because they have experience in designing and implementing resilience-building measures and adaptive practices as well as identifying risks and managing their practices in a manner that minimize their exposure to likely damages. He stressed that both key actors have significant roles in improving resilience in the energy sector in the aftermath of natural and engineered disasters- and need to work hand in hand to establish disaster-resilient and climate-proofed energy facilities that will contribute to economic and business community, and most importantly, the preservation of lives and resources.

Director Aquino highlighted some of the Philippine's efforts on energy resiliency, including:

- The Philippine Department of Energy has institutionalized the Energy Resiliency Policy (REP) in the energy sector. This policy aims to strengthen the existing energy systems and assist in the quick restoration and provision of alternative energy source to cushion the adverse impact of natural disasters to consumers.
- The National Electrification Administration has approved the Implementing Rules and Regulations of Vulnerability Risk Assessment and Emergency Restoration Planning.
- The National Power Corporation is striving to ensure least disruption to its mandate of providing electricity to the missionary areas (off-grid) in the event of disasters.

Director Aquino expressed hope that the workshop would take a step further and raise the bar, to better ensure that energy supply will be resilient given extreme weather conditions and impacts of climate change, through improved efficient and effective planning. Director Aquino closed his remarks by thanking participants for their attendance, and wishing all a fruitful and productive workshop.

Dr Jyuun-Shiauu Chern, the APEC EWG Lead Shephard, next gave brief opening remarks from the EWG. Dr Chern stressed that energy resiliency is an important overarching activity for the EWG and that he felt the training being given at the workshop would benefit all APEC economies

Presentation: Climate Impacts and Power System Impacts Overview

This presentation provided an overview of the climate change risks to the power sector, including power generation, transmission and distribution, and demand. The presentation described how power sector vulnerability to climate change can be broken down into three components:

- Level of *exposure* to climate stressors and hazards. The location of power infrastructure primarily determines the degree of exposure to changes in temperature, variability of water resources, extremes (flood, drought, heat waves, fire, and landslides), and changes in sea level and storm surge heights.
- Potential *sensitivities and impacts* from climate-related stressors and hazards. The sensitivity of the infrastructure—including factors such as condition, age, and design—influences the type and extent of impact to the power asset or system that will be incurred at a given level of exposure.
- *Adaptive capacity* to cope with various climate impacts. In addition to the degree of impacts, electric sector vulnerability is also a function of recoverability—how quickly an asset can be replaced or restored and able to deliver reliable electricity supply. The extent to which an individual power utility has the adaptive capacity to prepare for and manage these impacts will determine its relative vulnerability to similar levels of stress.

Dissecting power sector vulnerabilities into three interacting components is particularly useful for thinking through addressing risks, as vulnerability to climate change impacts can be reduced by addressing exposure, sensitivity, and/or adaptive capacity.

The presentation described different kinds of impacts, including direct and indirect, compounding and cascading impacts. The degree of direct damages will vary by the infrastructure location, type and condition, and climate stressor. For example, sea level rise along with more extreme weather and coastal erosion threaten to damage infrastructure in low-lying areas, while warmer temperatures and drought increase wildfire risks to infrastructure in inland locations.

Changes in climate can also directly affect efficiency (e.g., transmission) and performance (e.g., thermal generation) of infrastructure. In some cases, threshold conditions (as opposed to the mean or standard conditions), or shifts in the threshold caused by climate change can create vulnerability within the energy sector. For example, for each 1°C of higher ambient temperature, transformer capacity decreases by approximately 0.7%. Indirect impacts of temperature increases include reductions in water supply availability for hydropower or thermal cooling processes, as a result of higher competing water demands (and more directly, increases in surface water evaporation). On the other hand, in some instances, changes in climate can present opportunities for generation; for example, increases in precipitation may be beneficial to hydropower if generation facilities are adequately designed to take advantage of more water.

Climate changes can also affect the natural resource-based inputs for renewable energy:

- Hydro-generation may benefit or suffer from changes in variability in the amount and timing of rainfall. In general, a 1% change in precipitation is likely to result in at least a 1% change in power generation, although changes in generation are harder to predict for run-of-river systems.
- Wind generation potential may be impacted either positively or negatively by local changes to the wind regime. Wind turbines are generally designed to operate effectively under the critical conditions of a 50-year return period wind speed and the associated turbulence intensity.
- Biomass/biofuel generation could be affected by changes in climate that could impact cultivation and production of biomass. For example, optimum growth conditions for sugar cane, an important feedstock of ethanol production, range between mean daily temperatures of 22˚C and 30˚C and mean annual rainfall of 1600 mm, but these conditions are shifting depending on location.
- Solar power may be impacted by changes in temperature and cloud cover. It has been shown that if global solar irradiation is reduced by 2%, photovoltaic (PV) electricity output is reduced by about 6%.

The net demand for electricity is also projected to increase due to increased energy demand for cooling buildings because of temperature increases. Heat wave events may increase peak demand for energy demand for cooling, potentially overstressing energy infrastructure. Regional and seasonal demand and consumption patterns will also change with an increasing ambient temperature. For example, the sale of air conditioners in China nearly doubled from 2009 to 2014 as temperatures and incomes are rising, and utilities will need to sustainably keep up with increasing demand for electricity. Additionally, increases in long-term and extreme temperatures will lead to increases in water demands for domestic, agriculture, and other sectoral uses, resulting in competing demands for water in water-constrained areas. The indirect impacts of increasing temperatures on land and water resources, when taken in combination with the direct impacts, can affect energy reliability.

While the specific risks confronting a particular power network or facility will vary, the consequences can be severe. Climate-related events ultimately can affect a power utility's reputation, revenue, and sustainability. Climate stressors can increase production costs (e.g., switching to more expensive fuel sources if hydropower capacity declines), reduce operational flexibility and efficiency, and increase the costs of maintenance and upgrades.

Climate change also poses a challenge to the ability of utilities to achieve or maintain creditworthiness. Standard and Poor's analyzed ratings actions by natural catastrophe from 2005-2014, concluding that the energy sector (through a direct impact on production and distribution facilities and market dislocation) is one of the most exposed. The report further noted that climate change could lead to a more widespread weakening of corporate credit profiles and subsequently to more downgrades than in the past.

Furthermore, utilities may face unexpected challenges to meeting environmental regulations; for example, increases in water temperature may strain the capacity of hydropower plants to meet water quality regulations. Lastly, climate-induced service disruptions can reduce the reliability and affordability of power, thereby undermining essential services, poverty reduction objectives, and economic growth. Climate change impacts to the financial, regulatory, and social performance of individual utilities—and to the sector as a whole—presents an additional challenge to power sector reform and planning.

Since the power system is highly interconnected, the loss of key assets in a power system network due to extreme weather can lead to cascading failures, amplifying the impact. While some impacts may be localized, the electricity system may be connected across large areas or regions, such that loss of power in one area can lead to a widespread outage. In addition, a utility may depend upon electricity generated by other asset owners and may be vulnerable to impacts to other utilities, stressing the importance to coordinate power sector resilience efforts. Furthermore, given that the electricity sector is highly interconnected with other sectors, extended outages can lead to disruptions to several vital sectors, including healthcare facilities, emergency management, communications, and transportation systems. Adaptation measures, including decentralized solutions and building in system redundancies to address these risks, are discussed in more detail in the next section.

Exercise: Climate Impacts to the Power Sector

This exercise was designed to have stakeholders think through the types of climate impacts that has impacted on their respective power systems, and then to share and discuss their findings with other group members from differing economies, backgrounds, or locations. Participants were broken into 4 groups for the exercise, and provided with a handout detailing potential impacts on different power system components, by climate stressor. Exercise handouts can be found in Appendix B.

The exercise steps were as follows:

Step 1. Individually, fill out the handout matrix: (10 min.)

- Describe climate impacts that have affected your country's power system in the past.
- Describe how non-climate drivers have exacerbated these impacts.
- Circle the impacts have had the greatest effect on public safety, power reliability, and cost.

Step 2. In your group, discuss: (20 min.)

- Which impacts have had the greatest effect on the power system in your country? Which impacts are most concerning looking forward?
- What are some commonalities between impacts experiences across countries? Differences?
- How does non-climate country context influence climate impacts?
- How might climate change reduce or exacerbate these impacts?

Step 3. Regroup with the entire group and report out from small groups.

Presentation: Climate Resilient Power Systems and Project Level Planning Overview

This presentation focused on climate change adaptation to enhance reliability and resilience of the power sector. The presentation outlined an iterative process of 1) identifying priority vulnerabilities, 2) identifying, evaluating and selecting adaptation measures, 3) monitoring and evaluating implementation and effectiveness of the measures.

After identifying the priority climate vulnerabilities, the next step involves identifying a set of feasible adaptation measures that will address present and future climate risks. When identifying a pool of possible adaptation strategies to increase resilience, it is often helpful to consider both "hard" and "soft" strategies. Hard measures typically involve structural adjustments (including changes in land use and green infrastructure, and engineered solutions); soft measures include changes in policies, operations and management practices, education, and regulation. Frequently, a combination of mutually reinforcing adaptation strategies—combined in a portfolio approach—is most effective.

Adaptation strategies and measures include:

- "No-regrets" strategies are proactive measures that can help reduce the impacts of climate events while at the same time meeting other important objectives for the power project, such as increased energy efficiency, or improvements on demand-side management, such as smart grid technology. These strategies typically focus on identifying nonstructural, procedural, and operational modifications. ,
- "Low-regrets" strategies identify options where cost implications are modest while the benefits under future climate change are potentially large, albeit uncertain.
- Additionally, "climate-justified" strategies are most beneficial if the climate change expectations incorporated into the decisions being taken are realized. Climate-justified adaptation strategies might be considered project design alternatives.

Adaptation measures at the policy, planning, and institutional levels are particularly important considerations for sector reform and planning projects since longer-term and comprehensive adaptation planning has the potential to optimize power sector objectives that are also climate resilient. One approach to resilient energy planning is through integrated resource planning (IRP) that explicitly incorporates climate resilience.

Exercise: Climate Resilience in the Power Sector

This exercise was designed to have stakeholders think through the types of climate adaptation measures that could be employed to address climate change impacts on their respective power systems, and then to share and discuss their findings with other group members from differing economies. Participants were broken into 4 groups for the exercise, and provided with a handout detailing potential impacts on different power system components, by climate stressor. Exercise handouts can be found in Appendix C.

The exercise steps were as follows:

Step 1. At the top of the handout, list one of the priority impacts that you identified in the risk exercise. The facilitators will group you based on the impact you select. (5 min.)

In groups, brainstorm 1 – 2 potential resilience measures in each category, and record these in the matrix handout. See adaptation strategies handout for ideas. (10 min.)

Step 2. In groups, discuss and assess the advantages of and barriers to each measure you identified, and enter these into the matrix handout. Consider the following criteria in brainstorming the advantages and barriers of each measure: (10 min.)

- Effectiveness: How effective would this action be if implemented?
- Feasible: How easily could this action be accomplished? Do we have the capacity? Would it have support from key actors?
- Cost: What would it cost to do this? Are the resources available?
- Robustness: To what degree would this measure be effective under different conditions?
- Co-benefits: Would this action help achieve other objectives in addition to climate resilience? Would it interfere with other objectives?

Step 3. Rank each measure by priority (High, Medium, Low) based on your assessment of advantages and barriers. Circle 3 or 4 measures that you think are high priority. (5 min.)

Step 4. Report back to the full group and discuss your results (15 min.)

- Which measures did you identify as being high priority?
- What were the major advantages and barriers that you discussed?
- What information would you need to evaluate the effectiveness of your measures?

Presentation: Power System Resilience in Australia

Mark Paterson of Horizon Power presented on the transformation of Australia's electricity, including two case studies. Australia's National Electricity Market (NEM) incorporates around 40,000 km of transmission lines and cables, supplying about 200 terawatt hours (TWh) of electricity to businesses and households each year. It has a total electricity generating capacity of approximately 55,000MW. Mr Paterson introduced several instrumental studies and events, including the CSIRO Future Grid Forum where stakeholders convened over time to determine a range of range of plausible long-term futures to 2050, including:

- Set and forget (centralized)
- Leaving the grid
- Rise of the 'Prosumer'
- Renewables thrive

Mr Paterson noted that Australia leads the 'hyper-decentralization' of electricity. Australia has a goal of whole regions of Australia's electricity system being capable of operating securely, reliably and efficiently with 100% or more of instantaneous demand met from distributed energy resources by 2022. As a result, Australia's overall generation mix is changing dramatically, moving from heavy dependence upon black and brown coal today, towards the nearly 100% of electricity sourced from renewables by 2050 (rooftop and large solar PV (~150 Twh), onshore wind (~190 Twh), and hydropower (~10Twh), with small amounts of gas power). The major challenge will be grid optimization, as the system moves from thousands of end points to tens of millions of end points.

The first case study focused on an event in 2016 in South Australia, where cascading failures blacked out 1.7M people. On September 28, 2016, tornadoes with wind speeds in the range of 190–260 km/h occurred in areas of South Australia. Two tornadoes almost simultaneously damaged a single circuit 275 kV transmission line and a double circuit 275 kV transmission line, some 170 km apart. The damage to these three transmission lines caused them to trip, and a sequence of faults in quick succession resulted in six voltage dips on the Southern Australian (SA) grid over a two-minute period from around 4.16 pm. As the number of faults on the transmission network grew, nine SA wind farms exhibited a sustained reduction in power output as a protection feature activated. For the majority of these wind farms, their turbine protection settings resulted in a significant sustained power reduction of 456MW over a period of less than seven seconds. The reduction in wind farm output caused a significant increase in imported power flowing through the Heywood Interconnector.

Approximately 700 milliseconds after the reduction of output from the last of the wind farms, the flow on the Victoria – SA interstate transmission link reached such a level that it activated a special protection scheme that tripped the interconnector offline. The SA power system then became separated ("islanded") from the rest of the NEM. Without any substantial load shedding following the system separation, the remaining generation was much less than the connected load and unable to maintain the islanded system frequency. As a result, all supply to the SA region was lost at 4.18 pm (the Black System).

Mr Paterson indicated that it was clear that to plan for the future of increased frequency and severity of storms, the system needed to change. The Australian Energy Market Provider (AEMO) undertook an independent assessment: Integrated System Plan (2018). The findings indicated that a profound transition of the NEM would be required over the next two decades:

- The energy mix is transforming from one dominated by coal-fired generation to one with a large portfolio of VRE (variable renewable generation)
- The growing fleet of VRE is technologically and geographically diverse
- There is an increasing need for system flexibility to complement VRE generation. This will:
  - Mean strong and increasing roles for energy storage and regional inter- connection through transmission networks
  - Affect how energy storage and coal / gas-fueled generation are operated
  - Require the retention of existing coal-fired generation until retirement

This transformation requires the adoption of new technologies and approaches to provide the services needed to operate the power system that are currently provided predominantly by thermal generation, including:

- Voltage control – Network Service Providers (NSPs) will likely need to install reactive plant to maintain adequate voltage profiles in their networks as minimum demands decline due to the uptake of rooftop PV and energy efficiencies.

- System strength – as clusters of non-synchronous generation connect in close proximity, generators will need to offset their impact on system strength and TNSPs will need to ensure a basic level of fault current across their networks. This will drive new system strength investments for generator connections in north Queensland, south-western New South Wales, north-western Victoria, and South Australia.
- Frequency management – wind, solar, battery, pumped hydro, and demand-based resources are likely to compete for the provision of a projected increasing need for frequency control ancillary services (FCAS).

AEMO Integrated System Plan outlines the following new requirements:

- Power system inertia – AEMO has identified minimum inertia requirements to operate the power system under rare conditions where the risk of regional network separation is heightened. A minimum inertia requirement has been identified for South Australia, flagging an opportunity to optimize this service with synchronous condensers currently being designed for system strength.
- Connection standards – the technical standards applying to new connections need to be kept under review and updated as necessary to ensure security can be maintained as the nature of the power system changes.
- Dispatchability – there will be an opportunity for new sources of dispatchable generation. New energy storage developments, at both the utility-scale and aggregated distributed levels, and virtual power plant (VPP) services, such as the one proposed in South Australia, could help support this emerging need.

The question of who pays is central. Mr Paterson suggested that the 'Markets vs Controls' dichotomy is unhelpful, where market economists rely on identifying and optimizing market rules and prices and control engineers rely on setting up the right optimization equations. The solution is not one or the other approach, but both, where:

- Control advocates realize that markets as excellent sensors and optimization engines.
- Market advocates realize that markets do not handle grid physics and dynamics, so that controls are needed.
- Both mechanisms are needed – the architectural question is how they must be structured to interact and support each other

The second case study focused on the Esperance bushfires, which accelerated the exploration of 'Utility Off-grid' solutions. The Esperance fires in November 2015 destroyed overhead power supply to many properties. Temporary diesel generating sets were installed to provide power. Before the fires, Horizon Power had been working with Western Power to develop a Utility Off-grid trial in Ravensthorpe. It was clear that the Esperance situation warranted a rapid alternative solution rather than rebuilding the network.

A full electric utility service offering without 'poles and wires' was presented as an entirely new utility asset class. The mission-critical characteristics of this new utility asset class:

- Designed for multi-decade longevity and lifecycle efficiencies;
- Supported by a fully scalable 'Android' fleet-management platform that can remotely manage thousands of systems from different suppliers;

- Fully compliant with critical infrastructure cyber-security requirements; and,
- Fully integrated 'end-to-end' across utility back-office systems and processes.

Horizon Power's System Blueprints anticipate many hundreds of our more remote existing customers will be served most efficiently by Utility Off-grid solutions.

Mr Paterson finished his presentation with a video on enabling a distributed energy future.

Day 2: Understanding Climate Risks in Planning

The second day of the workshop focused on better understanding climate risks to the power system planning. The presentations and exercises from Day 2 are described below.

Presentation: Resilience in Power Sector Planning: Role of IRRP

Dr Ananth Chikkatur gave a presentation on resilience in the power sector with a focus on the role of integrated resource and resiliency planning (IRRP). The presentation highlighted the importance of power sector planning, the difference between resilience and reliability, and elaborated on the role of integrated resource and resilience planning (IRRP) in general.

The traditional objective of the power sector planning has been to meet projected demand for electricity at the *least cost*. The expected demand growth is met through least-cost investments of specific resource types based on their availability and cost. However, for the power industry today, least cost planning by itself no longer suffices due to several factors. Key among them being the demand uncertainty, rapid changes in renewable energy costs, non-wires alternatives, resource availability, impacts of climate change etc. Therefore, Dr Chikkatur explained that multiple criteria beyond least cost (e.g., resilience, reliability, environmental and social concerns) are needed.

He then went on to explain the differences between reliability and resilience. Reliability is the ability to deliver electricity in the quantity and with the quality demanded by users. The electric reliability performance can be measured by several metrics including resource adequacy (loss of load probability, expected unserved energy, effective load carrying capacity), transmission reliability (e.g. N-1 or N-1-1 assessments), distribution reliability (e.g., SAIFI, SAIDI, CAIDI etc.), and economic value of reliability (cost of unserved energy).

Resilience, on the other hand, was explained to be the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. The presentation summarized the main processes involved in resilience analysis process, based on the framework developed by Sandia National Laboratory,[1] which were:

- Definition of the resilience goals
- Definition of system and resilience metrics
- Characterization of threats
- Determination of level of disruption
- Definition and application of system models
- Calculation of consequence
- Evaluation of resilience improvements.

[1] https://cfwebprod.sandia.gov/cfdocs/CompResearch/docs/EnergyResilienceReportSAND2014-18019o.pdf

Dr Chikkatur then discussed about some the decision makers involved in resilience analysis such as the private and public utilities and national/regional/state regulators.

After discussing the differences between reliability and resilience, Dr Chikkatur described the main differences between the integrated resource planning (IRP) and the integrated resource and resilience planning (IRRP). The IRP has an objective of identifying a long-term power sector resource plan that will serve the expected electricity demand over time at least cost. This is done using peak and energy growth as its key drivers whilst considering all available generation resource options and transmission capabilities and other resource constraint (e.g. fuel availability, operational, environmental etc.). It evaluates cost and other factors over a 10-20year time frame or longer. The IRRP has similar objectives and characteristics as the IRP, but is slightly different in that it considers a range of other metrics (in addition to cost) when meeting the power sector demand, operations, and expansion goals. The framework for the IRRP detailed the various process involved with the key deliverable being an integrated power sector master plan (IPSMP). Dr Chikkatur finally highlighted the advantages of the IRRP including the explicit consideration of risks and future uncertainties and the robustness of the plan itself, which acts as insurance against worse outcomes.

Presentation: Case Study: IRRP Implementation in Ghana

In his second presentation, Dr Ananth Chikkatur discussed the implementation of IRRP in Ghana, as a case-study. The presentation covered the background for the Ghana IRRP, the principles and approach undertaken by ICF in implementing the IRRP in Ghana, and outlined the various activities undertaken by the IRRP project in Ghana.

Dr Chikkatur explained the genesis of the project in Ghana, wherein the Ghana Government (GoG) and the US government (USG) under the Partnership for Growth's Joint Country Action Plan (JCAP) jointly called for the development of an integrated power sector master plan (IPSMP). The development of this IPSMP is the key deliverable for the 3-year USAID-funded Ghana IRRP project. The IPSMP builds on the existing sub-sector master plans and provide guidance for future investment plan.

The key objectives of the Ghana IRRP include:

- Supporting the evaluation of various power sector policies and plans by assessing their broader implications
- Promoting energy efficiency within the framework of an IPSMP
- Developing tools for least-cost generation expansion planning
- Establishing a culture for IRRP, and strengthen the "community of practice" for power sector planning across Ghana's power sector, through training and capacity building
- Supporting Ghana's move toward a low-emissions / low-carbon development pathway for the energy sector, as stated in Ghana's National Climate Change Policy

The Ghana IRRP is being implemented with the Ghanaian power sector stakeholders rather than just for them, which fosters ownership of the IRRP work. ICF also hired local Ghanaians with strong power sector expertise to support the project which offered several different ways for stakeholder to interact and work with the project.

The detailed outline of key activities involved in IRRP project was presented which ranged from a variability of activities from mobilization and inception to the implementation of the IPSMP.

The presentation also included a general overview of the Ghanaian energy sector, the status of the generation capacities and key challenges facing the sector. A general outlook of an optimized generation model was presented including the criteria which led to the ultimate selection of the Integrated Planning Model (IPM®) for the Ghana IRRP Project. Criteria laid emphasis on the need for a model which has both generation and transmission expansion capabilities and could model zonal transmission transfer capabilities in addition to having a relatively lower license fees.

Required data and analysis performed on the project included zonal analysis, demand, supply, fuel and transmission analysis. The modelling methodology for the IPSMP development include:

- Developing specific zones for Ghana based on transmission constraints
- Updating Ghana demand forecast to ensure realistic expectations for new capacity needs
- Developing a database of performance and cost of existing generation sources
- Developing cost and performance characteristics for new generation technologies
- Assessing resources for renewable energy and natural gas supply (indigenous and imported gas)
- Evaluating transmission constraints across Ghana transmission grid at present and in the future
- Developing inputs and solving of "runs" using the IPM® model to determine the least-cost optimized dispatch and capacity expansion from 2016 to 2040
- Considering potential risks and uncertainties for the power sector and developing "Sensitivities" to account for identified risks
- Evaluating different policy "Strategies" under various Sensitivities to determine the "least-regrets" portfolio of new builds for Ghana's power sector

The defining metrics for determining the least-regrets strategy in Ghana were:

- Cost (cumulative investment and system cost),
- Reliability (unserved energy, unserved peak demand, transmission congestion),
- resilience (energy security-in GWh from domestic resources, fast ramp capacity, local reserve margin),
- Local environment (air quality, ash production), land use (power plant footprint), and
- Climate change (CO_2 emissions).

The different possible policy options(strategies) identified for Ghana were mainly:

- Business as Usual Strategy (BAU): No technology-specific constraints on build options. Reference assumptions on demand, technology costs, gas resource availability, RE bounds, TTCs, etc.
- Indigenous Resource Strategy: Utilize indigenous resources as a high priority, and invest in increasing these resources.
- Diversified Resources Strategy: Diversity fuel and resource mix to include coal, nuclear, biomass and biogas plants.
- Enhanced G-NDC Strategy: Reduce the growth of CO2 Emissions
- Export Oriented Strategy: Increase exports to neighbouring countries.

Results of the various metrics for the specific strategies under the 10-year planning horizon were presented. The average investment and total system cost for the various strategies were also presented, highlighting that the Indigenous Resource Strategy was the least cost and the least-regrets strategy in both the 10-year and the 20-year planning horizon. Dr Chikkatur then summarized the least regrets expansion by detailing the specific generation capacity additions and transmission upgrades that are needed in the future over the planning horizon.

Presentation: Case Study: IRRP Climate Change Risk and Resiliency Findings in Ghana

Dr Hellmuth presented the findings from the IRRP climate change risks and resilience assessment of the Ghanaian power system. The presentation focused on the potential climate change uncertainties and associated impacts on the power system, and the types of adaptation measures that could be implemented to address potential climate impacts, and how they can be incorporated into long-term planning to improve power system resilience.

Power planners need to recognize limitations and uncertainties when gathering and applying climate information to inform their decision making and investments. In Ghana, climate change projections are particularly uncertain for future changes in annual precipitation and runoff volumes, though there is higher confidence on projections of more frequent and intense rainfall which may lead to flooding. In addition, there is a lack of available, accessible, and useful data to conduct meaningful climate analysis in many locations in Ghana. However, uncertainty or lack of complete data is not a reason for inaction. Rather, there is a need to plan robust strategies to prepare for uncertain futures.

The presentation included analysis of potential climate changes and impacts to the power sector at a sub-national scale, to better reflect the different climatological zones of the country and to better integrate with the power systems modeling of the larger IRRP project. The four assessment zones, as determined for modeling of the power system using the Integrated Planning Model (IPM), included the Southeast and Southwest zones (wetter and are subject to changes in sea level and storm surge heights), and the North zone (where climate is hottest and driest).

By mid-century, Ghana's average annual temperature is projected to increase by 1.2 to 1.7°C. Change in annual precipitation is more uncertain, as models disagree on the sign of change. The multi-model averages indicate that there will be minimal changes in total annual precipitation (increases of 1 to 2 percent) but that precipitation will shift, with more rainfall occurring later in the year (October through December) and less occurring during the early part of the usual "rainy season" (April through June). Like rainfall, projections for change in annual runoff and consecutive dry days (a proxy for drought) are mixed in sign and projected to change only minimally, though they are likely to shift in patterns like precipitation shifts. There is more certainty in projections in extreme rainfall, with the clear majority of models projecting increases throughout the country. Sea level rise is also projected to increase by around 0.4 to 0.7 m by mid-century.

Based on the projected changes in climate conditions, potential impacts on Ghana's power system were presented. Of the power system components, hydropower impacts are particularly consequential because of the reliance of Ghana on hydropower. In addition, transmission and distribution infrastructure are particularly at risk to a range of climate impacts, especially assets located in low-lying coastal areas that may be exposed to rising sea level and storm surge heights, as well as increases in extreme rainfall, and temperature. Taken in combination, projected increases in extremes (drought, flood, or heatwaves) have the greatest potential to impose negative impacts across the power system because they are likely to increase demand while diminishing generation (hydropower) as well as transmission and distribution capacity. At the same time, there may be beneficial opportunities, such as increasing solar capacity due to an increase in irradiation.

To manage the impact of these climate stressors, a variety of adaptation measures were identified by stakeholders. Measures range from no-regrets actions, which are proactive and beneficial to the power system regardless of climate change, to climate-justified measures, which include actions that might only be justifiable if expected changes in climate materialize. Types of adaptation measures include policy and planning, operation and maintenance, technological, and structural measures.

The IRRP is being applied in Ghana to identify and assess the performance of different investment strategies in the power sector, given different growth and risk sensitivities (including climate), in order to inform a new "least-regrets" resource plan, which will then inform the power system master plan. A least-regrets plan assesses the performance of potential power system investments given a range of important metrics (e.g., cost, feasibility, load served, greenhouse gas emissions), allowing power sector planners to compare different investment performance against different objectives given potential future uncertainties.

Exercise: IRRP Scenario Building

For the group exercise, the participants were divided into groups that were assigned to identify the risks for specified Member Economies, and then develop potential scenarios and sensitivities and strategies that could help address these identified risks. The discussions were extensive, and each group then presented their findings to the entire workshop. Appendix E shows the final summary of the risks, sensitivities, and strategies for each Member Economy that was presented.

Presentation: Ghana Power Sector Master Plan

In his third presentation, Dr Ananth Chikkatur discussed the process for developing the Ghana integrated power sector master plan (IPSMP). He first defined what the IPSMP was—namely that the IPSMP is a strategic planning document that provides a clear, comprehensive and coherent view of the future development of a power sector. The master planning process was also explained, highlighting the importance of consulting existing sectorial ministries and departments, and local, regional, and private stakeholders to obtain buy-in and build consensus for the master plan. Dr Chikkatur also showcased the linkages of the IPSMP with other existing plans such as the national level plans, the energy sector plans, annual supply-demand plans, transmission system plans and the distribution planning processes.

A summary of the various elements of an IPSMP presented, which included:

- Vision: what is the end-state for the electricity sector?
- Objectives: what needs to be done to reach the end state?
- Context: what is the current state of the sector, what are the socio-political and economic conditions within which the development takes place?
- Key Decisions & Recommendations in Time: what decisions must be made soon, and what can be taken in the future?
- Strategic Plans (institutions, markets, and projects): how should institutions be organized around the development of the sector?
- Specific Policies (planning, regulations, legal, oversight): what specific policy changes are needed to reflect technical and political requirements?
- Implementation Plans, with timeframe: what recommendations to implement and when?
- Future Information Needs: what more is needed to update the Master Plan in the future, and how to develop the information?

- Monitoring/Evaluation and Updating Plans**:** how should the implementation of the IPSMP be monitored, and on what criteria?

Dr Chikkatur then discussed the key findings and recommendations from the Ghana IPSMP in the areas of generation, transmission, utilization of Ghana's indigenous resources including natural gas, and finally procurement and planning.

The presentation concluded with the lesson learnt from the Ghana IRRP, including:

- The IRRP process cannot be a one-size-fits-all approach. Each Member Economy will need to develop a specific process and approach, based on their needs.
- The value of an IRRP to politicians, planners, and power sector agencies must be established up front.
- Development of institutional and human capacity is critical since they affect the implementation of IRRP.
- Coordination among the development partners is important, in order to prevent duplication and build synergies.
- Collaboration and coordination among all stakeholders is critical for success.
- Any IRRP must recognize limits to data availability and start with existing data, but aim towards continuously improve the data over time.
- Modelling tools should be fit-for-purpose, and their value and role must be communicated well. Continuous training on the use of the selected models is necessary to ensure buy-in from the sector agencies and future updates of the IPSMP.

Presentation: Access to Sustainable Energy Project: Strengthening Climate Resilience of Electric Cooperatives (ECs)

Patrick Co, Consultant for the World Bank, presented on the Access to Sustainable Energy Programme (ASEP), a joint undertaking of the European Union and the Philippine Department of Energy (DOE). The Investment Support component of ASEP is administered by the World Bank to enhance the capacity of Electric Cooperatives (ECs) to implement the rural electrification objective and promote RE-based energy systems.

The presentation focused on technical assistance provided on i) Detailed wind data-driven analysis and mapping, and ii) Capacity building for design support software. The wind analysis and mapping:

- Provides a basic understanding of how high wind risk areas can be identified and integrated into distribution network planning
- Allows for comparison against older engineering standards (e.g., a national or zonal standard)
- Helps to inform decisions on whether measures to manage such risks are necessary, for example, through undergrounding of lines, strengthening of poles, building redundancy in the network design to have alternative paths for supplying critical loads, and
- Helps to inform decisions on the necessity of softer measures such as use better warning systems in the distribution level SCADA, and vegetation management taking into consideration timing of high wind risk events

High resolution wind risk data is necessary to inform these investment decisions, and is more cost effective, as there is a wide spatial variation of wind speeds that would not be captured using low resolution data and could result in hardening of areas that are not at risk. Advisable to delineate wind speed risk as high, medium, and low taking into account the spatial variability of wind stress, rather than drawing lines to broadly partition the country into zones.

The objective of the technical assistance provided for capacity building for design support software was designed to build capacity among EC technical staff to model, analyze & design various T&D support structures whether for new projects, upgrading or retrofitting of existing lines, or adding ancillary equipment to existing lines – to enhance the overall resilience of the network against typhoons. This involved training on Power Line Systems (PLS) Software, the most widely used overhead line design program globally.

Day 3: A Focus on Solutions

The third day of the workshop focused on developing climate resilience solutions in the power sector. The day included presentations, an exercise, and a discussion, as described below.

Presentation: Addressing Climate Impacts to Reliability and Resilience for Power Utilities

Dr Robert Kay, ICF presented on utility-level climate impacts and resilience efforts. The presentation showcased a spectrum of approaches to enhance the work of APEC economy energy utilities to ensure service continuity in the face of current climate and projected changes.

The presentation described good practice from the east and west coasts of the United States, where utilities are investing in infrastructure resilience enhancements in response to climate-driven disasters, including storm surges, wind, wildfire, and extreme heat. For example, utilities across 14 States & the District of Columbia are making investments in response to Hurricane Irene (2011) and Superstorm Sandy (2012) to enhance resilience to future storm events was presented. Dr Kay also described California's regulatory reform process aimed at supporting utility-level resilience building. The Californian example allowed for discussion of how reform processes evolve over time. Specifically, Dr Kay described the current Order Instituting Rulemaking (OIR) on Climate Adaptation, issued by the California Public Utilities Commission (CPUC) earlier in 2018. Participants were encouraged to visit the CPUC OIR website to download the OIR itself and to review the responses provided by utilities. Dr Kay also elaborated on specific technical approaches to assessing climate impacts on energy systems, drawing on recent work undertaken by ICF in partnership with San Diego Gas & Electric (SDG&E) through a California Energy Commission grant.

During the discussion, the Philippines highlighted the best practice of embracing a culture of resilience in the energy sector. The recent issuance by the Department of Energy (PH-DOE) of the Energy Resiliency in the Planning and Programming of the Energy Sector to Mitigate Potential Impacts of Disasters (Department Circular (DC2018-01-0001) seeks to implement the Philippines Energy Resilience Policy. Energy stakeholders, including power plant operators, utilities and refineries were required to submit their Resilience Compliance Plan (RCP) by 31 July 2018. The objective is to develop a minimum resiliency standard for each type of facility. This initiative is supplemented by the Republic Act (RA) 10174 is the amendment to the Climate Change Act (RA9729) that seeks to provide climate finance to programs and projects of the local government units and non-government organization that will enable communities and sector to adapt to climate change. For the energy sector, the Electric Cooperatives Emergency and Resiliency Fund was passed into law (July 2018) to assist the Electric Cooperatives (EC) to be able to complement the efforts of the local government units affected by disasters. The funds can be used for disaster mitigation, disaster preparedness and restoration as well as rehabilitation of damaged EC facilities. ECs are required to come up with vulnerability and risk assessments to determine mitigation measures and areas that needs to be improved including strengthening of critical infrastructures to be ready or less affected by future climate change impacts.

Exercise: Advancing Power Utility Resilience

Participants were split into economies and asked to answer a series of prompting questions designed to stimulate dialog on a spectrum of initiatives to support utility-scale resiliency – ranging from voluntary actions through to government regulation requiring investment (Exercise handout can be found in Appendix F). All economies at the workshop reported that there are a range of voluntary actions taking place and/or climate change coordinating processes. These include an Energy Resilience Task Force in the Philippines, coordinating mechanisms between agencies in Malaysia, Thailand and Indonesia; climate monitoring committee in China; and Thailand Climate Change Watch.

Several economies reported that investments being made to protect against climate change impacts in the energy sector and regulators or investors providing guidance on adaptation investments. For example, Indonesia reported that the National Investment Board provides such advice. In the Philippines, advice is provided to the proponents of power generation projects in the coastal zone to consider sea-level rise through the Environmental Impact Assessment process. Malaysia reported an example of electricity sub-station relocation that was funded as a result of flooding. Viet Nam highlighted the importance of continued investment in early-warning systems to ensure that the prediction of short-term climate events, such as river flooding and typhoon winds, to help with ongoing adaptation efforts.

Three economies reported that specific laws, regulations, or policies have been adopted, or are under development, to build resilience in the energy sector climate to assist change adaptation. Chinese Taipei highlighted the compulsory requirements for the siting of major energy infrastructure to consider climate change adaptation. In addition, the government is undertaking a program of vulnerability assessments of existing infrastructure. The Philippines stressed that the combination of the implementation of their Energy Resilience Policy and the Climate Change Act required climate change factors is planned to be integrated into future Resilience Continuity Plans of energy utilities. Chile reported that it had recently passed a law on the transmission sector that risk assessment is incorporated into the planning process. A complementary law covering the distribution system where resilience will be integrated is being developed.

Presentation: Screening Hydropower Facilities for Climate Change Risks to Business Performance

An additional consideration is the implication of climate change on the effectiveness of low emission development. As investments in climate sensitive renewable energy increase, climate impacts to these investments should be considered to ensure that objectives for economic growth and low emissions development are both achieved. If production expectations of renewables are not met, unanticipated investments in higher emitting energy resources could be turned to, to bridge supply gaps—resulting in increased emissions. For example, in Mindanao, Philippines, increasing electricity demand, coupled with hydropower generation reductions due to recurrent drought and reservoir sedimentation, has resulted in repeated black-outs. The lack of reliable electrical service hampered economic growth, causing political turmoil and social unrest. Utility managers have increased the load of thermal energy sources as a short-term fix—a strategy that was economically costly and also increased carbon emissions. Longer-term investments in fossil fuels to increase baseload are being made, as a “bridge” fuel to meet supply gaps until renewable technologies catch up.

The Framework for Screening Hydropower Facilities for Climate Change Risks is designed to help:

(1) Hydropower plant managers and operators identify vulnerabilities of existing facilities; and
(2) 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 climate change knowledge. Guidance is provided throughout the tool to explain climate change concepts and provide links to resources for users to better understand anticipated 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 impacts of climate change is critical to ensuring sustainable hydropower implementation and operation. Exploring and anticipating these impacts early in the planning process (for new hydropower projects) allows for consideration of appropriate steps to avoid, mitigate, or compensate for impacts. Despite being less flexible to adapt and change, existing hydropower plants can benefit from a better understanding and anticipation of the impacts of climate risks, which can result in improved operational decisions or investments to reduce or manage these risks.

Exercise: Hydropower Screening

Participants were provided with a narrative outlining the characteristics of a hypothetical hydropower plant, including the plant capacity, location, type, and the climate and non-climate characteristics and stressor. Participants were also provided with a handout that was based on the Framework for Screening Hydropower Facilities for Climate Change Risks (see Appendix G).

The exercise steps were as follows:

Step 1. You will be assigned one hydropower performance objective to evaluate

Step 2. Individually, assess the level of risk to your performance objective

- Refer to your worksheet on climate stressors, and the background information above
- Rate the potential impact from climate-related stressors on achievement of the objective.
- Rate the potential impact from non-climate drivers on achievement of the objective.
- Rate the extent to which adaptive capacity can counteract or manage these potential impacts to help achieve the objective.

Once you have completed these steps, discuss your findings as a group, and combine your ratings for climate-related stressors, non-climate drivers, and adaptive capacity into a single risk rating for the objective.

Step 3. As a group, identify appropriate next steps

Presentation: Case Study of IRRP Tanzania Hydropower Drought Scenario Analysis

Hydropower has historically been the largest source of electricity in Tanzania, although dependence upon hydropower has been declining over time due to concerted efforts to increase reliability and diversify supply. Current supply and future planned investments ensure that hydropower will continue to remain an important power supply source for Tanzania.

Large hydro currently comprises 35 percent of total generation capacity in Tanzania, down from about two-thirds a decade ago.[2] Tanzania's total technical hydroelectric energy potential is reported to be in excess of 3,200 megawatts (MW) of firm capacity (of which about 12 percent has been developed).[3] Tanzania currently has 15 MW of small hydro (≤ 10 MW) installed, but has an estimated potential of 480 MW.[2] There are 20.5 MW of small hydro projects currently underway and 29.9 MW in planning. [2] Additionally, there are small hydro feasibility studies being conducted in several administrative regions.[2] The country also has 55 mini-hydro generators, with a total generation capacity of 23 MW, supplying 135 kilometers of area that is not connected to the grid.[3] Future hydropower potential depends in part on how climate conditions change in the basins in which the plants are located.

Presentation: Climate Resilient Power Planning Case Study of O Mon IV Thermal Power Station[4]

Dr Charles Rodgers, Asian Development Bank, presented on a case study demonstrating how a rapid climate change impact assessment was applied to identify the possible impacts of climate change on the O Mon IV combined cycle power station project in southern Viet Nam (approved in November 2011). Five climate-related threats were identified as being of potential significance: air temperature, river water temperature, direct precipitation, flood depth and duration, and erosion. The nature of the exposure and impacts of these threats varies. Some, like air and river water temperatures, threaten day to day performance of plant operations, while heavy precipitation and flooding can affect maintenance schedules and downtime. Erosion and flooding could potentially cause damage to planned infrastructure.

The most significant potential climate change threats were identified as rising air and river water temperatures. Climate change projections indicate that the proportion of the year when river water temperature is at or above the design temperature of 29.2°C will significantly increase. The components most vulnerable to reduced performance are the gas and steam turbines, the air compressors, and the circulating water pumps. Most other components are expected to have minor vulnerability to climate change. Asset damage (possibly resulting from river bank erosion and floods) is not projected to be of significance.

Within the context of Viet Nam's official emissions scenario, the study shows that the O Mon IV power plant, as currently designed, may experience an aggregate loss in power output of approximately 827.5 GW because of projected increases in air and water temperature over the period 2015–2040. This corresponds to approximately 0.8% of its total design power output over that same period. In addition, the reduction in net efficiency will result in a relative increase in fuel consumption. In present value terms, the loss of power output and increased fuel consumption are estimated to cost approximately $11.0 million over the period 2015–2040. These numbers, in the context of the O Mon IV power plant, remain

[2] Asian Development Bank (ADB). (2015). Tanzania Country Profile. Renewable Energy in Africa.
[3] Germany Federal Ministry of Economics & Technology. (2009). Tanzania Small-Hydro Energy Market.
[4] Note that the text in this section has been excerpted from the report ADB Climate Resilient Power Planning Case Study of O Mon IV Thermal Power Station

relatively small. It shall not be presumed that similar results would apply to other power plants in the region.

Adaptation responses examined in the study include the following:

- Improving performance of the gas turbine cycle: Adaptation options are focused on the gas turbine technology and revolve around either pretreatment of the intake air to reduce temperature or redesigning the topping cycle technology to accommodate a warming climate.
- Improving performance of the cooling water cycle: Adaptation options are focused on reducing the intake water temperature or increasing the performance of the cooling water system pumps and heat exchangers.
- Improving management of the coolant discharge: Adaptation options are focused on reducing the proportion of coolant feedback at the water intake structures and improving mixing of the coolant plume in the Hau River water column

The analysis reveals that in order not to violate existing environmental standards in Viet Nam and to avoid adverse impacts on power generation, retrofitting with additional equipment (such as a cooling tower) may be required in the future, if actual temperatures fall within the range of current projections. Such retrofitting will require that space be available near the power plant for the installation of the equipment. Hence, while such an investment may be postponed, it may be appropriate to ensure that the needed space will be available if indeed such investment were to prove necessary. Adaptation approaches of this nature have been referred as "climate readiness," indicating that while climate proofing may not be recommended today, a cost-effective course of action may be to ensure that the investment (the project) is ready for adaptation in the future.

Discussion: Summary Observations and Takeaways

The last session of the workshop focused on articulating key learnings and takeaways from the member economies. Participants identified the following learnings, recommendations, and next steps for their economies.

Learnings:

- It is important to define and incorporate resilience metrics into planning. These metrics should be first defined and then directly incorporated into planning (e.g., monitoring and evaluation) to better ensure transparency and efficient use of financial resources.
- It is important to identify and reflect climate change impacts in planning. (Malaysia contribution)
- While the focus has been on reliability for the last few years to decades, there is a clear need to include resilience in power system planning (China).
- Regulators need to be engaged early. There is a need to bring regulators on board and to get their feedback/approval, so that investments in resiliency are included in the revenue base.
- Climate change can be included in Environmental Impact Assessments (Viet Nam).
- The Ministry of Energy in Indonesia is looking at Renewable Energy resources as a clean energy resource, but should bear in mind climate change related risks to those resources during planning.

- Climate change impacts can have a ripple effect on other sectors/areas, so adaptation approaches need to be multi-pronged in addressing these direct and potentially indirect impacts.

Recommended Next Steps:

- Integrated Resource and Resilience Planning (IRRP) should be explored further for implementation in APEC member countries, to better ensure that climate and other risks are taken into consideration, and managed in power system planning. IRRP can be implemented to ensure that:
    - The focus on climate change impacts and resilience is broadened to include all parts of the energy sector (generation, transmission, distribution, and demand)
    - An 'end-state' vision of where the sector needs to go is developed, that will help to identify resilience pathways in the short-to-medium term
    - Engagement of all key stakeholders in the power sector to bring change and move all of the stakeholders along the 'resilience path'
- There is clear need to develop a series of critical documents and guidance targeted at supporting climate resilient planning for utilities in the region, including:
    - Development of tools and software to assist planners in climate change risk and vulnerability assessment
    - APEC sponsored support will need to be tailored to each Economy
    - Share more lessons learned from dealing with disasters (and changes in planning) from various Economies with each other (ERTF could be a venue to do this, as they occur)
    - Training sessions on guidance and tools to assist in their uptake
- The climate change vulnerabilities and resilience should be considered in the "downstream" oil sector (e.g., oil depots, import facilities), including:
    - APEC has oil and gas security initiative that could benefit from incorporation of climate change considerations (sponsored by Japan)
    - Training sessions on how to incorporate climate change resilience for future energy infrastructure (e.g., LNG) should be held to develop capacity
- There is an urgent need to increase capabilities and competencies within the Philippines DOE and government agencies to evaluate the resilience compliance plans (RCPs) including:
    - Fully implementing the resilience circular requires much greater capacity within DOE (e.g., guidance documents in various energy sectors)
    - Clearly articulating how APEC could support this integration
    - Consideration of how RCPs can be linked with disaster plans at the provincial level. Pilot this integration in Cebu.
- There is a need for resilience metrics, including:

    - Need to quantify and measure the level of resiliency over time. Include them into the utility performance evaluation.
- There is a need to have internal meetings to assess how to put the lessons learned from the training into practice at the national and local government
- Energy system resilience needs to be better reflected in the Economy NDCs, National Communication, National Adaptation Plans, and other critical national planning documents.

Economy-level next steps:

- Malaysia
    - Plans to inform senior decision makers of the knowledge gained during this training
    - Is interested in implementing IRRP in Saba state
- Chile
    - Needs support in defining resilience metrics (building on SAIDI/SAIFI concepts)
    - Needs to undertake further analysis to understand the interconnection of energy resilience with resilience of other sectors (e.g., communication)
- Thailand
    - Needs to understand global trends in resilience and incorporate in future planning
- Viet Nam
    - EIAs often look at how project affect environment, but need to think about how environment and climate change impacts on projects
    - SEAs and Master Plans to include resilience assessments – how to evaluate master plans on this aspect?
    - Needs support to incorporate resilience in master plans both at national, sub-national, and regional levels
    - Develop engineering design standards into power infrastructure that enhances resilience
- China
    - Need for clear resilience metrics
    - Need to explore the use of 'big data' analysis for improving resilience
    - Utilities need support to understand, identify, access and use climate data to develop metrics.
- Indonesia
    - Field trips to support training of energy system resiliency enhancement
- Philippines

- Develop a memorandum of understanding between utilities and organizations to work together to develop metrics to track system resiliency enhancements

Appendix A. Workshop Agenda

Day 1: Introduction to the Workshop and Climate Resilience				
8:30 AM	-	9:00 AM	Arrival & Registration	
9:00 AM	-	9:15 AM	Opening Remarks	Patrick T. Aquino, Director, Philippines Department of Energy
9:15 AM	-	9:30 AM	Welcome from the APEC EWG Lead Shephard	Dr Jyuun-Shiauu Chern, EWG Lead Shephard
9:30 AM	-	9:45 AM	Introduction to the Workshop Objectives and Agenda	Cary Bloyd, PNNL, Project Overseer
9:45 AM	-	10:00 AM	Participant Introductions	
10:00 AM	-	10:45 AM	Climate Impacts and Power System Impacts Overview	Molly Hellmuth, ICF
10:45 AM	-	11:00 AM	Coffee Break	
11:00 AM	-	11:45 AM	Small Group Exercise on Climate Impacts to the Power Sector	Molly Hellmuth, Ananth Chikkatur and Robert Kay, ICF
11:45 AM	-	12:15 PM	Facilitated Discussion on Impacts	Plenary Discussion
12:15 PM	-	1:30 PM	Lunch	
1:30 PM	-	2:45 PM	Climate Resilient Power Systems and Project Level Planning Overview	Molly Hellmuth, Ananth Chikkatur,ICF
2:45 PM	-	3:30 PM	Small Group Exercise on Climate Resilience in the Power Sector	Molly Hellmuth, Ananth Chikkatur and Robert Kay, ICF
3:30 PM	-	4:00 PM	Facilitated Discussion on Resilience Measures	Plenary Discussion
4:00 PM	-	4:15 PM	Coffee Break	
4:15 PM	-	4:45 PM	Power System Resilience in Australia	Mark Paterson, Horizon Power
4:45 PM	-	5:00 PM	Day 1 Conclusion	Cary Bloyd, PNNL

Day 2: Understanding Climate Risks in Planning				
8:30 AM	-	9:00 AM	Arrival & Registration	
9:00 AM	-	9:15 AM	Opening Comments & Summary of Day 1	Cary Bloyd, PNNL
9:15 AM	-	10:00 AM	Resilience in Power Sector Planning: Role of IRRP	Ananth Chikkatur, COP USAID IRRP
10:00 AM	-	10:45 AM	Case Study: IRRP Implementation in Ghana	Ananth Chikkatur, COP USAID IRRP
10:45 AM	-	11:00 AM	Coffee Break	
11:00 AM	-	12:00 PM	Case Study: IRRP Climate Change Risk and Resiliency Findings in Ghana	Molly Hellmuth, ICF
12:00 PM	-	1:15 PM	Lunch	
1:15 PM	-	2:15 PM	IRRP: Group Exercise on Scenario Building	Ananth Chikkatur and Molly Hellmuth, ICF
2:15 PM	-	2:45 PM	Facilitated Discussion on Scenarios	Ananth Chikkatur and Molly Hellmuth, ICF

2:45 PM	-	3:15 PM	Coffee Break	
3:15 PM	-	4:15 PM	Ghana Power Sector Master Plan	Ananth Chikkatur, ICF
4:15 PM	-	4:45 PM	Climate Resilience in the Energy Sector in the Philippines: Access to Sustainable Energy Program (ASEP)	Patrick Ko, World Bank
4:45 PM	-	5:00 PM	Day 2 Conclusion	

Day 3: A Focus on Solutions				
8:30 AM	-	9:00 AM	Arrival & Registration	
9:00 AM	-	9:15 AM	Opening Comments & Summary of Day 2	Cary Bloyd, PNNL
9:15 AM	-	10:00 AM	Addressing Climate Impacts to Reliability and Resilience for Power Utilities	Robert Kay, ICF
10:00 AM	-	10:45 AM	Exercise: Advancing Power Utility Resilience	Robert Kay, Ananth Chikkatur, Molly Hellmuth, ICF
10:45 AM	-	11:00 AM	Coffee Break	
11:00 AM	-	11:45 AM	Screening Hydropower Facilities for Climate Change Risks to Business Performance	Molly Hellmuth, ICF
11:45 AM	-	12:30 PM	Hydropower Screening Exercise	Molly Hellmuth and Robert Kay, ICF
12:30 PM	-	1:30 PM	Lunch	
1:30 PM	-	2:00 PM	Case Study: IRRP Tanzania Hydropower Drought Scenario Analysis	Molly Hellmuth, ICF
2:30 PM	-	3:30 PM	ADB Climate Resilient Power Planning; Case Study: O Mon IV Thermal Power Station	Charles Rodgers, Asian Development Bank
3:15 PM	-	3:30 PM	Coffee Break	
3:30 PM	-	4:30 PM	Summary Observations and Takeaways	

Appendix B. Day 1 Exercise: Climate Impacts to the Power Sector Handout

Fill in the matrix with the ways in which climate stressors affect your country's power sector, and how non-climate drivers (e.g., land use, population growth, energy demand) exacerbate these impacts. Circle impacts that have had the greatest effect on the power system, in terms of safety, reliability, and affordability.

Climate Stressor	Generation			Transmission & Distribution	Demand
	Hydropower	Thermal	Renewables		
Temperature	e.g., Reduced generation capacity and efficiency. Exacerbated by increased agriculture resulting in increased competing water demands and decreased water supply availability.				
Extreme Rainfall & Drought	e.g., Damage to turbines due to increased sedimentation. Exacerbated by deforestation.				
Water Flow, Volume, and Timing					
Sea Level Rise					
Wildfire					

Appendix C. Day 1 Exercise: Climate Resilience in the Power Sector Handout 1

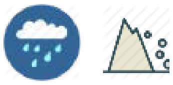
Priority Climate Impact: ______________________________

Policies & Plans	Technologies	Operations and Maintenance	Structural
Measure: **Advantages:** **Barriers:** **Priority:** **Low** **Med** **High**	**Measure:** **Advantages:** **Barriers:** **Priority:** **Low** **Med** **High**	**Measure:** **Advantages:** **Barriers:** **Priority:** **Low** **Med** **High**	**Measure:** **Advantages:** **Barriers:** **Priority:** **Low** **Med** **High**
Measure: **Advantages:** **Barriers:** **Priority:** **Low** **Med** **High**	**Measure:** **Advantages:** **Barriers:** **Priority:** **Low** **Med** **High**	**Measure:** **Advantages:** **Barriers:** **Priority:** **Low** **Med** **High**	**Measure:** **Advantages:** **Barriers:** **Priority:** **Low** **Med** **High**

Appendix D. Day 1 Exercise: Climate Resilience in the Power Sector Handout 2

Adaptation Options

CLIMATE STRESSOR(S)	GENERATION ADAPTATION STRATEGY	GENERATION TYPE	JUSTIFICATION
	Secure adequate water supply through enhancements to water use efficiencies and conservation.	Thermal, Hydropower	No-regrets
	Equip plants with technologies that capitalize on water reuse.	Thermal	
	Couple improvements in short-term and seasonal hydrologic forecasting to analyses of long-term climate change to improve management and operational decisions (e.g., to maintain more winter carryover reservoir storage and reduce discretionary reservoir water releases).	Hydropower	
	Evaluate operational changes (reservoir rule curve changes) assuming climate change to optimize energy output, given other constraints and water priorities.	Hydropower	Low-regrets
Drought	Invest in biomass crops that tolerate drought; Tanzania's largest biomass resource (sugar bagasse) is produced primarily in the Coastal, Central, and Northwest zones.	Renewables	
	Secure adequate water supply through contracts and contingencies based on an understanding of future hydrology.	Hydropower	
	Reduce supply sensitivity to loss of hydropower availability by increasing reservoir system capacity.	Hydropower	Climate-justified
	Retrofit power plants with additional cooling equipment and processes, including dry cooling technologies in water-limited areas.	Thermal	
	Prepare emergency contingency plans to ensure adequate cooling water to cope with high temperatures, accounting for competing water demands.	Thermal	No-regrets
	Leverage designs that improve passive airflow beneath PV mounting structures under increased extreme and average temperatures, reducing panel temperature and increasing power output; choose modules with more heat-resistant PV cells and module materials designed to withstand short peaks of very high temperature.	Renewables: Solar	Climate-justified
Temperature Increases & Extremes	Install steam-powered chillers to reduce burden on local power system on hot days.	Thermal	
	Build flexibility into the original plant design to allow for changes in the future.	All	Low-regrets
	Retrofit existing generation facilities to prepare for flood conditions.	Hydropower	
	Change the number and capacity of turbines in the design to take into consideration expected higher flows.	Hydropower	Climate-justified
	Modify design of the reservoir and spillways to take into consideration expected higher flows.	Hydropower	
	Site solar PV systems where expected changes in cloud cover are relatively low.	Renewables: Solar	No-regrets
	Evaluate reservoir rule curve changes assuming climate change to optimize energy output, given other constraints and water priorities.	Hydropower	Low-regrets
Precipitation & flow variability & timing	Develop improved hydrological forecasting techniques and adaptive management operating rules.	Hydropower	
	Modify design of the reservoir and spillways to take into consideration variable and changing flow amounts.	Hydropower	Climate-justified

CLIMATE STRESSOR(S)	GENERATION ADAPTATION STRATEGY	GENERATION TYPE	JUSTIFICATION
 Erosion and sedimentation due to increased precipitation intensity	Protect watershed to secure adequate water supply to reduce silt loading and attenuate peak flow.	Hydropower	No-regrets
	Employ sediment expulsion technology.	Hydropower	
	Implement erosion control measures to reduce siltation and sedimentation.	Hydropower	
	Integrate water resource management approaches in the basin and develop water regulations that reflect climate change.	All	Low-regrets
	Restore and better manage upstream land including afforestation to reduce floods, erosion, silting, and mudslides.	All	
	Modify spillway capacities and install controllable spillway gates to flush silted reservoirs.	Hydropower	Climate-justified
 Sea level rise, storm surge, & coastal erosion	Require utilities to develop storm-hardening plans on a regular basis.	All	No-regrets
	Develop siting rules for new coastal power plants to minimize flood risk.	Thermal	Low-regrets
	Design turbines, systems, and structures to better handle changing wind speeds and to capture greater wind energy with taller towers.	Renewables: Wind	Climate-justified

JUSTIFICATION	TYPE	GENERATION ADAPTATION STRATEGY
No-regrets	Technology	Invest in improved weather prediction to improve operational management.
	Policy & Planning	Acquire standby energy equipment and backup restoration supplies.
		Seek out new peak generation and purchasing sources for summer months.
Low-regrets	Policy & Planning	Choose generation infrastructure sites that are not at high current exposure risk and account for projected changes in coastal and riverine flooding.
		Revise infrastructure design thresholds using climate change projections.
	Structural	Install backup systems for critical hospital and home needs.
		Invest in decentralized power generation (e.g., rooftop PV or household geothermal).
		Expand networks, network protection, and energy storage to enhance reliability.
		Build additional generation capacity to account for decreased generation efficiency or increased customer loads due to climate impacts.
Climate-justified	Policy & Planning	Ensure adequate backup generation and cooling systems for plants facing increased exposure to flooding, drought, and other extremes.
	Structural	Relocate or reinforce key generation infrastructure to reduce exposure and sensitivity to sea level rise, storm surge, extreme precipitation and floods, drought, extreme temperature, and other extreme weather events.

CLIMATE STRESSOR(S)	TRANSMISSION & DISTRIBUTION ADAPTATION STRATEGY	APPROACH TYPE	JUSTIFICATION
	Increase fire corridors around transmission lines.		No-regrets

CLIMATE STRESSOR(S)	TRANSMISSION & DISTRIBUTION ADAPTATION STRATEGY	APPROACH TYPE	JUSTIFICATION
Drought	Collaborate with adjacent landowners to reduce wildfire hazard along transmission lines and near other critical infrastructure.	Land Use Planning	
Average & extreme temperature	Create "green" buffers around T&D infrastructure to reduce tree contact with sagging lines due to extreme temperatures.	Land Use Planning	No-regrets
	Install new types of cooling and heat tolerant materials/technology at substations.	Structural	Climate-justified
	Install cooling systems for transformers.		
	Use transmission line materials that can withstand higher temperatures.		
Extreme precipitation, flooding, sea level rise, & storm surge	Map landslide risk along transmission line rights-of-way.	Policy and Planning	No-regrets
	Consider extreme events threats in new siting.		
	Elevate substation control rooms to reduce potential flooding hazards.	Structural	
	Relocate, or reinforce or replace towers/poles with stronger materials or additional supports to make them less susceptible to wind and flood damage.		
	Construct levees, berms, floodwalls, and storm surge barriers to protect exposed T&D infrastructure.	Structural	Climate-justified
	Elevate or relocate substations.		
	Use submersible equipment that can withstand corrosion from salt-water exposure in vulnerable locations.		
	Install in-building supply systems (thermal or power) at elevations above anticipated flooding levels.		
	Place transmission lines underground.		

JUSTIFICATION	TYPE	TRANSMISSION & DISTRIBUTION ADAPTATION STRATEGY
No-regrets	Technology	Automate restoration procedures to bring energy system back on line faster after weather-related service interruption.
	Operations & Maintenance	Regularly inspect vulnerable infrastructure (e.g., wooden utility poles).
		Update aging T&D equipment.
		Invest in improvements to short- and medium-term weather, climate, and hydrologic forecasting to improve lead times for event preparation and response.
Low-regrets	Operations & Maintenance	Increase resources for more frequent maintenance.
	Structural	Support variable and distributed generation, through smart grid improvements, and local T&D lines.
		Build additional transmission capacity to cope with increased loads and to increase resilience to direct physical impacts.
		Build additional generation capacity to account for increased line losses and weather-related infrastructure damage.
		Install guy wires to poles and other structures in at risk areas.

JUSTIFICATION	TYPE	DEMAND ADAPTATION STRATEGY
No-regrets	Policy and Planning	Establish public education programs to promote lifestyles that are less energy-dependent.
		Explore energy market mechanisms to meet demand. Consider power exchange agreements, purchasing from the spot market, and options purchasing.
		Establish or expand demand-response programs which encourage consumers to voluntarily reduce power consumption during peak demand events.
		Time of Use Tariffs to encourage consumers to reduce power consumption during peak hours.
		Improve and enforce energy-efficient building codes.
		Adopt mandatory minimum energy performance standards for buildings and appliances (including air conditioners).
	Policy and Planning, Structural	Install smart meters and grids to reduce power consumption during peak demand events.
	Structural	Employ passive building design strategies to maintain minimum comfort or lighting levels even in situations where energy system losses occur.

Appendix E. Day 2 Exercise: Risks, Sensitivities, and Strategies

The groups reported out by APEC Economy on their findings from the small group exercises on climate change and non-climate risks, sensitivities, and adaptation strategies, as follows.

Indonesia

- Identified climate risks:
  - In Sulawesi there are 2 electrification systems that experienced impacts to transmission and distribution (T&D) towers and lines from extreme rain and wind (July, 2017), that resulted in power cuts
- Potential scenarios to test for sensitivity of power system:
  - Test for system failure due to extreme weather
- Identified adaptation strategies
  - Improving T&D foundations
  - Improved vegetation clearing and development of buffer zones
  - Installation of temporary towers (6 months)

Viet Nam

- Identified climate risks:
  - During drought or dry season depletion of hydropower reservoir (40% of electricity generation in Viet Nam is hydropower)
  - Coastal location of thermal plants at risk to sea level rise
  - High intensity rainfall results in sedimentation of hydropower reservoirs, that is exacerbated by deforestation and land use changes
  - As hydropower resources are depleted, cost of energy increases, as natural gas is imported from Singapore
- Potential scenarios to test for sensitivity of power system:
  - Cost of natural gas is higher than planned (test for fuel price sensitivity)
  - Reduction in capacity of reservoirs/ lower generation (test for lower hydro capacity)
  - Potential inundation and disruption of thermal generation (test for shock to thermal generation)
- Identified adaptation strategies:
  - Substitution of other fuels
  - Improved inter reservoir regulations
  - Reforestation and improved land use policies
  - Watershed management

Chile

- Identified climate risks:
  - High fuel cost volatility exposure for thermal plants (50% dependency on thermal), in part due to variability in hydropower generation (40% dependency on hydropower)
  - Port damaged and supply chain disruption for fuel due to high waves/ alternative port and longer transportation
- Potential scenarios to test for sensitivity of power system:
  - Lower hydropower capacity due to environmental change
  - High dependency on thermal and hydropower
  - Changes in fuel delivery and price
  - Reductions in renewable cost
- Identified adaptation strategies:
  - Increase renewable capacity in order to reduce dependency on hydropower and thermal resources

- Mitigate market variability
- Invest in battery- pumped storage as an auxiliary services for renewable generation

Malaysia

- Identified climate and non-risks:
  - Uncertainty of market price for coal and gas
  - Injection of RE into system- ability to take onto grid capacity
  - Solar and agriculture land use competition
  - New coal power regulations in the future
  - East to west transmission constraints in Saba
  - Limits to building coal plants- land use regulations
  - Feed in Tariff costs are high, more renewables result in higher costs
- Potential scenarios to test for sensitivity of power system:
  - Incentive based regulation for thermal generation
  - More or less stringent clean air regulations
- Identified adaptation strategies:
  - 2030 -2 GW RE limit (especially solar; reduce land use intensity for solar)
  - Improve T&D over next 5 years in Saba
  - SIDI index?
  - Government subsidies up to 2.3 billion
  - Remove FiT for future RE projects- competitive bid RE plants to bring costs down

Thailand

- Identified climate risks:
  - Transmission outage due to lack of maintenance and storm damage for 9 hours
- Potential scenarios to test for sensitivity of power system:
  - Loss of economic activity due to transmission outage (test shock/ loss of T&D)
- Identified adaptation strategies:
  - Build new thermal generation in the South
  - Upgrade transmission line capacity from 230 to 500 kvh

Philippines (Group 1)

- Identified climate and non-climate risks:
  - Infrastructure risk
  - Geothermal power plant
  - Heavy rains from tropical storm, flooding on specific site which damaged the steam lines
- Potential scenarios to test for sensitivity of power system:
  - Generation units offline reducing capacity
- Identified adaptation strategies:
  - Increase support to the pipeline, stockpiling inventory of spare parts for emergency situations- rapid access to spare parts to reconstruct/rehabilitate more quickly
  - Resite away from flood prone area

Philippines (Group 2)

- Identified climate and non-climate risks:

    - High load growth
    - Lack of supply in summer months (yellow alert)
    - Surge in electricity rates
    - Hotter weather leading to lower hydro capacity in summer
    - Depletion of natural gas supply in 2022
    - Aging plants, poorly coordinated maintenance schedule- resulting in a yellow alert as baseload plant went into maintenance mode
    - Regulatory risks that could slow down in commissioning of scheduled plants
    - Institutional risks- ERC board not in place, resulting in slow regulation
    - Security –hydropower- climate change and increasing water competition
    - Land use- high priority, energy sector will be affected as land constrained
    - Fuel dependency- coal importation- hijacked by pirates
- Potential scenarios to test for sensitivity of power system:
    - High load growth in the summer resulting in high rates
    - Reduced hydropower capacity
    - Delayed commissioning of plants
- Identified adaptation strategies:
    - Timely commissioning of powerplants, shorter permitting process
    - Diversify sources- nuclear power
    - Add more LNG terminals
    - Decrease coal imports
    - Transmission strategy- connecting Mindanao by 2020 interconnection- less reserve margin required
    - Smart grids, micro grids
    - EE standards for all sectors

China

- Identified climate and non-climate risks
    - Imbalance in generation and consumption locations:
    - 70% generation coal- in NW part of China, load in SE of chain
    - Energy security during transition process from coal to other non fossil fuel resources for power generation
    - Integration of renewables into grid, uncertainty of grid capacity
    - Air pollution from coal use for heating, LNG price increase as transition to natural gas heating- import dependency LNG
    - Low lying coastal power plants at risk to SLR/surge
- Potential scenarios to test for sensitivity of power system:
    - Reliability during transition from coal to non-fossil fuel resources
    - LNG cost
    - Limit coal capacity
- Identified adaptation strategies:
    - Nuclear capacity
    - Commonalities
    - Hydropower
    - Fuel risk volatility, dependency on imports
    - Lack of interconnectivity; long transmission lines
    - Integration of variable renewables into grid
    - Subsidized electricity prices
    - Increase local reserve margin or decrease net demand via EE/DSM

Appendix F. Day 3 Exercise: Advancing Power Utility Resilience Handout

Economy name ____________________

*Consider the **climate change adaptation** framework in your economy – specifically for your energy sector*

Could	**Y/N**	**Provide Details?**
Do you have voluntary partnerships on climate change adaptation in the energy sector?		
Do you have climate change coordinating processes in your economy (e.g. committees, task forces)?		
Other (please specify)		
Should		
What are the investments being made to protect against climate change impacts?		
Are regulators or investors providing guidance on adaptation investments?		
Other (please specify)		
Must		
What are the laws/regulations/policy in your economies specifically on energy sector climate change adaptation?		
Other (please specify)		

Anything else you would like to add?

Appendix G. Day 3 Exercise: Hydropower Screening Handout

Hydropower Exercise Background Information

Background:
You are an investor and are planning on building a 100 MW capacity, conventional storage hydropower plant to provide more electricity to a small, but growing city that frequently experiences power shortages. The reservoir would be located on a tributary that originates in the mountains, and that provides water resources for a range of upstream water users, including agricultural water users. Upstream of the planned hydropower plant, land clearing for agriculture and community development has led to increased sedimentation downstream. This will be the first reservoir to be built on the tributary.

Recent climate: The climate is influenced by its varied topography, changing from high elevation mountains in the north where the tributary begins, to the lower lying plains in the south where the hydropower plant is planned. The average annual temperature is 12.4°C, ranging from 25°C in the plains to 0°C at higher altitudes. Rainfall is driven by the monsoons between June and September, when 75 to 80 percent of rainfall occurs. Average annual precipitation is 1,311 mm, peaking around 330 mm in July and falling to below 50 mm per month from November through April. Historical trends indicate increases in high-intensity rainfall extremes that have led to flooding downstream, and more frequent drought (particularly during the dry season) that have increased conflict amongst water users during the dry season.

Future climate (2050): Average annual temperature is projected to increase by about 2.0°C. Average annual rainfall projected to increase, with largest increases during the monsoon season; at the same time the number of consecutive "dry" days are projected to increase by about 5 percent and extreme rainfall projected to increase by about 40 percent. The dry season projected to be drier and monsoon months wetter.

Instructions

Step 1. You will be assigned one of the following hydropower performance objectives to evaluate

Environmental Performance

Meet instream flow requirements	☐
Minimize ecosystem damage (maintain DO levels, minimize fish mortality, maintain stream health)	☐

Financial Performance

Maximize revenue and maintain high operating efficiency from power generation and ancillary services	☐
Minimize infrastructure maintenance, upgrade, and retrofit costs	☐

Social Performance

Positively impact community (e.g., quality of life, livelihoods)	☐
Ensure safety of nearby communities	☐

Step 2. Individually, assess the level of risk to your performance objective

- Refer to your performance objective worksheet and the background information on recent and future climate above
- In the first table of the worksheet, rate the potential impact from **climate-related stressors** on achievement of the objective.
- In the second table of the worksheet, Rate the potential impact from **non-climate drivers** on achievement of the objective.
- In the third table of the worksheet, Rate the extent to which **adaptive capacity** can counteract or manage these potential impacts to help achieve the objective.

Step 3. Once you have completed these steps, discuss your findings as a group, and combine your ratings for climate-related stressors, non-climate drivers, and adaptive capacity to develop an overall risk rating for the objective (at the bottom of the performance objective worksheet).

Step 4. As a group**, i**dentify appropriate next steps using the Next Steps worksheet.

Environmental Performance Objective: Meet instream flow requirements

Climate-related Stressors

Climate stressor impact on hydropower	Impact on objective	Recent	Future
Temperature: Temperature increases can result in increased evaporation from reservoirs and reductions in the volume of water stored, particularly in reservoirs with high surface area to volume ratios, and in arid regions. The smaller the reservoir capacity, the less storage buffer for meeting energy and competing demands, and for ensuring efficient operations.	Reduced stored water volumes can affect the ability of dam operators to meet instream flow or reservoir elevation requirements, which can be further exacerbated if competing water and energy demands (e.g., domestic, agricultural) increase due to temperature increases.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Flow Volume and Timing: Reductions in annual flow can result from projected decreases in annual precipitation; increases in annual flow can result from projected increases in annual rainfall. Changes in the timing, duration, and quantity of rainfall (including monsoons) will result in shifts in flow amount and timing. Changes in timing and quantity of meltwater from glaciers and snowpack can change flow volume and timing; increasing spring melt in the short run, and decreasing melt in the long term where glaciers are receding.	Reductions in mean annual flow increase challenges for meeting instream and reservoir elevation requirements. Changes in flow volume and timing that result in prolonged seasonal dry periods can make it more difficult to meet instream and elevation needs. Conversely, increases in flow may ease pressure, and changes in timing and amount of flow that increase flow during dry periods can enhance ability to meet these regulations.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Sedimentation: Sedimentation and erosion can increase as a result of more intense and frequent rainfall events, or flooding. Sedimentation can lower the storage volume of reservoirs, increase wear and tear on infrastructure, disrupt generation, increase upstream flood footprint, and reduce downstream ecosystem health.	Reservoir may lose storage capacity due to sedimentation, effectively reducing the volume of water stored, which may impact ability to meet instream flow requirements.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Extreme Events: More frequent and intense floods, droughts, and heat waves are anticipated under climate change in many parts of SE Asia. Droughts can reduce water availability and increase water demand on large scales. Floods can increase flow volume. Heat waves can reduce water availability, and increase water demand.	Reduced water volumes can make it more difficult to meet instream flow, and elevation requirements. Large increases in water volume can make it more difficult to maintain a flood buffer in the reservoir.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Non-Climate Drivers

Climate stressor impact on hydropower	Impact on objective	Recent	Future
Land Use/Land Cover: Changes in land cover may include regrading, removal of vegetation, adding impermeable surfaces, revegetation, and reforestation. Related land use changes include deforestation for agricultural production. These changes in land use and land cover may result in more or less flow volume for hydropower generation. They may result in higher sedimentation rates, or introduce or increase pollutants. Reforestation, building terraces, or other practices can help to reduce sedimentation.	Upstream changes in land use that increase water abstraction can reduce flow and storage volumes, making it more difficult to respect instream and elevation requirements. Upstream land use changes can also increase water volumes, and/or sedimentation rates, which may alleviate ability to meet instream flow requirements, but exacerbate efforts to maintain flood elevation buffers.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Up/Downstream Hydro: Hydropower plants located upstream and downstream change the natural hydrology, and can regulate flows to optimize water use, or minimize potential flood or drought impacts.	Other hydro plants can change the flow regime in the river, requiring coordination in order to meet instream flow and reservoir elevation requirements.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Population Growth: Population growth will result in increases in water and energy demands, including peak demands.	Population growth can increase water abstraction and demand, potentially making it more difficult to meet flow and reservoir elevation requirements.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Energy Demand: Energy demand will increase as ASEAN member countries continue to develop.	For peaking plants in particular, plants may struggle to meet increases in peak demand while satisfying instream flow and reservoir elevation requirements.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Adaptive Capacity

Climate stressor impact on hydropower	Impact on objective	Recent	Future
Operational flexibility	Ability to customize operations to a given system state (e.g., water levels, demand, season, etc) can help to ensure that regulations are met, even during periods of low flow.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Storage: Storage allows for some operational flexibility to accommodate demand and flow fluctuations.	With storage, facilities can regulate water discharges to meet these environmental requirements - larger capacity storage provides a larger buffer to manage variability and changing demands.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Access to high-quality forecasts: Hydrologic or climate forecasts can provide advance notice of changing conditions and flows.	Hydrological forecasts can help operators plan ahead to ensure that flows are managed appropriately for changing conditions. In some areas, seasonal climate forecasts can provide useful information 3-6 months in advance.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Climate-sensitivity of grid: At larger geographic scales, energy supply could be disrupted by climate-related events, which could constrain ability to meet energy demands. For example, transmission grid reliability can be effected by climate-related extreme events, landslides, fires, and grid efficiency can be reduced by increasing temperature.	Increasing hydro demands as a result of other energy supply failures (due to climate related disruptions such as fire, landslides, flooding, or heatwaves), may constrain operators from meeting flow requirements and energy demands.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Overall Risk Rating

Recent: ☐ High ☐Moderate ☐Low ☐ None

Future: ☐ High ☐Moderate ☐Low ☐ None

Environmental Performance Objective: Minimize ecosystem damage (maintain DO levels, minimize fish mortality, maintain stream health)

Climate-related Stressors

Climate stressor impact on hydropower	Impact on objective	Recent	Future
Temperature: Temperature increases can result in increased evaporation from reservoirs and reductions in the volume of water stored, particularly in reservoirs with high surface area to volume ratios, and in arid regions. The smaller the reservoir capacity, the less storage buffer for meeting energy and competing demands, and for ensuring efficient operations.	Higher water temperatures can reduce dissolved oxygen levels and affect biological processes for fish and other aquatic species.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Flow Volume and Timing: Reductions in annual flow can result from projected decreases in annual precipitation; increases in annual flow can result from projected increases in annual rainfall. Changes in the timing, duration, and quantity of rainfall (including monsoons) will result in shifts in flow amount and timing. Changes in timing and quantity of meltwater from glaciers and snowpack can change flow volume and timing; increasing spring melt in the short run, and decreasing melt in the long term where glaciers are receding.	Lower flow volumes can result in higher pollution concentrations. Changes in flow volume and timing can affect aquatic species' habitats and reproduction. Increases in annual discharge can help maintain ecosystem integrity, and reduce pollution concentrations.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Sedimentation: Sedimentation and erosion can increase as a result of more intense and frequent rainfall events, or flooding. Sedimentation can lower the storage volume of reservoirs, increase wear and tear on infrastructure, disrupt generation, increase upstream flood footprint, and reduce downstream ecosystem health.	Higher sediment loads can affect the health of the upstream riverine ecosystem. Lower sediment loads downstream can negatively impact ecosystem; increased sediment loads in reservoir itself may impact health of reservoir ecosystem and aquatic species.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Extreme Events: More frequent and intense floods, droughts, and heat waves are anticipated under climate change in many parts of SE Asia. Droughts can reduce water availability and increase water demand on large scales. Floods can increase flow volume. Heat waves can reduce water availability, and increase water demand.	More frequent and intense floods can result in increased ecosystem and habitat damage. More frequent and intense droughts, and heat waves, can reduce water quality (including increasing salinity), and harm ecosystem health.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Non-Climate Drivers

Climate stressor impact on hydropower	Impact on objective	Recent	Future
Land Use/Land Cover: Changes in land cover may include regrading, removal of vegetation, adding impermeable surfaces, revegetation, and reforestation. Related land use changes include deforestation for agricultural production. These changes in land use and land cover may result in more or less flow volume for hydropower generation. They may result in higher sedimentation rates, or introduce or increase pollutants. Reforestation, building terraces, or other practices can help to reduce sedimentation.	Deforestation, removal of vegetation, agricultural practices, and other land uses can affect erosion, sedimentation/ siltation, and water quality. Land use practices might introduce pesticides, nitrogen, phosphorus, reducing water quality. Reforestation or other practices may reduce sedimentation, which can improve water quality.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Up/Downstream Hydro:	Ecosystem impacts may be exacerbated by installation of hydro up-stream and down-	□ Very Negative □ Negative	□ Very Negative □ Negative

Hydropower plants located upstream and downstream change the natural hydrology, and can regulate flows to optimize water use, or minimize potential flood or drought impacts.	stream if it results in changes in hydrology or water quality.	◻ Neutral ◻ Positive ◻ Very Positive	◻ Neutral ◻ Positive ◻ Very Positive
Population Growth: Population growth will result in increases in water and energy demands, including peak demands.	Industry, agriculture, and other human uses of water can exacerbate harm to local ecosystems by increasing pollutants, and decreasing water availability.	◻ Very Negative ◻ Negative ◻ Neutral ◻ Positive ◻ Very Positive	◻ Very Negative ◻ Negative ◻ Neutral ◻ Positive ◻ Very Positive
Energy Demand: Energy demand will increase as ASEAN member countries continue to develop.	Higher generation needs could put more pressure on hydropower plants to satisfy other requirements, including maintaining ecosystem integrity.	◻ Very Negative ◻ Negative ◻ Neutral ◻ Positive ◻ Very Positive	◻ Very Negative ◻ Negative ◻ Neutral ◻ Positive ◻ Very Positive

Adaptive Capacity

Climate stressor impact on hydropower	Impact on objective	Recent	Future
Storage: Storage allows for some operational flexibility to accommodate demand and flow fluctuations.	The different types of storage have different adaptive capacity and design requirements- e.g. deep reservoirs face the challenge of releasing cooler or low oxygen water.	◻ Very Negative ◻ Negative ◻ Neutral ◻ Positive ◻ Very Positive	◻ Very Negative ◻ Negative ◻ Neutral ◻ Positive ◻ Very Positive
Access to high-quality forecasts: Hydrologic or climate forecasts can provide advance notice of changing conditions and flows.	Hydrological forecasts can help operators plan ahead through use of storage or controlled abstraction/distribution of water, helping to ensure that flows are managed appropriately for changing conditions.	◻ Very Negative ◻ Negative ◻ Neutral ◻ Positive ◻ Very Positive	◻ Very Negative ◻ Negative ◻ Neutral ◻ Positive ◻ Very Positive

Overall Risk Rating

Recent: ☐ High ☐Moderate ☐Low ☐ None

Future: ☐ High ☐Moderate ☐Low ☐ None

Financial Performance Objective: Maximize revenue from power generation and ancillary services

Climate-related Stressors

Climate stressor impact on hydropower	Impact on objective	Recent	Future
Temperature: Temperature increases can result in increased evaporation from reservoirs and reductions in the volume of water stored, particularly in reservoirs with high surface area to volume ratios, and in arid regions. The smaller the reservoir capacity, the less storage buffer for meeting energy and competing demands, and for ensuring efficient operations.	Reduced stored water volumes can affect the ability of hydropower plants to meet power generation and associated revenue goals, especially given competing water demands. High temperatures can decrease the efficiency of transmission (may not be a concern for HPP operators).	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Flow Volume and Timing: Reductions in annual flow can result from projected decreases in annual precipitation; increases in annual flow can result from projected increases in annual rainfall. Changes in the timing, duration, and quantity of rainfall (including monsoons) will result in shifts in flow amount and timing. Changes in timing and quantity of meltwater from glaciers and snowpack can change flow volume and timing; increasing spring melt in the short run, and decreasing melt in the long term where glaciers are receding.	Lower flow and storage volumes can reduce generation, while high water volumes may increase generation (if turbine and reservoir capacity can take advantage of it). Impacts on generation can be both long-term (reduced annual capacity) and seasonal (e.g., unable to meet expected generation due to shifts in seasonal flow and volumes).	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Sedimentation: Sedimentation and erosion can increase as a result of more intense and frequent rainfall events, or flooding. Sedimentation can lower the storage volume of reservoirs, increase wear and tear on infrastructure, disrupt generation, increase upstream flood footprint, and reduce downstream ecosystem health.	Sedimentation can reduce stored water volumes, and water availability for hydropower and competing water users. Damage to turbines can reduce power generation.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Extreme Events: More frequent and intense floods, droughts, and heat waves are anticipated under climate change in many parts of SE Asia. Droughts can reduce water availability and increase water demand on large scales. Floods can increase flow volume. Heat waves can reduce water availability, and increase water demand.	Droughts and floods can inhibit generation. Floods can directly damage infrastructure and disrupt generation. Floods may provide an opportunity to produce more electricity if reservoir and generation can accommodate. Heat waves can reduce transmission efficiency, and damage transmission lines (might not be a concern for HPP operators).	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Non-Climate Drivers

Description	Impact	Recent	Future
Land Use/Land Cover: Changes in land cover may include regrading, removal of vegetation, adding impermeable surfaces, revegetation, and reforestation. Related land use changes include deforestation for agricultural production. These changes in land use and land cover may result in more or less flow volume for hydropower generation. They may result in higher sedimentation rates, or introduce or increase pollutants. Reforestation, building terraces, or other practices can help to reduce sedimentation.	Changes in land use and land cover can result in more or less sedimentation, more or less flow (including peak flows) and stored water volumes, for example by altering the amount of impermeable surface or forested area, or increasing agricultural water demands. These changes can effect power generation positively or negatively.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Up/Downstream Hydro:	Depending upon operation and coordination-upstream hydropower plants or storage reservoirs	□ Very Negative □ Negative	□ Very Negative □ Negative

Hydropower plants located upstream and downstream change the natural hydrology, and can regulate flows to optimize water use, or minimize potential flood or drought impacts.	can negatively or positively affect downstream HPP operations- reducing or increasing water available to the plant, regulating/ changing timing and amount of downstream flow. Careful coordination will be required to maximize or optimize power generation.	□ Neutral □ Positive □ Very Positive	□ Neutral □ Positive □ Very Positive
Population Growth: Population growth will result in increases in water and energy demands, including peak demands.	Changes in population surrounding the HPP can effect water quantity and quality.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Energy Demand: Energy demand will increase as ASEAN member countries continue to develop.	Increases in peak demand can raise energy prices, boosting revenue. Though in many cases revenue and the price of energy is fixed, and demand changes may have little effect on plant revenue.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Adaptive Capacity

Description	Impact	Recent	Future
Operational Flexibility:	Operational flexibility (e.g. adjustable speed drive electronics, advanced monitoring systems) allows the plant to tweak systems in order to maximize generation.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Storage: Storage allows for some operational flexibility to accommodate demand and flow fluctuations.	Storage buffers low flow periods and in some places may also allow the plant to optimize generation based on peak demand/pricing.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Access to high-quality forecasts: Hydrologic or climate forecasts can provide advance notice of changing conditions and flows.	In some locations, revenue can be optimized by tailoring operations (reservoir releases, generation, meeting competing needs, etc.) to the hydrological forecasts and aligning generation with peak prices.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Climate-Sensitivity of Grid: Larger-scale energy supplies could be disrupted by climate-related events, which could constrain ability to meet energy demands across the board. For example, grid reliability can be effected by climate-related extreme events, landslides, fires, and efficiency can be reduced by increasing temperature.	Climate-sensitive grids require greater regulatory services and operating reserve, which reservoir storage can provide. At an HPP level, broader grid disruptions due to climate impacts may impact plant operations and efficiencies.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Overall Risk Ranking

Recent: □ High □Moderate □Low □ None

Future: □ High □Moderate □Low □ None

Financial Performance Objective: Minimize infrastructure maintenance, upgrade, and retrofit costs

Climate-related Stressors

Description	Impact	Recent	Future
Temperature: Temperature increases can result in increased evaporation from reservoirs and reductions in the volume of water stored, particularly in reservoirs with high surface area to volume ratios, and in arid regions. The smaller the reservoir capacity, the less storage buffer for meeting energy and competing demands, and for ensuring efficient operations.	Reduced stored water volumes may necessitate changes or upgrades in hydropower infrastructure, in order to ensure efficient operation given lower water storage volumes, or higher temperatures.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Flow Volume and Timing: Reductions in annual flow can result from projected decreases in annual precipitation; increases in annual flow can result from projected increases in annual rainfall. Changes in the timing, duration, and quantity of rainfall (including monsoons) will result in shifts in flow amount and timing. Changes in timing and quantity of meltwater from glaciers and snowpack can change flow volume and timing; increasing spring melt in the short run, and decreasing melt in the long term where glaciers are receding.	Hydropower plant operation at higher-than-optimal loads (e.g., increased water volumes) can increase risk of cavitation damage to turbines. Floods can result in direct damage to infrastructure.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Sedimentation: Sedimentation and erosion can increase as a result of more intense and frequent rainfall events, or flooding. Sedimentation can lower the storage volume of reservoirs, increase wear and tear on infrastructure, disrupt generation, increase upstream flood footprint, and reduce downstream ecosystem health.	Higher sediment loads can dramatically increase wear and tear on turbines and lead to much higher maintenance costs. Removal of sediments from the reservoir can be costly.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Extreme Events: More frequent and intense floods, droughts, and heat waves are anticipated under climate change in many parts of SE Asia. Droughts can reduce water availability and increase water demand on large scales. Floods can increase flow volume. Heat waves can reduce water availability, and increase water demand.	Floods can directly damage infrastructure, inhibit access to facilities, and cause high repair costs. More frequent and severe flooding may also force expensive upgrades to the dam in order to provide adequate flood protection.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Non-Climate Drivers

Description	Impact	Recent	Future
Land Use/Land Cover: Changes in land cover may include regrading, removal of vegetation, adding impermeable surfaces, revegetation, and reforestation. Related land use changes include deforestation for agricultural production. These changes in land use and land cover may result in more or less flow volume for hydropower generation. They may result in higher sedimentation rates, or introduce or increase pollutants. Reforestation, building terraces, or other practices can help to reduce sedimentation.	Land use/land cover changes could result in higher sedimentation, which could result in higher maintenance costs. Alternatively, reforestation can improve water quality, reducing upgrade costs.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Up/Downstream Hydro: Hydropower plants located upstream and downstream change the natural hydrology, and can regulate flows to optimize water use, or minimize potential flood or drought impacts.	Upstream dams should be managed in a coordinated effort to reduce impacts on downstream assets. Upstream reservoirs can have a positive impact by reducing flood impacts and sedimentation in downstream reservoirs, if sediments are not flushed downstream.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Adaptive Capacity

Description	Impact	Recent	Future
Insurance:	Storage: Insurance coverage limits the financial impact of floods and other extreme events that may damage key assets.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Storage: Storage allows for some operational flexibility to accommodate demand and flow fluctuations.	Proper management of storage reservoirs can reduce maintenance costs.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Access to high-quality forecasts: Hydrologic or climate forecasts can provide advance notice of changing conditions and flows.	If low flow or high flow (flooding) is forecast, dam operators can reduce potential damage by releasing or holding water. An early warning system allows for protective/preparatory measures to be put in place to reduce damage to assets.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Overall Risk Ranking

Recent: ☐ High ☐Moderate ☐Low ☐ None

Future: ☐ High ☐Moderate ☐Low ☐ None

Social Performance Objective: Positively impact community (e.g., quality of life, livelihoods)

Climate-related Stressors

Description	Potential Impact	Recent	Future
Temperature: Temperature increases can result in increased evaporation from reservoirs and reductions in the volume of water stored. The smaller the reservoir capacity, the less storage buffer for meeting energy and competing demands, and for ensuring efficient operations.	Reduced stored water volumes can constrain the ability of reservoirs to meet competing water demands. Higher temperatures can result in reductions in dissolved oxygen, or increases in concentrations of pathogens, negatively influencing ecosystems, productivity of fishing, and human health.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Flow Volume and Timing: Reductions in annual flow can result from projected decreases in annual precipitation; increases in annual flow can result from projected increases in annual rainfall. Changes in the timing, duration, and quantity of rainfall (including monsoons) will result in shifts in flow amount and timing.	Lower flows may result in difficulties meeting competing water needs, influencing ability to meet upstream or downstream livelihood needs (e.g. floodplain farming, etc.). Reductions in water quality as a result of lower water volumes can also negatively affect livelihoods and quality of life (e.g., farming, bathing, fishing). Changes in seasonal amounts of flow, particularly if rainfall shifts, may affect water demands for agriculture, and other competing water needs- which could constrain hydropower output or the ability of the reservoir to meet these needs.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Sedimentation: Sedimentation and erosion can increase as a result of more intense and frequent rainfall events, or flooding. Sedimentation can lower the storage volume of reservoirs, increase wear and tear on infrastructure, disrupt generation, increase upstream flood footprint, and reduce downstream ecosystem health.	Downstream changes in the riverine ecosystem as a result to less sedimentation, or increases in sedimentation in the reservoir or upstream river reaches, may negatively affect livelihoods.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Extreme Events: More frequent and intense floods, droughts, and heat waves are anticipated under climate change in many parts of SE Asia. Droughts can reduce water availability and increase water demand on large scales. Floods can increase flow volume. Heat waves can reduce water availability, and increase water demand.	Hydropower plants may face challenges in trying to satisfy competing local demands, and meet energy generation objectives. Especially during droughts, and heat waves which may constrain water availability and increase competing water demands. Droughts can also result in reduced water quality downstream, including increased salinity, impacting both water quality and a range of livelihoods dependent upon good water quality. Floods pose a challenge to hydropower plants, when downstream releases can impact livelihoods and quality of life, and can damage plant infrastructure. (Risks to safety are in 'community safety'.)	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Non-Climate Drivers

Description	Impact	Recent	Future
Land Use/Land Cover: Changes in land cover may include regrading, removal of vegetation, adding impermeable surfaces, revegetation, and reforestation. Related land use changes include deforestation for agricultural production. These changes in land use and land cover may result in more or less flow volume for hydropower generation. They may result in higher sedimentation rates, or introduce or increase pollutants. Reforestation, building terraces, or other practices can help to reduce sedimentation.	Other land uses may compete for water with the plant (industry, agriculture), increasing tensions with the local community.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Adaptive Capacity

Description	Impact	Recent	Future
Storage: Storage allows for some operational flexibility to accommodate demand and flow fluctuations.	Multipurpose reservoirs can enhance livelihoods by providing water supply in the dry season. The size of the reservoir will enhance or limit capacity to meet competing needs.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Access to high-quality forecasts: Hydrologic or climate forecasts can provide advance notice of changing conditions and flows.	Managers can use the forecasts to better operate the reservoir to meet different needs.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Overall Risk

Recent: ☐ High ☐Moderate ☐Low ☐ None

Future: ☐ High ☐Moderate ☐Low ☐ None

Social Performance Objective: Ensure safety of nearby communities

Climate-related Stressors

Description	Impact	Recent	Future
Temperature: Temperature increases can result in increased evaporation from reservoirs and reductions in the volume of water stored, particularly in reservoirs with high surface area to volume ratios, and in arid regions. The smaller the reservoir capacity, the less storage buffer for meeting energy and competing demands, and for ensuring efficient operations.	Higher temperatures can result in reductions in dissolved oxygen, or increases in concentrations of pathogens, negatively influencing ecosystems, productivity of fishing, and human health.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Flow Volume and Timing: Reductions in annual flow can result from projected decreases in annual precipitation; increases in annual flow can result from projected increases in annual rainfall. Changes in the timing, duration, and quantity of rainfall (including monsoons) will result in shifts in flow amount and timing. Changes in timing and quantity of meltwater from glaciers and snowpack can change flow volume and timing; increasing spring melt in the short run, and decreasing melt in the long term where glaciers are receding.	Higher flow may result in larger flooded /saturated areas, or larger water releases from the dam, which may contribute to increased flooding impacts, particularly during rainfall extremes.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Sedimentation: Sedimentation and erosion can increase as a result of more intense and frequent rainfall events, or flooding. Sedimentation can lower the storage volume of reservoirs, increase wear and tear on infrastructure, disrupt generation, increase upstream flood footprint, and reduce downstream ecosystem health.	Less buffering capacity given higher sediment volumes in the reservoir, may increase downstream and upstream flood risks.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Extreme Events: More frequent and intense floods, droughts, and heat waves are anticipated under climate change in many parts of SE Asia. Droughts can reduce water availability and increase water demand on large scales. Floods can increase flow volume. Heat waves can reduce water availability, and increase water demand.	More frequent and intense floods (that exceed design standards) may endanger the community. The community may also perceive that the plant exacerbates floods and droughts, so more frequent and intense extreme events may raise tensions between the facility and community.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Non-Climate Drivers

Description	Impact	Recent	Future
Land Use/Land Cover: Changes in land cover may include regrading, removal of vegetation, adding impermeable surfaces, revegetation, and reforestation. Related land use changes include deforestation for agricultural production. These changes in land use and land cover may result in more or less flow volume for hydropower generation. They may result in higher sedimentation rates, or introduce or increase pollutants. Reforestation, building terraces, or other practices can help to reduce sedimentation.	Increasing permeable surfaces can increase runoff rates and peak flows, exacerbating flooding. Sedimentation as a result of deforestation can result in increased flooding footprint upstream.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Up/ Downstream Hydro: Hydropower plants located upstream and downstream change the natural hydrology, and can regulate flows.	"Back-to-back" hydro plants on a single river can lead to a cascading series of failures and seriously exacerbate flooding. Coordinated operation of cascading reservoirs can lead to reduced flood risk to communities.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Population Growth: Population growth will result in increases in water and energy demands, including peak demands.	Population growth can increase population exposed to floods and other extreme events.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Adaptive Capacity

Description	Impact	Recent	Future
Storage: Storage allows for some operational flexibility to accommodate demand and flow fluctuations.	Storage: Reservoirs that serve as flood protection also enhance safety, though large releases for energy generation, or as a result of full reservoirs can exacerbate flooding.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive
Access to high-quality forecasts: Hydrologic or climate forecasts can provide advance notice of changing conditions and flows.	Early warning system and action plan allows for evacuation and other preparatory measures to be taken in nearby communities. Managers can use the forecasts to better operate the reservoir to meet different needs.	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive	□ Very Negative □ Negative □ Neutral □ Positive □ Very Positive

Overall Risk Ranking

Recent: ☐ High ☐Moderate ☐Low ☐ None

Future: ☐ High ☐Moderate ☐Low ☐ None

Step 4. Next Steps

Consider the list of potential next steps provided – what might be useful next steps for your planned project?

Recommendations at the Project Conceptual Stage:

Implemented by:	Recommendation:
Plant Developers	**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 reservoir to take into consideration expected higher or lower flows, changing number and capacity of turbines, employing sediment expulsion technology, and changing design of flood control measures. New studies may be required to evaluate whether design changes are necessary for existing infrastructure.
Plant Developers	**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.
Plant Developers	**Improve or acquire data for flood risk mapping that includes climate change** 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. The flood risk maps can be enhanced by taking into consideration climate change, for example, changes in return period rates of the 1:100 year flood.
Plant Developers	**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 non-compliant 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.
Government Policymakers	**Integrate water management approaches in the basin and revisit water regulations in light of 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.
Government Policymakers	**Implement or improve new 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.
Government Policymakers	**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 back-up supply during brownouts or blackouts.
Others?	