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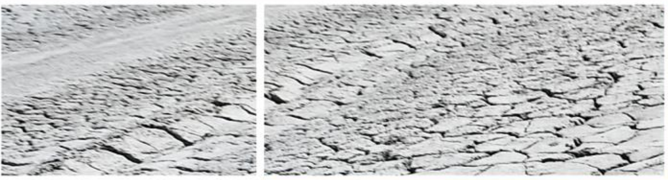
Addressing Climate Vulnerability for Power System Resilience and Energy Security



A Focus on Hydropower Resources

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EXECUTIVE SUMMARY

This paper aims to inform energy planners and investors about i) how climate change can affect power generation resources, particularly hydropower resources; and ii) an approach that can be taken to address climate change risks, both at the project and sector level, to improve power system resilience and enhance energy security.

As a clean and renewable energy source, hydropower can be a cornerstone of low emission development strategies (LEDS)[1] that help countries enhance energy security and curb greenhouse gas (GHG) emissions. Energy security has regained interest because of ever increasing demand for energy, aspirations to provide energy access for all, worries about global scarcity of fossil fuels, and environmental concerns related to fossil fuel use (LEDS GP, 2016). Now more than ever, there is a need for *win-win* solutions, as countries strive to meet national development goals, including Nationally Determined Contributions (NDCs).[2]

Recognizing this, hydropower development has been growing rapidly worldwide. In 2015, an estimated 33 gigawatts (GW) of capacity was put into operation globally—most notably in China (19.4 GW), other countries in Asia (8.2 GW), and South America (3.4 GW). Hydropower investment is also expected to increase in Africa, as the region focuses on achieving energy security, with significant hydro projects underway in Ethiopia, Congo, and other countries. Likewise, new financial instruments such as green bonds, and engagement from multilateral agencies, are making some types of hydropower investment (typically smaller-scale hydropower) more attractive (IHA, 2016).

Yet hydropower itself faces challenges associated with climate change. In particular, changing precipitation patterns, increases in temperature, more frequent or intense incidence of droughts, extreme weather events, sea level rise, and resulting flooding and landslides can all affect hydroelectricity generation capacity, damage infrastructure, disrupt service, and lead to difficulties in meeting environmental regulations, among other things. Moreover, for a myriad of reasons, most investors, managers, and operators of hydropower facilities do not yet consider projected changes in climate and weather as part of a business risk analysis or in power planning.[3] Unless these risks are addressed, the intended benefits of hydropower may be short-lived; particularly if electricity grids must turn to traditional, carbon-intensive energy sources such as coal-fired plants when hydropower becomes constrained.

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[1] This is particularly true for smaller-scale hydro, as large-scale hydro often brings concerns about greater GHG emissions, as well as environmental and social impacts, associated with large storage reservoirs. The GHG impacts of freshwater reservoirs is an area of active scientific research, with emissions depending on climate, vegetation, and human activities vis-à-vis storage reservoirs.

[2] See U.S. Agency for International Development (USAID) (2016a) for a summary analysis of Intended Nationally Determined Contributions (INDCs).

[3] This may be because investors and managers of hydropower facilities: (a) do not recognize that future climate trends will differ from past ones; (b) are uninformed about the potential risks to their business operations over various timescales; (c) lack a clear understanding of how climate change could undermine their investments; (d) lack access to relevant climate and weather information to incorporate into infrastructure design, operations and maintenance, and business continuity plans; and/or (e) they are discouraged by perceived costs of making adjustments to their business plans.

To help address this challenge, this paper outlines a four-step approach for integrating climate resilience approaches into power planning by iteratively identifying and managing climate risks to better ensure long-term energy security and sustainability. These steps involve: (1) assessment of climate risks and vulnerabilities; (2) identification, evaluation, and prioritization of options to address climate risks; (3) integration of climate change considerations into project implementation, power planning, and operations and maintenance; and (4) monitoring, evaluating, and adjusting plans over time. The paper provides key resources to help planners and investors undertake these steps. The paper also emphasizes that detailed local assessments, as well as explicit consideration of tradeoffs associated with different investment alternatives, are critical to providing greater understanding of climate vulnerabilities and identifying feasible planning and management measures.

INTRODUCTION

The availability of electricity is essential for businesses to produce goods and services, for farmers to irrigate and cultivate crops, for hospitals to provide medical care, for municipalities to deliver essential services to their communities, and for individuals and households to improve the quality of their lives. The lack of adequate energy service is a serious constraint to economic and social development in many countries. Electricity shortages and lack of access to power are caused by many factors that may exist throughout the energy value chain, including inadequate generation to meet base and peak demand; lack of transmission lines and distribution systems to serve remote populations; and service disruptions due to weather, inadequate operation, and poor maintenance.

The increasing demand for electricity is driving rapid investment in new power generation to enhance energy security by narrowing the gap between supply and access to reliable, affordable electricity. At the same time, countries are striving to meet targets for GHG emissions reductions, and are thus faced with the challenge of addressing the demand for energy without triggering growth in GHG emissions that will further exacerbate the impacts of climate change. Another challenge facing countries is how to meet energy demand in a way that does not increase the vulnerability of the electricity system to the impacts of climate change, such as disruptions or reductions in services as a result of increasing incidence and intensity of droughts.

As a result of the increasing demand for electricity – particularly electricity that does not increase GHG emissions – the pace of hydropower development is growing rapidly worldwide. In 2015, an estimated 33 GW of capacity was put into operation globally, including 2.5 GW of pumped storage. In that year, Asia[4] and South America added the most capacity (31 GW), while significant new hydropower projects in Africa are expected to come online in the near future, including Ethiopia's Grand Renaissance Dam (6 GW) in spring 2017 (IHA, 2016; Salini Impregilo, 2014).

The international community and national governments are increasingly hopeful that through LEDS, developing countries can meet the dual goals of increased energy access and reduced growth in GHG emissions. As a proven and clean technology, hydropower can be a key component of LEDS. The UNFCCC's Clean Development Mechanism (CDM), which recognizes projects that reduce GHG emissions while advancing other economic and social goals, has placed considerable emphasis on hydropower. As of July 2016, the CDM Executive Board has registered more than 1,500 hydropower projects representing 19% of all registered CDM projects. Hydropower is second among the renewable energy sources that CDM recognizes (UNFCCC, 2016). Similarly, between 2002 and 2014, the World Bank Group financed more than USD 8.8 billion in 50 countries in East Asia, Europe, Africa, and South America to install or restore 17 GW of hydropower (World Bank Group, 2014). New financial instruments are also making some types of hydropower investment (typically smaller-scale hydropower) more attractive through engagement from multilateral agencies and green bonds; in 2015, hydropower represented one-third of

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[4] Including 19.4 GW from China.

all energy-themed green bonds, accounted for the largest sub-sector within these climate-aligned bonds (IHA, 2016).

Yet, while development of hydropower is seen as an effective GHG mitigation strategy, particularly smaller-scale hydro[5] (see Text Box 1), it is particularly vulnerable to climate change given its dependence on water for power generation (as detailed in the next section). This can inadvertently lead to the adoption of carbon-intensive alternatives if the use of fossil fuel generation sources is increased as a stop-gap measure to address future energy shortfalls should hydropower reliability become compromised.

Many hydropower operators have begun to recognize these risks. A 2015 survey of more than 50 companies active in the hydropower sector worldwide found that 40% of operators believe that climate change already influences their engineering and design measures to a large extent or completely (IHA, 2015)[6] (see Figure 1). However, most investors, managers, and operators of hydropower facilities do not yet consider future climate conditions as part of a business risk analysis, nor do energy planners adequately consider climate change risks in power planning. This may be due to a variety of factors, as investors, managers, and operators either (a) do not recognize that future climate trends will differ from past ones; (b) are uninformed about the potential risks to their business operations over various timescales; (c) lack a clear understanding of how climate change could undermine their investments, (d) lack access to relevant climate and weather information to incorporate into infrastructure design, operations and maintenance, and business continuity plans; or (e) they are discouraged by perceived costs of making adjustments to their business plans (see Text Box 2). This lack of consideration could lead to reduced power system reliability in both the short- and long-term, directly impacting local economic services, communities, as well as national energy security and economic growth. In addition, unanticipated investments in accessible carbon-based alternatives may result in order to ensure power system service reliability over both short and longer term periods. The experiences of the Philippines and Ghana, where the use of thermal energy sources and diesel generators was increased to address repeated black-outs, illustrate this problem, as described in Text Box 3.

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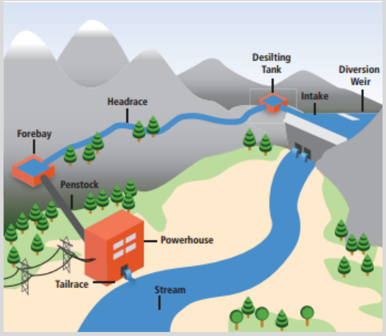
[5] Large-scale hydropower often brings concerns about GHG emissions, as well as environmental and social impacts associated with large storage reservoirs.

[6] Survey conducted in 2015 by the International Hydropower Association (IHA). Respondents were primarily hydropower owners, operators, or consultants, and are globally representative.

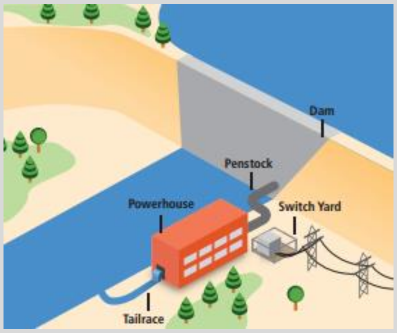
Text Box 1. Types and sizes of hydropower

There are three primary types of hydropower:

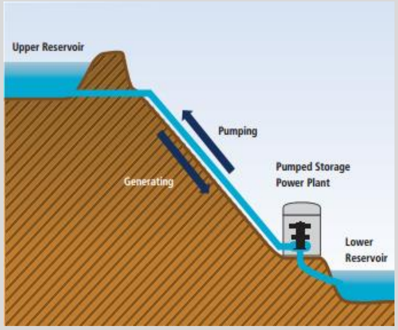
- **Run-of-river.** A run-of-river hydropower plant uses available river flow for energy generation. This type of plant has a small intake basin with little or no storage capacity. Water availability results in substantial daily, monthly, and seasonal variations in generation.
- **Storage.** A conventional storage hydropower plant contains a reservoir to hold water for later consumption. This type of plant can deliver a broad range of energy services such as base load, peak, and energy storage. Often, storage reservoirs are multi-purpose, serving a range of competing water demands (e.g., industrial, agricultural, domestic, hydropower), and purposes (e.g., flood control, navigation, tourism).
- **Pumped Storage.** A pumped storage hydropower plant is typically used to meet peak energy demands, and consists of an upper and a lower storage reservoir. A net energy consumer, pumped storage takes advantage of price differentials during peak and off peak times, generating energy during peak times, and pumping water from the lower reservoir to the upper reservoir during off-peak hours. This type of plant is the largest-capacity form of grid energy storage (“battery”).



Run-of -river



Storage



Typical pumped storage

Source: IPCC Special Report (2011).

While there is no global consensus on project size classification, the IPCC (2011) classifies hydropower projects by megawatts (MW) of installed capacity as follows: **pico** (<0.005), mini (<0.1), **micro** (<1), **small** (1-100), **medium** (>100), **large** (>500). Conversely, “small” is classified by many countries as <10 or < 15 MW. The capacity classification can be important as it has legal and eligibility ramifications for incentive programs for investors, manufacturers, and developers. For example, smaller-scale hydropower (i.e., mini, micro, and small) is receiving growing investments from the development community to support the goals of accelerating both clean energy development and rural energy access.

Sources: IPCC Special Report, 2011; Liu et al. 2013; Kaunda et al., 2012.

The cautionary examples from the Philippines and Ghana underscore the need to integrate climate change considerations into hydropower investments, and to find cost-competitive, scalable, and sustainable (renewable) alternatives to both variable hydropower resources and higher GHG emitting energy technologies. To do so, an integrated planning approach for climate resilient, low emission development is necessary.

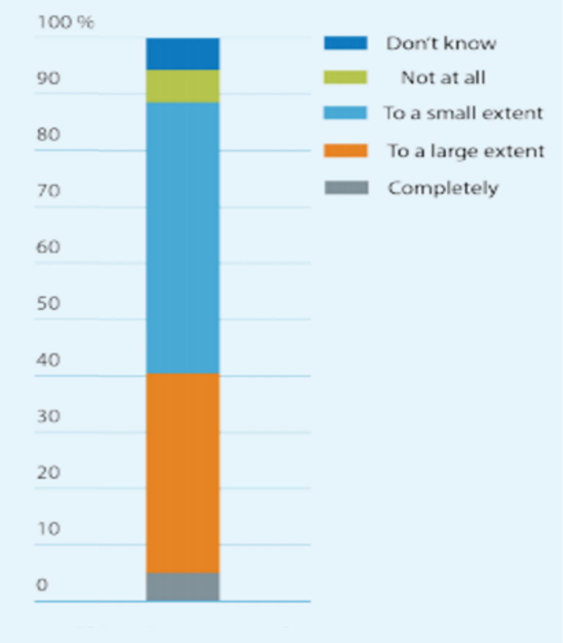


Figure 1. Degree to which hydropower utilities believe climate change is already influencing their engineering and structural design measures. Source: IHA, 2015.

Text Box 2. Can climate change projections be used reliably for energy planning?

As with any projection of the future, climate change projections have a degree of uncertainty. The amount of uncertainty is different for different climate variables, with greater uncertainty levels for projections of precipitation, and other projections at local geographic scales. But confidence in climate change projections is steadily increasing, and while climate change science is not perfect, enough is known to help planners make smart decisions regarding energy assets.

A diversity of information–including observed data and trends, downscaled climate models, and theory (i.e., warming, acceleration of hydrologic cycle)–helps to build evidence towards a plausible future climate. Further, confidence in projections of future climate change has increased, particularly those about future global temperatures, sea level rise, and glacial melt. Thus, it is now both possible and critical to make decisions that take climate change into account, and experts are developing robust decision making approaches that help decision makers consider risks and performance trade-offs of implementing different adaptation strategies in the power sector.

Text Box 3. Climate impacts on electricity generation and low emission development in the Philippines and Ghana

In the Philippine island of Mindanao, where 51% of the power supply had come from hydropower, a combination of drought, deforestation, river siltation problems, and increasing electricity demand led to repeated black-outs in the summer of 2012. This limited economic growth and caused political and social unrest. In response, system managers increased the load of thermal energy sources (e.g., coal-fired plants) to help meet short-term demand, increase baseload capacity over the long-term, and ensure system reliability (Navarro, 2012; Rappler 2016).

Similarly, in Ghana drought conditions led to power rationing in 2007. Power output dropped by 66%, impacting all economic sectors and led companies to spend an additional USD 62 million per month on extra power generation, mainly from diesel. This shortage cut the year's economic growth by 1.5 to 2.5% (Bekoe and Logah, 2013).

THE RISKS OF CLIMATE CHANGE TO HYDROPOWER

As noted previously, hydropower is vulnerable to climate change, given its dependence on water availability for generation, and its direct proximity to flowing water. Projected changes in the seasonal distribution and amount of precipitation due to climate change may result in proportional changes in hydropower generation. In addition, changes in the frequency and intensity of flooding present a direct physical risk to a facility's infrastructure and surrounding communities. Moreover, climate impacts are compounded across the power system; for example, rising temperatures increase peak demand for electricity at the same time that generation capacity is reduced, thereby compounding system stress. In the Northwestern United States, for example, shifts in peak flow from summer to early spring are expected to reduce the water available for hydropower generation during summer, when peak demands are expected to increase due to higher demand for air conditioning (Melillo et al., 2014).

Based on historic trends, hydropower planners expect that decreases in hydropower generation in dry years will be balanced with increases in generation during wet years (Gleick, 2016). But climate change threatens to disrupt this balance (see Text Box 4). In some regions, annual runoff is expected to increase, which offers potential benefits to hydropower generation if the plants are designed accordingly. In other areas, however, runoff is expected to decrease, which would result in underperformance over time.

Increased hydrologic variability and associated flood risk pose serious challenges for hydropower managers, particularly to their ability to meet reputational, financial, and regulatory goals. Reputation can be affected if customers' satisfaction of expected service is not maintained, if electricity is not delivered (e.g., drought, heat waves), or if plant operation poses upstream or downstream risks to people and their livelihoods (e.g., flooding). Variability in expected flows can lead to volatility in revenues that is financially disruptive, while flood or sedimentation-related impacts to infrastructure or other assets can lead to additional capital expenses and revenue loss.

Table 1 (below) provides an overview of potential climate change impacts to hydropower performance, electrical transmission and distribution, and water and energy supply and demand. These impacts are organized by six key climate-related stressors:

- changes in seasonal distribution and amount of precipitation;
- increased average temperature and incidence of extreme heat;
- increased incidence of drought;
- increased frequency and intensity of precipitation and storm events; and
- increased sea level and storm surge heights.

The sensitivity of hydropower plants to climate change varies by size and type, so impacts are described here by type of hydropower plant. In general, plants with larger storage reservoirs have greater operational flexibility and a larger storage buffer than those with smaller reservoirs.

Electricity generation of run-of-river plants is more sensitive to changes in low flows (particularly minimum flows) than storage plants, for example, as they do not have significant storage to buffer changes in flow. Though impacts to conventional storage and pumped storage are similar, pumped storage is generally less vulnerable, given its effective capture and re-use of stored water, offering additional operational flexibility.

In addition to climate stressors, non-climate stressors are also important and should be considered as part of a business risk analysis. Non-climate stressors that are outside of the hydropower plant's control—such as aging infrastructure, growing urban populations, deforestation, increasing competition for water resources—create additional challenges to managing risks to hydropower services (Danilenko et al., 2010). For example, deforestation in a watershed could exacerbate sedimentation and reduce water storage for competing water users, including hydropower facilities. In the absence of policy and behavioral changes, non-climatic factors are likely to aggravate or attenuate the adverse effects of climate change on water availability, as well as have a significant influence on energy and water demand.

Text Box 4. Why are historical climate data no longer enough to project the future climate?

Hydropower managers and power system planners routinely factor weather and climate variability into their management decisions based on historical data. However, many are not aware of the risks associated with long-term changes and increasing extremes which the future climate change is likely to bring. In its most recent assessment of climate change (the Fifth Assessment Report [AR5]), the IPCC states that, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased".

Over the past 60 years, temperatures are rising at an increasing rate, and the number of record highs have increased, while the number of record lows have decreased. Temperatures are projected to continue to increase during all seasons, with heat waves projected to become more intense and more frequent around the world. In the coming decades, wet regions around the globe are expected to become wetter, and dry regions are expected to become drier. Over the past 50 years, droughts have become more frequent in some regions, including southern Europe and western Africa. The global sea level is estimated to have risen about eight inches since 1880 and is projected to rise another one to four feet by the end of the century. Coastal infrastructure (e.g., energy, water, transportation) is highly sensitive to higher sea levels, storm surges, erosion, and other climate-related changes. The specific characteristics of climate change—both observed and projected—vary by region. Therefore, power system managers and investors must be aware of trends and future projected climate changes as they apply to their local and regional context.

Sources: IPCC, 2013; IPCC, 2014.

Table 1. Potential climate impacts to hydropower performance, electrical transmission and distribution, and water and energy demand

		Impacts on Power System Component		
Climate Change Stressor	Change in Condition	Hydropower Performance and Management	Transmission/ Distribution	Electricity Demand and Competing Water Demands
Changes in seasonal distribution and amount of precipitation	Changes in water flow amount and timing	*Storage & Pumped Storage:** ▪ Change in available water for generation (increase or decrease) ▪ Reductions in flow affects ability to meet instream flow and reservoir elevation requirements ▪ Increased risk of damage to turbines from plant operation at higher-than-optimal loads (e.g., increased water volumes) ▪ Shifts in peak flow affect timing of peak generation *Run-of-river:* ▪ Increased frequency and duration of minimum (design) flows, and lower minimum flows, reduce generation ▪ Reputational risks to not performing as expected, given reduced flexibility to buffer variable flow (and generation) rates	None	▪ Under a lower flow scenario, increased competing water and electricity demands (e.g., for pumping of irrigation water) could further reduce water available for generation ▪ Potential mismatches between peak seasonal electricity demand and peak flow
Increased average temperature; increased incidence of extreme heat	Increased near-term runoff from snow and glacial melt; high evaporation and transpiration rates	*Storage & Pumped Storage:** ▪ In non-glacial fed rivers, less water available for generation due to increased evapotranspiration; in glacial-fed rivers potential increased near term generation (decreased long term generation), and shifts in peak generation earlier in the spring ▪ Higher water temperatures can reduce dissolved oxygen levels and affect biological processes for fish and other aquatic species *Run-of-river:* ▪ Potential for increased minimum flow, and reductions in performance ▪ Higher ambient temperatures can lead to increases in water temperatures and salinity concentrations in the river reach where water is diverted ▪ Increased demand for competing water users can result in less water for generation	Reduced efficiency of transmission and distribution Heat stress on transmission lines creates increased rate of degradation, which can result in line sag at more extreme temperature	▪ Increased demand for energy to support air conditioning, cooling, irrigation pumping ▪ Increased demand for competing water users (e.g., irrigation, cooling water for thermal generation) can result in less water for generation ▪ Potential mismatches between peak seasonal electricity demand and peak flow


		Impacts on Power System Component		
Climate Change Stressor	Change in Condition	Hydropower Performance and Management	Transmission/ Distribution	Electricity Demand and Competing Water Demands
Increased incidence of drought	Reduced water volume; high evaporation rates; increased risk of wildfire	*Storage & Pumped Storage:** ▪ Potential long-term and large-scale reduction of stored water under drought, significant reductions in generation *Run-of-river:* ▪ Lack of storage buffer, potential severe power generation reductions during droughts	Direct infrastructure damage from wildfires	▪ Compounding strain on the grid ▪ Increased energy demands for irrigation pumping ▪ Increased demand for water from competing users
Increased frequency and intensity of precipitation and storm events	Increased frequency and intensity of flooding; increased rainfall intensity and wind speeds associated with severe typhoons; increased sedimentation	*Storage & Pumped Storage:** ▪ Direct infrastructure damage and service disruptions, inhibiting access to plant, higher repair costs ▪ Depending upon reservoir capacity and design, flooding or increased rainfall can increase generation capacity, and replenish reservoirs ▪ Floods can directly damage infrastructure, inhibit access to facilities, and result in high repair costs ▪ Reduced capacity of dams and reservoirs ▪ Damage to turbines and related high maintenance costs *Run-of-River:* ▪ Direct infrastructure damage and service disruption ▪ Weirs or holding ponds may lose storage capacity, reducing the volume of water that can be diverted or stored ▪ Damage to turbines and related high maintenance costs	Direct infrastructure damage from floods and winds	None
Increased sea level and storm surge heights	Higher coastal sea levels; erosion	*Storage and Pumped Storage:** ▪ Ability to meet environmental flow requirements. ▪ Combination of reduced downstream flow and sedimentation due to upstream impoundment in hydropower reservoir, increased downstream saltwater intrusion, land subsidence, and coastal erosion, impacting food, livelihood, and water security.	Damage to coastal infrastructure from inundation	None

Source: USAID, 2017.

* Does not apply to “closed-loop” pumped storage, which is highly resilient, as it is not connected to (or dependent upon variable) river flows, but is rather an enclosed system (e.g., in a mine shaft).

A SOLUTION: INTEGRATING CLIMATE RESILIENCE INTO HYDROPOWER INVESTMENTS AND BROADER POWER PLANNING AND INVESTMENTS

The risks of climate change to hydropower should be addressed by integrating climate resilience into short- and long-term hydropower—and broader energy system—project planning, development, and operations and maintenance. Such planning should consider both climate risks and GHG reduction opportunities across the energy supply and demand chains, and the interrelationships and dependencies between variable renewable resources. Planners and investors should also evaluate the trade-offs of different investments in order to promote the resilience of individual hydropower plants, as well as the power system as a whole. A first step to enable this type of planning is raising awareness among energy planners/investors and utility managers and operators of evolving vulnerabilities.

Building this awareness means helping energy planners and investors understand the climate change risks to hydropower efficiency and reliability, as well as the cost-effective alternatives available to achieve resilient and low GHG-emitting projects and energy systems. The right knowledge and skills, along with adequate resources and incentives, can help motivate investors and energy planners to reduce climate vulnerabilities and harness potential opportunities that may arise from a changing climate. Since consideration of climate change is likely to be novel for many power sector planners/investors, concerted capacity building investments, including training, may be required. Similarly, utility managers and operators require technical assistance to make informed decisions for managing short-term and long-term changes. While the set of skills, knowledge, resources, and incentives needed is a high bar to achieve, some tools and resources have already been developed to help planners and investors understand potential climate change impacts on hydropower and energy systems, as well as associated climate change adaptation measures available to manage risks. These are outlined at the end of this paper, under "Additional Resources".

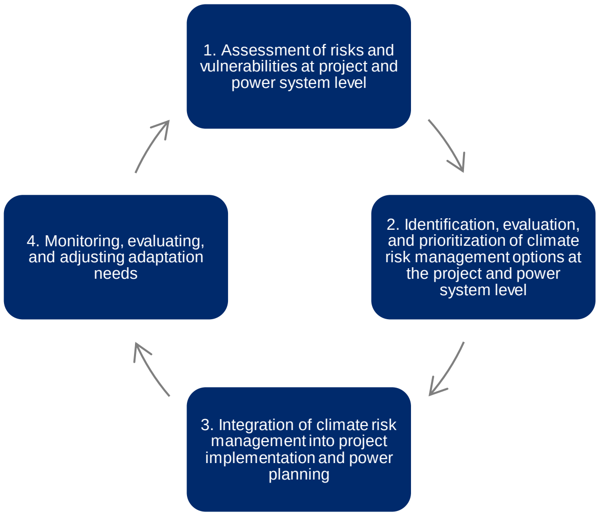


Figure 2. Iterative steps for integrating climate risk management into hydropower projects and power system planning

Once risk awareness is achieved, an adaptive management process should be adopted by energy planners/investors to integrate climate risk management into hydropower planning and power sector investments. Figure 2 (above) shows a series of iterative steps that can be taken by project managers and power system planners/investors to integrate climate change into decision-making, as outlined below.

1. **Assessment of risks and vulnerabilities at the project and power system planning levels** to help managers determine how climate variability and change may affect an existing or planned power sector strategy, or an individual project.
2. **Identification, evaluation, and prioritization of climate risk management options** at the project and power system level taking into consideration effectiveness, technical feasibility, and cost.
3. **Integration of climate risk management into project implementation and power planning** to build resilience and flexibility into projects and better direct and coordinate power sector investments so that "surprises" are anticipated and development objectives (e.g., lowering GHG emissions) are met over time.
4. **Monitoring, evaluating, and adjusting adaptation needs** is an ongoing process that supports managers in identifying, measuring and addressing possible risks, and in incorporating new information about conditions and performance in order to take steps to reduce risk and improve performance.

More detail on each of these steps is provided below, with a focus on considerations for hydropower projects and power sector planning.

Step 1: Assessment of risks and vulnerabilities at the project and power system planning levels

Vulnerability assessments allow planners to estimate the degree to which a system is exposed to, sensitive to, or unable to cope with the adverse impacts of climate stressors—including climate variability, extreme events, and longer-term climate change. Vulnerability assessments help managers to determine how climate variability and climate change may affect an existing or planned power sector strategy, or an individual project. Risk assessments reveal the magnitude, *likelihood*, and timing of these potential consequences of climate change impacts. At both project and sector levels, vulnerability and risk assessments can help to identify areas where potential climate impacts are particularly consequential, and where adaptation actions are most needed. See Text Box 5 for information on the type of information needed to conduct a vulnerability assessment.

Climate risk screening is increasingly being mandated by governments and development banks (e.g., U.S. Agency for International Development [USAID], World Bank, Asian Development Bank, and African Development Bank) as part of routine due diligence for new project-level investments in order to protect their investments and promote climate resilient development. For example, USAID has developed operational requirements for climate risk screening and management in essentially all new regional and national strategies and in project- and activity-level plans.[7] As a result, a host of tools are being developed for project- and energy systems-level screening (see Table 2).

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[7] See USAID (2015) and USAID (2016b).

Text Box 5. What information is needed to conduct a vulnerability assessment?

Not all energy sector-level strategies or projects require an in-depth vulnerability or risk assessment. The level of analysis required depends on the stage of planning and the investment cycle; typically, analysis of climate risks and adaptation measures becomes more information-intensive as investors move from project scoping to engineering designs. Other considerations for the level of detail of risk assessments include how critical the project is to the power sector, what threshold of risk tolerance would require action, and the cost required to undertake the assessment compared to the cost of a likely adaptation response (including inaction).

The level of analysis helps to determine the level of information and data required, including the level of technical detail and the temporal and spatial scope of the assessment. These characteristics apply not only to the climate data, but also to data associated with impacts. It is possible to complete rapid, screening-level assessments drawing on public data and existing tools on climate and impacts, expert consultation, and basic modeling. For detailed analyses—such as those needed to inform engineering design—high-resolution data, extensive hydrology and hydropower modeling, and information on the cost of potential damages and adaptation options may be needed in order to evaluate the potential risks and tradeoffs of different actions, given uncertain climate change.

Table 2. Climate change risk screening tools

Resource Name	Provider	Screening Level	Description
Climate & Disaster Risk Screening Tools: Energy Sector	World Bank	Project-Level: Risk Screening	Energy project developers evaluate potential impacts of climate change, with modules for: thermal power, hydropower, other renewables, energy efficiency, transmission and distribution, and energy capacity building.
Hands-on Energy Adaptation Toolkit	World Bank	Power Sector-Level: Risk Screening & Adaptation	A stakeholder-based, semi-quantitative risk-assessment to prioritize risks to a country’s energy sector and identify adaptation options.
Hydropower Screening Tool	USAID	Project-Level: Risk Screening & Adaptation	Hydropower developers and investors evaluate potential climate change impacts on regulatory, reputational, and financial business objectives. Recommends steps for adaptation measures based on identified risks.

At the project level, climate vulnerability screening and risk assessment can be applied to hydropower facilities to quickly identify at-risk infrastructure, operations, assets, ecosystems, or populations. One tool to help with this is USAID’s Hydropower Screening Tool, which has been applied by hydropower plant managers in five Asian countries (see Text Box 6). Detailed risk assessments can build on the results of initial tool-based screenings (such as those generated by the Hydropower Screening Tool) to provide a more nuanced understanding of the risks posed to the hydropower plant.

Text Box 6. USAID hydropower screening tool

The Hydropower Screening Tool, developed under the USAID ASEAN Connectivity through Trade and Investment (ACTI) project, provides a practical framework for screening hydropower facilities and operations for business risks to climate change (see Figure 3). This tool, which will soon become publicly available, provides guidance to assess climate risks to the financial, environmental, and social performance of conventional, run-of-river, and pumped storage hydropower plants. The tool can be used by project investors or managers for screening in order to flag climate risks at an early stage of project development, or it can be used on existing facilities to identify existing or future risks (to inform the need for more detailed risk analysis). It can also be used to develop detailed terms of reference, or mandated by government agencies as a requirement of due diligence for new hydropower projects. It provides a set of high-level, practical recommendations based on identified project risks. The tool has been applied by hydropower plant owners and staff from national ministries of energy in Laos, Malaysia, the Philippines, Thailand, and Vietnam.

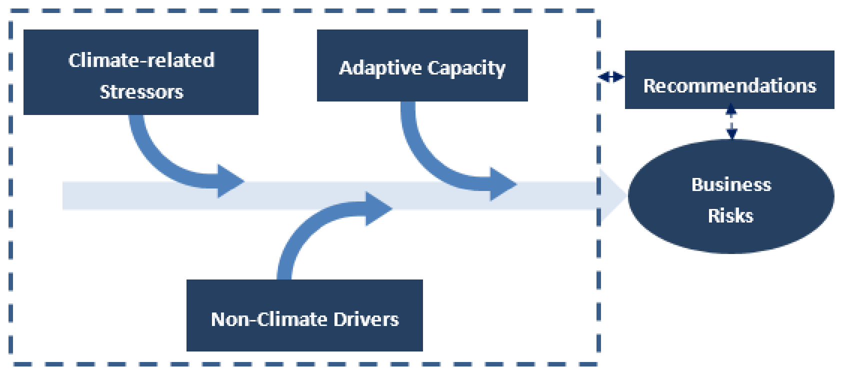

Figure 3. Conceptual framework for the tool

Source: Hellmuth, 2016.

Similarly, sector-level planning assessments are needed to assess climate risks (alongside other potential non-climate risks and drivers of change) and to inform decisions across the power sector in the near- and long-term. While hydropower transmission/distribution and demand are particularly vulnerable to climate change (as depicted in Table 1), climate change can also impact conventional energy generation systems (see NREL, forthcoming), as well as different renewable energy generation technologies, which must also be considered (see Text Box 7). At the grid-level, the climate risks to hydropower and other renewables introduce uncertainty around future costs and the feasibility of grid integration of renewable energy resource generation, including the potential ancillary services of hydropower as a provider of firming[8] and reserve capacity to balance and stabilize the grid (U.S. Executive Office of the President, 2016). High-level screening of

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[8] Hydropower storage provides firming capacity, ensuring that power output can be maintained at a committed level for a period of time, by smoothing power output from variable, intermittent power sources (eliminating rapid voltage and power swings on the electrical grid).

the power sector can help countries and LEDS stakeholders develop policies and projects that are robust in the face of climatic uncertainties, and assist them in managing energy assets as the climate changes. This is key to maximize the benefits of renewable energy sources, which can play important roles in supporting more resilient energy systems through spatial diversification, modularity, water use reductions, integration of electricity storage, and reliance on locally available fuel sources (see NREL, forthcoming).

Text Box 7. Climate sensitivities of non-hydro energy sources

Climate change is likely to affect other power generation technologies, not only hydro. The nature of these effects will vary by region. For example, climate changes can affect the natural resource-based inputs for both renewable and non-renewable energy resources, which can impact their efficiency and result in damage to assets. In particular:

- **Thermal resources** will be impacted by warmer intake temperatures of cooling water, which will effect generation efficiency (for each 1°C increase above 15°C, nameplate capacity of natural gas-fired power plants decrease by 0.3 to 1.0 depending on cycle type). Similarly, drought or shifts in timing and amount of precipitation may lead to reduced reliability of power plants due to insufficient supply of cooling water.
- **Wind generation** potential may be impacted positively or negatively by local changes to the wind regime, as well as changes in icing frequency on wind turbines, and sea ice extent. 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.
- **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%.
- **Biomass/biofuel generation** could be affected by changes in the 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 1,600 mm. The locations with these growing conditions are shifting due to climate change.

In addition, the **infrastructure assets** of all low-lying energy generation sources are vulnerable to direct physical damage due to coastal and riverine flooding or extreme weather events. Sea level rise and storm surge also pose risks to these assets in terms of increased corrosion of electrical components, as well as temporary inundation and erosion damage to facilities and access roads, and increasing repair costs.

Sources: Sathaye et al., 2013; Neumann and Price, 2009; Acclimatise, 2009; Ebinger and Vergara, 2011; Hammer et al., 2011; Asian Development Bank (ADB), 2012; American Society of Civil Engineers (ASCE) and American Wind Energy Association (AWEA), 2011; ESMAP and World Bank Group, Undated.

Step 2: Identification, evaluation, and prioritization of climate risk management options at the project and power system level

A number of adaptation strategies are available to hydropower planners and investors to address climate change risks. Many hydropower utilities have begun to take steps to evaluate climate risks. According to a 2015 survey conducted by the International Hydropower Association (IHA), 60% of utilities surveyed are developing partnerships with research institutions and 52% are employing trained staff to address climate resilience (see Figure 4). However, many of the surveyed utilities have yet to undertake meaningful actions to enhance resilience, such as developing a climate risk management strategy, performing climate risk screening, or allocating budget to climate-proofing assets (IHA, 2015).

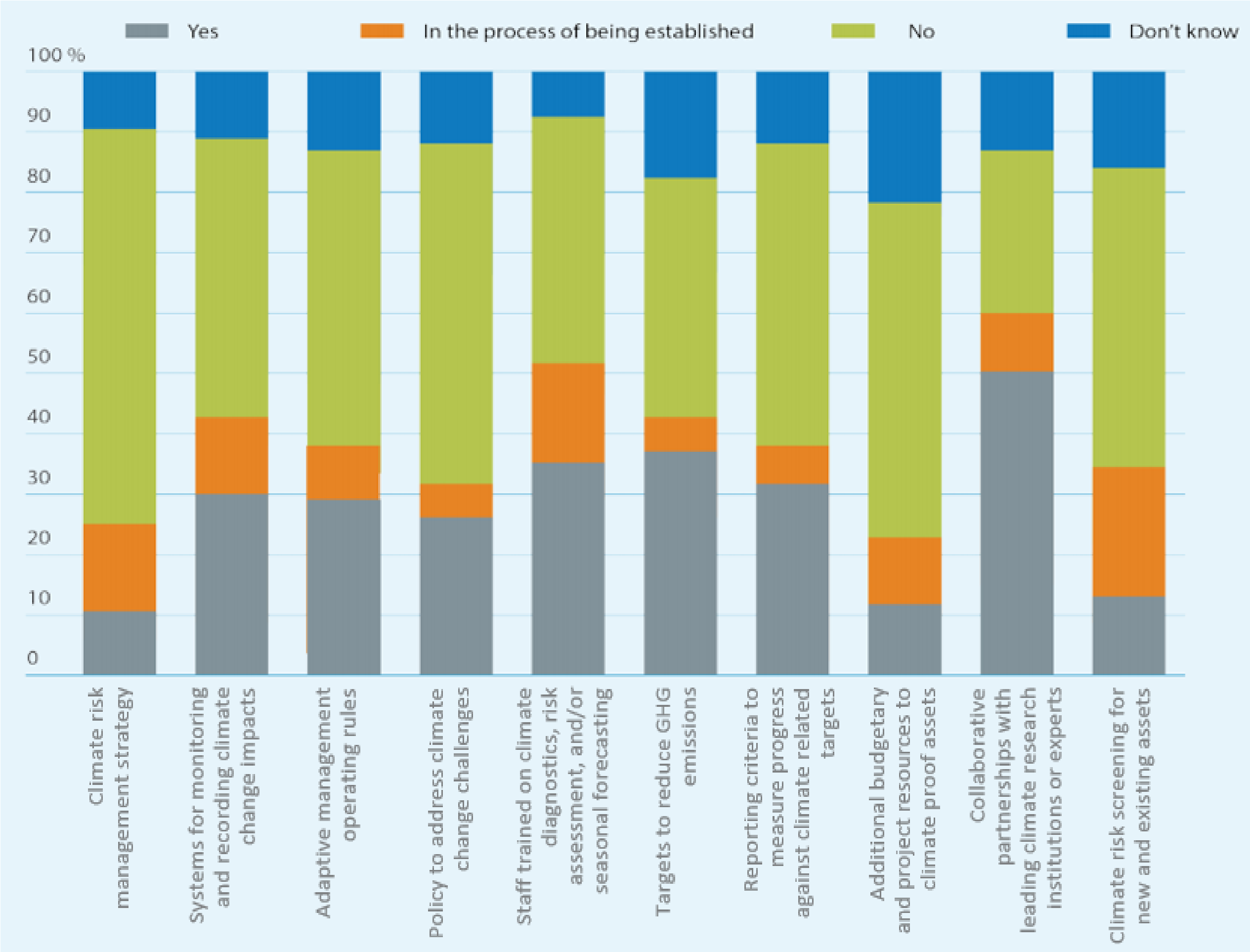

Figure 4. Proportion of hydropower utilities engaging in various climate resilience activities.

Source: IHA, 2015.

In many cases, adaptation measures can be taken that also address inefficiencies, increase adaptive capacity, and reduce demand-side pressures. These "no-regrets" measures offer benefits regardless of climate change, while also increasing the ability of the facility or system to withstand climate stress. In other cases, "climate-justified" measures (i.e., measures that are most beneficial only if the climate change expectations incorporated into the decisions actually occur) may require high investment levels, but would avoid serious disruptions to hydropower generation in the event that certain climate conditions occur. Feasible, flexible, incremental approaches can effectively reduce the potential of regrets by allowing for decisions to be adjusted over time to emerging risks as new information becomes available. Incorporating risk management considerations early in project design can set the tone, help to manage costs, and enable a more systematic and focused approach to management of climate risks. An example of an emerging "no-regrets" approach that is of particular interest to the LEDS community is the concept of Payment for Watershed Services (PWS), described in Text Box 8.

Text Box 8. Payment for watershed services: A climate resilient, low emission development strategy

Payment for Watershed Services (PWS) is an emerging "no-regrets" approach that is of particular interest to the LEDS community. The PWS approach aims to reward upstream communities – particularly farmers – that adopt techniques such as terracing, mulching, and agroforestry that help control water flow, thereby reducing sedimentation and reducing extremes in water flow that affect downstream hydropower plants. Such upstream watershed management can allow the hydropower plants to better meet their design conditions. In addition, the agricultural interventions themselves can increase crop yields and crop quality, thereby increasing incomes for the farmers (Hunink et al., 2016).

Several detailed engineering studies and modeling exercises have been completed that demonstrate the principles of PWS. A pilot study of Kenya's Tana River Basin, an area that spans more than 17,000 km2 and is home to almost 150,000 smallholder farmers, found that PWS could save in the range of USD 12-95 million per year, with half of this savings due to reduced siltation and better control of water flow to downstream hydropower stations. At the same time, the annual costs would amount to only USD 2-12 million, with significant benefits accruing to smallholder farmers. A detailed desk study of Sebou Basin in Morocco (an area of 40,000 km2 with six million residents) also concluded that PWS would be viable and would have an attractive cost-benefit profile.

Sources: IFAD, 2012; Benabderrazik, 2011.

It is in the realm of "climate-justified" measures that hydropower investors need to make difficult decisions about how to balance political, economic, social, and environmental costs of action versus non-action, given an uncertain future (Danilenko et al., 2010). In general, as the consequences of potential climate impacts increase, the justification for higher-cost adaptation measures increases as well. For example, a major hydropower plant represents a high investment capital project with a long lifetime, and significant investment in up-front structural design changes may be justified to avoid higher-cost consequences in future years. On the other hand, in some cases the selection of flexible adaptation approaches as part of feasibility and engineering designs may be a sufficient option that allows plant operators to adjust to changing conditions over time. An iterative, adaptive management approach can allow managers to track performance, monitor trends and new climate projections, and implement adaptation measures over time.

Options for reducing hydropower project risks

At the project level, hydropower investors and planners should adopt structural, operational, and planning/design measures to manage risks and improve adaptive capacity to avoid damage to infrastructure or service disruptions, as outlined in Table 3 below. By adhering to "rule curves" and protocols in isolation of future climate change considerations, hydropower managers may find that operational modifications are required to maintain services, safety, and/or efficiency under new climatic conditions. One example where hydropower design is being modified to take advantage of projected climate change is Tajikistan's Qairokkum hydropower plant. This plant will be rehabilitated to bolster the plant's resilience to climate change and take advantage of higher peak flows by increasing installed capacity from 142 to 170 MW (IHA, 2016).

Table 3. Examples of risk management measures for hydropower plant managers and investors

Generation Capacity and Infrastructure	Type
Restore and better manage upstream land, including afforestation to reduce floods, erosion, silting, and mudslides	Policy and Planning
Integrate water resource management approaches in the basin and develop water regulations that reflect climate change	Policy and Planning
Improve or acquire data (e.g. on elevation, local hydro meteorology, local terrain, the built environment, populations) for flood risk mapping	Planning
Develop improved hydrological forecasting techniques and adaptive management operating rules	Planning and Operations
Implement or improve flood risk and plant performance monitoring systems	Planning and Operations
Develop drought- and flood-management plans that incorporate anticipated climate change impacts	Planning and Operations
Modify emergency preparedness and response plans to incorporate climate change	Planning and Operations
Modify design of the reservoir to take into consideration expected higher or lower flows	Structural
Change the number and capacity of turbines in the design to take into consideration expected higher or lower flows	Structural
Employ sediment expulsion technology	Structural
Change the design of flood control measures to account for climate change	Structural
Build flexibility into the original plant design to allow for changes in the future	Structural
Retrofit existing generation facilities to prepare for flood or drought conditions	Structural
Relocate or reinforce key generation infrastructure from floods, storms, and other extreme weather events (e.g., change land use, add drainage, implement flood protection)	Structural
Implement erosion control measures to reduce siltation and sedimentation	Structural
Modify spillway capacities and install controllable spillway gates to flush silted reservoirs	Structural
Modify canals or tunnels to handle expected changes in water flows	Structural
Review dam maintenance programs in light of potential climate change effects	Operational
Evaluate reservoir rule curve changes given climate change to optimize energy output, given water priorities and other constraints	Operational

Sources: Modified from USAID Hydropower Screening Tool, 2015; WECC, 2014a; ADB, 2012.

Adaptation measures, particularly those that require large investments, are subject to cost/benefit analysis to assess their economic and technical performance over time; for example, some structural adaptation investments may have additional or high upfront costs, longer payback periods, uncertain returns, and higher perceived risks. However, over the lifecycle of the investment, the benefits of reduced damages, maintenance and operations costs, or service disruptions would outweigh costs. In general, structural adjustments (retrofits) to existing plants will bring higher costs over the lifetime of the project than incorporating measures (that may have higher upfront costs) for new plants early on in the planning cycle. There can be inherent difficulties in calculating the return on investments in adaptation measures, particularly when the frequency of future events is uncertain. Moreover, the co-benefits of adaptation measures (e.g., increased safety, healthier ecosystems) are also difficult to quantify, and are not typically captured in traditional cost-benefit analysis. Planners should consider adaptation measures that are appropriate for the level of climate risk for the utility, and be careful to ensure that their actions do not lead to unintended consequences including maladaptation (e.g., by increasing vulnerabilities downstream, such as flooding). Evaluation criteria can also influence the timeframe of implementation of the adaptation measures. For example, projects with high capital costs may require additional time to obtain financing and may have to be implemented over various stages. Effectively, hydropower managers must weigh the tradeoffs associated with making alternative choices about which risks to reduce and which ones to bear.

Options for reducing risks across the power system

It is important to understand and manage climate-related risks across the power system—including generation technologies,[9] transmission and distribution, and demand. Similar to hydropower projects, structural, policy and planning strategies exist to reduce climate risks across the power sector value chain. While this paper primarily focuses on hydropower, diversification of generation resources to meet supply shortfalls is an important risk management strategy; in fact, diversifying investment to include renewable resources is being promoted as a strategy to increase resilience, meet off-grid demands, and reduce emissions.[10]

Some examples of adaptation measures for renewables, for transmission and distribution networks, and for demand-side management are provided in Tables 4, 5, and 6, respectively. All of these strategies should be considered in an integrated manner in order to better understand the trade-offs, including the potential conflicting and reinforcing strategies across the power system. Mexico's national utility, CFE, has adopted a suite of climate resilience strategies, described in Text Box 9.

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[9] An in-depth discussion of risks across power generation technologies, and adaptation options is beyond the scope of this paper. For more information see ADB, 2012.

[10] See NREL (forthcoming) and REN21 (2015).

Text Box 9. Mexico's national utility adapts its practices to respond to climate change

Mexico's national power utility, CFE, owns generation, transmission, and distribution infrastructure throughout the country. Distribution equipment is particularly vulnerable to hurricanes, tropical storms, floods, and earthquakes.

To enhance resilience, CFE has focused on improving restoration times following damages. Efforts have included strengthening pole foundations and anchoring transformers and conductors to poles. These changes have been cost-effective and have improved the chances of distribution lines continuing to provide service during storms.

CFE has also improved resilience by developing natural disaster contingency plans and establishing close communication with the National Meteorology Services monitoring center.

Source: Ebinger and Vergara, 2011.

Table 4. Examples of renewable energy resources risk management measures for energy planners and investors

Renewable Generation	Category
Choose sites for new installations that take into account expected changes in wind speed, storm surge, sea level rise, and river flooding during the life of the turbine	Design
Site solar photovoltaic systems where expected changes in cloud cover are relatively low	Design
Invest in decentralized power generation such as rooftop PV generators or household geothermal units	Structural
Design turbines and structures to better handle changing wind speeds and gusts to capture greater wind energy with taller towers. Design new systems better able to capture energy of increased wind speeds	Structural
Leverage designs that improve passive airflow beneath photovoltaic mounting structures, reducing panel temperature and increasing power output. Choose modules with more heat-resistant photovoltaic cells and module materials designed to withstand short peaks of very high temperature	Structural
Expand networks and network protection to ensure reliability of more intermittent renewables	Structural
Store electrical energy to allow a greater percentage of renewable energy into the grid	Structural, Operational
Invest in improved weather prediction in order to improve the reliability of expected output	Operational

Sources: ADB, 2012; DOE, 2016; WECC, 2014b.

Table 5. Examples of transmission and distribution risk management measures for energy planners and investors

Transmission and Distribution	Type
Integrate sea level rise projections and storm surge actions in coastal siting of transmission and distribution (T&D)	Structural
Relocate or reinforce key T&D infrastructure, such as substation control rooms, from floods, storms, and other extreme weather events	Structural
Build additional transmission capacity to cope with increased loads and to increase resilience to direct physical impacts	Structural
Reduce line capacity requirements by producing a larger fraction of power at or near the destination	Structural
Place transmission lines underground (also helps with fire and storm damage threats)	Structural
Proactively install new types of cooling and heat-tolerant materials/technology and install cooling systems for transformers	Structural
Reinforce or replace towers/poles with stronger materials or additional supports to make them less susceptible to wind and flood damage	Structural
Review T&D maintenance programs in light of potential climate change effects	Operational
Employ energy smart technology, including automated feeder switches and smart meters that help pinpoint and reduce the number of customers affected by an outage	Operational

Sources: ADB, 2012; DOE, 2016; Ebinger and Vergara, 2011.

Table 6. Examples of demand-side management measures for energy planners and investors

Demand	Type
Implement public outreach activities to raise awareness of water scarcity in light of climate change and increasing water demand	Policy and Planning
Support water use efficiency and demand-side management	Policy and Planning
Promote end-use energy efficiency and reductions in peak demand (e.g., efficient buildings, smart meters, time of use tariffs [a])	Policy and Planning
Improve coordination between competing water users given climate related water scarcity	Policy and Planning

[a] Time-Of-Use (TOU) pricing is a variable rate structure that charges for energy depending on the time of day and the season the energy is used, in order to incentivize shifting energy use to (cheaper) off-peak hours.

Sources: ADB, 2012; USAID, 2012.

Step 3: Integration of climate risk management into project implementation and power planning

Given that the climate will continue to change even as risk management strategies are implemented, flexible, adaptive approaches to implementation that are designed to incorporate new information will increase the likelihood of success (USAID, 2014). At the power sector planning level, integrating climate change into a long-term, comprehensive planning strategy is likely the best approach to direct and coordinate power sector investments that anticipate "surprises" and meet key objectives over time (e.g., climate resilience, low emission development, increased energy access, cost effective power supply). Instead of undertaking decisions on a project-by-project basis, a strategic power sector plan is proactive, comprehensive, structured, long-term, and enduring (DOE, 2013).

Recognizing this, the international community is increasingly investing in and testing new approaches that proactively integrate climate change considerations into existing power planning processes. *Climate Change in USAID Strategies: A Mandatory Reference for ADS Chapter 201*, broadly outlines operational requirements for climate risk screening and management in new strategies and plans, including power sector investments (USAID, 2015). For example, USAID, in partnership with ICF, is building on traditional integrated resource planning (IRP)—a least-cost planning paradigm introduced in the 1970s that puts generation and energy efficiency on an equal footing in North America by helping utilities plan for meeting forecasted energy demand. Known as Integrated Resource and Resiliency Planning (IRRP), this adapted planning process lends significant innovations to the IRP process by (1) adding a more focused analysis of resilience of the power sector to the impacts of climate change, particularly for hydropower resources affected by climate-related changes in the hydrologic cycles; (2) an extensive scenario-based analysis to assess more resilient resource options that take into consideration risks and uncertainties in the cost and performance of generation technologies, fuel prices and availability, and transmission links; (3) evaluation of how future renewable and energy efficiency resources can be better integrated into transmission and distribution planning; and (4) integration of distributed generation, demand-side management, and other demand-side strategies that reflect emerging technology and market changes (ICF International, 2014). The IRRP approach, depicted in Figure 5, is being piloted in Tanzania (see Text Box 10) and Ghana.

The IRRP approach is a key component of a climate resilient, low emission development strategy, as it can be employed to minimize both climate impacts and emissions. The IRRP approach includes application of a power sector planning model that allows decision makers to better understand how changes in generation capacity as a result of climate change might influence system reliability. For example, hydropower is one of the cheapest load balancing resources in a power system that enables variable renewable energy (VRE) resources at relatively low integration cost. A power sector planning model could outline the implications of a decline in hydropower capacity on the cost and feasibility of integrating different VRE portfolios. Applying these approaches for climate-resilient LEDS to power planning—by systematically developing power plans (and individual project investments) in light of climate uncertainty and associated risks—represents a change to traditional practice.

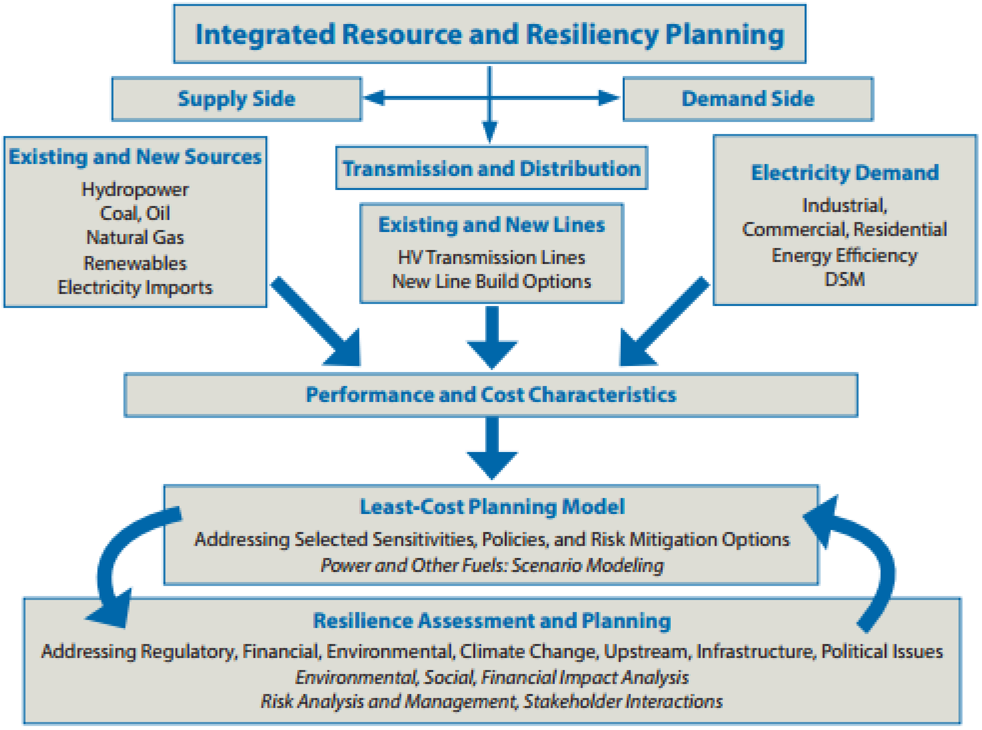

Figure 5. Overview of the IRRP Framework

Source: ICF International, 2014.

Text Box 10. USAID Tanzania Integrated Resources and Resiliency Program (IRRP)

Through a USAID-funded program, Tanzania is applying IRRP to identify the types of approaches and energy technologies that could be implemented to enhance power system resilience while meeting growing demands. Traditionally, power grid resilience has been narrowly defined as the ability of systems that are confronted by disasters to withstand damage and to recover rapidly. However, for the Tanzanian power system, it is important to assess the resilience of the power grid to not only withstand or recover from shocks and stressors, but the ability of the grid to transform and develop in the face of these threats. Therefore, the resilience assessment in the IRRP will consider a range of potential uncertainties, risks, or “stressors”, including fuel prices and availability, fuel and transmission grid infrastructure, changes in climate that affect generation resource and electricity demand, changes in economic and population growth, energy regulations, policy drivers, natural and man-made disasters, and technology cost and characteristics. The expected outcome is a power systems master plan that incorporates climate risks. The least-regret strategy (or strategies) will be determined by analyzing the robustness of metrics of specific generation resource plans under various scenarios (see Figure 5, above). Metrics from each strategy will be appropriately weighted and combined to determine a score for each strategy. These strategies will then be ranked to identify the most resilient resource plan across the different scenarios.

Step 4: Monitoring, evaluating, and adjusting adaptation needs

Enhancing climate resilience of power systems and projects should be an ongoing process; adaptation measures take time and resources to implement, the climate continues to change, and scientific understanding of future climate change impacts evolves. Adaptive management is a flexible, iterative process for revisiting and improving adaptation practices based on monitoring and evaluation (M&E). Adaptive management can occur at project- or system-level scales, and may include:

- Monitoring the consequences of weather-related events on a specific power asset or across the power sector;
- Monitoring changing demand for electricity given observed climate variability and change, changing demographics, and changing economic and social conditions;
- Evaluating the adequacy of implemented adaptation measures; and
- Monitoring local climate variations and observed changes, and keeping up-to-date on future climate projections.

Based on findings from M&E, project and power system managers can iteratively and strategically adjust operations (e.g., to flood risk management protocols) or undertake new adaptation measures accordingly, both at individual hydropower plants and/or across the power sector. While this type of M&E is still at a nascent stage (in part because implementation of adaptation measures to enhance hydropower resilience is relatively new), many hydropower sector practitioners are beginning to invest in this area by developing collaborative partnerships with research organizations and training staff to better understand climate diagnostics (IHA, 2015). In the United States, for example, San Diego Gas & Electric (a public utility that provides energy service to 3.6 million people) has invested in an extensive weather station network, a custom-built fire forecasting system, and in development of a wildfire threat index to help monitor adaptation to wildfire hazards in a changing climate (SDG&E, 2016).

CONCLUSIONS

As planners and investors look to new hydropower as a solution for enhancing energy security, expanding energy access, and reducing GHG emissions, they should address climate vulnerabilities by taking an integrated approach to power sector planning. While efforts to move towards climate resilient, low emission projects and planning are in a nascent stage, requirements on reducing both climate risks and emissions in project planning and development are becoming more common, and increasingly stringent. LEDS practitioners should address these risks in a number of ways. First, practitioners should assess risks and vulnerabilities at the project- and power system-planning levels; second, they should evaluate risk management options; third, they should integrate climate risk management into project implementation and power planning; and fourth, they should monitor, evaluate, and adjust operations and adaptation measures as knowledge about the climate and its impacts continues to evolve. This type of iterative approach can help power planners and investors better understand and manage climate risks to hydropower and power system performance, in order to more effectively ensure energy security and meet low emission objectives over time.

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ADDITIONAL RESOURCES

Title	Author/Publisher	Description
Adapting to Climate Change: A guide for the Energy and Utility Industry (2011)	Business for Social Responsibility	Summarizes how energy companies are reporting on climate change and highlights guidelines for climate change adaptation.
Addressing Climate Change Impacts on Infrastructure: Preparing for Change - Energy Systems	USAID	Explains climate change impacts on infrastructure and options for building long-term climate resilience and lowering carbon emissions.
Best Practices in Climate Change Risk Analysis for the Electric Power Sector (2006)	Ceres	Summarizes best practices in climate risk analysis for the electricity sector-level and recommends steps that investors, financial analysts, and companies can take to conduct and improve climate risk analysis.
Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation (2011)	World Bank	Provides an overview of how climate change might affect the energy sector, risks of impacts, and adaptation options at the power sector-level.
Climate Risk and Adaptation in the Electric Power Sector (2012)	Asian Development Bank (ADB)	Discusses climate change risk at the energy sector-level and identifies adaptation options for energy generation, distribution and end use.
Climate Vulnerability Assessment: An Annex to the USAID Climate-Resilient Development Framework	USAID	Provides an introduction to climate vulnerability assessments, including key definitions, a conceptual framework to increase the consistency of such assessments, sample questions at the country/sector/local levels, and an overview of methods and outputs. It is aimed at those who are designing and managing vulnerability assessments.
Evaluating Adaptation Options: Assessing Cost, Effectiveness, Co-Benefits, and Other Relevant Considerations	USAID	Describes a process that officials in developing countries and their partners can use to evaluate climate adaptation options and best determine which are most suitable to implement.
Guidelines for Climate Proofing Investment in the Energy Sector (2013)	ADB	Provides guidance to project teams as they integrate climate change adaptation and risk management into each step of a project.
Key Economic Sectors and Services, Chapter 10 IPCC AR5 (2014)	IPCC	Presents a discussion of climate change risks, impacts, and adaptation options at the energy sector-level.
Special Report on Renewable Energy Sources and Climate Change Mitigation (2011)	IPCC	This report focuses on renewables in the context of climate change at the power sector-level. It examines the technical potential worldwide and opportunities for growth and improvement.
Water, Energy and Climate Change: A contribution from the business community (2009)	World Business Council for Sustainable Development	Identifies risks at the power sector-level. Highlights the climate impacts and interdependencies between the energy and water sectors and includes case studies of business implications.

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