LAO POWER SECTOR VULNERABILITY ASSESSMENT AND RESILIENCE ACTION PLAN

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Acronyms

ADB	Asian Development Bank
C	Celsius
CAIDI	Customer Average Interruption Duration Index
DEPP	Department of Energy Policy and Planning, MEM
DOE	U.S. Department of Energy
EDL	Électricité du Laos
EDL-Gen	EDL-Generation Public Company
ENSO	El Niño-Southern Oscillation
GDP	gross domestic product
GOL	government of the Lao PDR
IEEE	Institute of Electrical and Electronics Engineers
IPP	independent power producer
IRRP	integrated resource and resilience planning (or plan)
JICA	Japan International Cooperation Agency
Lao PDR	Lao People's Democratic Republic
m	meters
MEM	Ministry of Energy and Mines of the Lao PDR
MOAF	Ministry of Agriculture and Forestry
MOF	Ministry of Finance
MoIC	Ministry of Industry and Commerce
MoNRE	Ministry of Natural Resources and Environment
MPI	Ministry of Planning and Investment
MOU	Memorandum of Understanding
NREL	DOE's National Renewable Energy Laboratory
NSEDP	National Social Economic Development Plan
PDP	Power Development Plan
PPA	power purchase agreement
PV	photovoltaic
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	supervisory control and data acquisition
USAID	United States Agency for International Development
USD	U.S. dollars
VA	vulnerability assessment

Executive Summary

The Lao People's Democratic Republic (Lao PDR) recognizes that access to reliable, secure, and affordable electricity is essential to powering economic growth and development and becoming a major regional power provider. The Lao power sector is at risk from an array of natural, technological, and human-caused hazards that may interrupt the provision of electricity or lead to a chronic undersupply of power. A resilient Lao power system could thrive under changing conditions and withstand, respond to, and recover rapidly from the impacts of hazards. To address risks, policymakers, planners, and system operators of the Lao PDR conducted a power-sector vulnerability assessment (VA) and resilience planning process to safeguard their systems. The Lao PDR now has the opportunity to develop comprehensive policies and implement actions that increase its power-sector resilience incrementally over time.

The United States Agency for International Development (USAID) partnered with the Lao PDR government to support this resilience planning process. A power sector resilience planning team (Resilience Team) composed of experts from Abt Associates, the USAID's implementing partner for the USAID Clean Power Asia program, and the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL), with the support of USAID, led a process consisting of two activities:

1. **VA**: A comprehensive assessment of the Lao PDR power sector's vulnerability to climate and nonclimate natural hazards and to human and technological hazards.[1,2]
2. **Resilience Action Plan**: A resilience planning activity to propose strategies that address the high-risk vulnerabilities for the Lao PDR power sector. [3]

These activities relied on extensive engagement of a VA Advisory Group composed of high-level power-sector decision-makers from the Ministry of Energy and Mines (MEM), Électricité du Laos (EDL), and EDL-Generation Public Company (EDL-Gen), as well as a VA Stakeholder Group and a Resilience Stakeholder Group consisting of representatives from various ministries and relevant organizations.

This report details the process used to conduct the VA and resilience action plan and the outcomes of those processes. The outcomes of this work are presented in this report to support planning in the Lao PDR and are the results of an extensive stakeholder engagement. No commitment for implementation from the Lao government is implied. The sections below discuss the process and key outcomes of the power-sector VA and Resilience Action Plan.

Power-Sector Vulnerability Assessment

The Resilience Team assessed the Lao PDR power sector's vulnerability to climate and nonclimate natural hazards and to human and technological hazards. This VA involved extensive stakeholder engagement with the VA Advisory Group and a broader, more diverse VA Stakeholder Group. Appendix B lists the VA Stakeholder Group participants.

In August 2018, the Resilience Team met with the VA Advisory Group to identify the most important hazards to the Lao power sector and to determine an appropriate scope for the VA. Then, in a three-day VA workshop, the Resilience Team and the VA Stakeholder Group collaborated to assess hazards to the sector, describe their impacts, and identify and assess priority vulnerabilities. Through this VA process, the VA Stakeholder Group and the Resilience Team determined that extreme precipitation, flooding, landslides, and extreme temperatures pose the greatest risks to power-sector activities and expose important vulnerabilities. Stakeholders determined that the highest-risk vulnerabilities associated with these hazards include:

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[1] Vulnerabilities are weaknesses in infrastructure, processes, and systems, or the degree of susceptibility to various hazards. Measures can be taken to reduce vulnerability or improve adaptive capacity to hazards.
[2] Hazards are anything that can damage, destroy, or disrupt the power sector. Hazards can be natural, technological, or human-caused. Hazards are not typically within the control of power system planners and operators. They can include wildfires, hurricanes, storm surges, cyberattacks, and more.
[3] Power sector resilience is the ability of the power sector to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions.

- Power system rules, regulations, and technical standards do not meet current and changing environmental conditions in Lao PDR;
- Dam construction does not follow design specifications;
- Installation does not follow design specifications; and
- Lack of compliance with codes in design.

Table ES-1 lists the 17 highest-risk vulnerabilities (out of 32 total vulnerabilities) the team identified in the VA workshop. The vulnerabilities identified in the VA then served as input to the resilience action planning process.

Table ES-1. List of Highest-Risk Vulnerabilities and Risk Scores

Risk Score*	Vulnerability
High	Power system rules, regulations, and technical standards do not meet current and changing environmental conditions.
	Dam construction does not follow design specifications.
	Installation does not follow design specifications.
	Lack of compliance with codes in design.
Medium-High	Corruption leads to code violations.[4]
	System operations are not flexible enough to respond to changes in demand and supply.
	Demand forecasting is not responsive to changing load conditions.
	Heavy power-sector reliance on hydro generation.
	Inadequate domestic generation capacity requires costly energy imports.
	Hydro generation reservoir is too small for drought conditions.
	Large industry (mining, cement, and economic zones) constitutes approximately 40% of demand and revenue.
	Poor coordination between dam operators.
	Transmission infrastructure located in wildfire prone areas.
	Transmission equipment located in zones prone to flooding.
	Transmission equipment located in zones prone to landslides.
	Transportation impacts occur with power-sector impacts.
	Unreliable or inadequate meteorological, hydrological, and climate change data for decision-making.

*For additional details on these Risk Score vulnerabilities for the Lao PDR, see (Vogel et al. 2018).

Power-Sector Resilience Action Plan

The Resilience Team led the development of a power-sector resilience action plan that provides strategies to address the high-risk vulnerabilities identified in the VA. This report reviews the high-risk vulnerabilities that stakeholders identified in the VA and discusses the actions to address these high-risk vulnerabilities in detail.

In November 2018, the Resilience Team engaged the VA Advisory Group in reviewing the high-risk vulnerabilities and determining criteria for the evaluation of resilience strategies. The VA Advisory Group selected a final set of four criteria that the Stakeholder Group would later use to evaluate resilience strategies. A Resilience Stakeholder Group workshop that included 26 stakeholders convened after the VA Advisory Group meeting to identify resilience strategies to address the high-risk vulnerabilities for the Lao PDR. The outputs of this workshop formed the basis of the power-sector resilience action plan for the country.

[4] The Stakeholder Group agreed that "Corruption leads to code violations" is a high-risk vulnerability; however, members decided that they did not have the authority to address this issue directly through resilience strategies. Therefore, this issue may need to be addressed separately by the Advisory Group or other high-level group.

This resilience action plan is not the final step to improving Lao power-sector resilience. Immediate, medium-term, and long-term steps that build on this action plan will enable decision-makers to address high-risk vulnerabilities and improve power-sector resilience for the long term. The resilience actions will be incorporated into ongoing Integrated Resource and Resilience Planning (IRRP), and Lao PDR intends to disseminate the outputs of this report to a wider group of stakeholders.

As power-sector decision-makers work to implement these actions, they may wish to consider the value of developing comprehensive resilience policies and strategies that would improve technical and organizational capacity for implementing and managing additional future actions. Policies and strategies can establish the range of appropriate and feasible options for addressing high-risk vulnerabilities; assign responsibilities to key power-sector actors; and detail government oversight and enforcement mechanisms that ensure implementation of these actions.

This resilience action plan categorizes activities to increase resilience into immediate, medium-term, and long-term steps. The resilience action plan identifies four key grouped power-sector resilience actions:

1. Develop and implement resilient power system policies
2. Improve power system flexibility
3. Improve coordination across hydropower dam operations
4. Facilitate better sedimentation management in hydropower watersheds.

Figure ES-1 shows a proposed timeline for implementing these grouped actions, organized according to the immediate actions (within the first 12 months) and the medium-term actions (through Years 2 and 3):

- Immediate steps are actions to be taken within the first 12 months of plan implementation that will form a solid foundation for medium- and longer-term resilience solutions.
- Medium-term steps focus on the actions in Years 2 and 3. Building resilience requires coordination between the power sector and the broader community. Many of the medium-term steps build on the foundation set in earlier steps and involve a more diverse stakeholder group in developing power-sector resilience through community outreach, education, and involvement.
- In the longer term, there is a need to build on the stakeholder engagement and capacity developed in earlier stages to ensure a resilient Lao PDR power sector in perpetuity. This includes analyzing and updating the resilience strategies on a regular basis to include new and changing technologies, climate, and economic realities, and to address changes in environmental and political conditions and changes in the power system.

New lessons and innovative power-sector resilience strategies will evolve and emerge as the Lao PDR and other countries build experience addressing high-risk power-sector vulnerabilities. It will be crucial for Lao PDR to continually evaluate its vulnerabilities and incorporate novel resilience strategies under a continual power-sector planning framework. Extensive engagement of diverse stakeholders will help identify, evaluate, and implement the most appropriate new strategies and lessons in the planning process. The ongoing IRRP activity is an opportunity for the Lao PDR to ensure resilience strategies from this and future resilience action plans are incorporated into the country's power-sector planning framework.

The remainder of this report details the process used to conduct the VA and resilience action plan and the outcomes of those processes:

- Section 1—introduces the VA and power-sector resilience action planning process
- Section 2—provides background information about the Lao PDR social and economic setting, power sector, and regional climate, climate impacts, and projected climate change
- Section 3—summarizes the methodology applied in this process
- Section 4—presents outcomes of the VA
- Section 5—presents the resilience action plan
- Section 6—proposes potential next steps in developing a resilient Lao power sector.

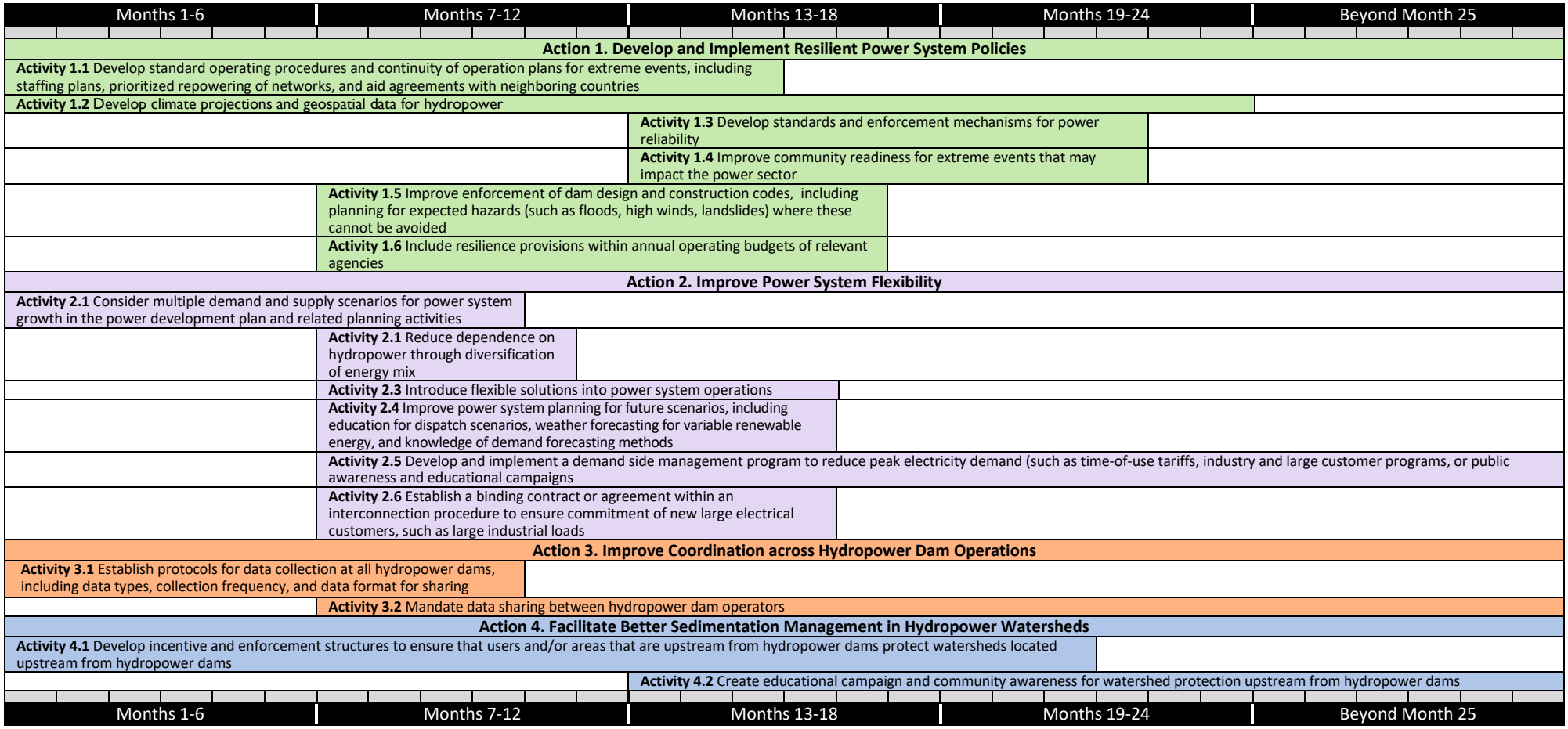

Figure ES-1. Proposed timeline for implementation of key resilience actions

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1 Introduction

The Lao People's Democratic Republic (Lao PDR) recognizes that access to reliable, secure, and affordable electricity is essential to powering economic growth and development and to becoming a major regional power provider. The Lao power sector is at risk from an array of natural, technological, and human-caused hazards that may interrupt the provision of electricity or lead to a chronic undersupply of power. To address these risks, policymakers, planners, and system operators of the Lao PDR conducted a power-sector vulnerability assessment (VA) and resilience planning process to safeguard their systems. The U.S. Agency for International Development (USAID) and the USAID Clean Power Asia program partnered with the Lao PDR government to support this process.

A power-sector resilience planning team (Resilience Team) composed of experts from Abt Associates, USAID's implementing partner for the USAID Clean Power Asia program, and the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL), with the support of USAID and USAID Clean Power Asia staff and consultants, led a process consisting of two activities:

1. **VA**: A comprehensive assessment of the Lao PDR power sector's vulnerability to climate and nonclimate natural hazards and to human and technological hazards. Box 1 provides the definitions that guided this VA.
2. **Resilience Action Plan**: A resilience planning activity to develop strategies that address the high-risk vulnerabilities for the Lao PDR power sector. Box 2 shows the definition of resilience that guided this work.

These activities relied on extensive engagement of a VA Advisory Group composed of high-level power-sector decision-makers (Appendix A), as well as a VA Stakeholder Group (Appendix B) and a Resilience Stakeholder Group (Appendix F).

Box 1. Power-Sector Vulnerabilities

Vulnerabilities are weaknesses within infrastructure, processes, and systems, or the degree of susceptibility to various hazards. Different measures can be taken to reduce vulnerability or improve adaptive capacity to hazards to the power sector.

Hazards are anything that can damage, destroy, or disrupt the power sector. Hazards can be natural, technological, or human-caused. Hazards are not typically within the control of power system planners and operators and can include wildfires, hurricanes, storm surges, cyberattacks, and more.

For additional descriptions of power-sector vulnerabilities, see Stout et al. (2019).

Box 2. Power-Sector Resilience

Power-sector resilience is the ability of the power sector to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions.

For additional descriptions of power-sector resilience, see Lee and Stout (2018; 2019).

The remainder of this report details the process used to conduct the VA and resilience action plan and the outcomes of those processes:

- Section 2—provides background information about the Lao PDR social and economic setting, power sector, and regional climate, climate impacts, and projected climate change.
- Section 3—summarizes the methodology applied in this process.
- Section 4—presents outcomes of the VA.
- Section 5—presents the resilience action plan.
- Section 6—proposes potential next steps in developing a resilient Lao power sector.

2 Background

This section provides context on the Lao social and economic setting, power sector, and climate.

2.1 Social and Economic Setting

The Lao PDR has a population of approximately 6.5 million people. While much of this population is engaged in local economic activity, there are significant neighboring-market opportunities in the Greater Mekong subregion. Lao PDR has seen growing diversification in wholesale and retail services, tourism, and construction.

The Lao PDR achieved consistent economic growth over the last decade. The gross domestic product (GDP) rose from $626 U.S. dollars (USD) per capita in 2006 to $2,027 USD in 2016. From 2011–2016, GDP rose 7.5%. Much of this growth was driven by the natural-resource sector, including mining, timber extraction, and hydropower. Mining represented 34% of total exports in 2016, and the export of hydropower electricity represented 21% (ADB 2017).

Economic growth slowed slightly in 2018 to 6.3% from 6.9% in 2017, and the Asian Development Bank (ADB) forecasted a 6.2% growth rate for 2019 and 2020 (ADB 2019)

2.2 Power-Sector Background

The Ministry of Energy and Mines (MEM) is the lead government agency responsible for Lao PDR's energy sector, with the Department of Energy, Policy and Planning (DEPP), responsible for setting the national policies and regulations (ADB 2015). Électricité du Laos (EDL), a state corporation, owns and operates the country's electricity generation, transmission, and distribution assets.

The Lao PDR prioritized hydropower development as a key element of its National Social Economic Development Plan (NSEDP) (Lao Ministry of Planning and Investment 2016). Prioritization of hydropower was achieved through planning and efforts to attract international investment. In 1975, only five cities of the Lao PDR were electrified, and approximately 10% of the population had access to the electricity generated at three hydroelectric plants with a capacity of 32 MW (annual generation of 240 GWh) (Laspho 2016).

The Lao power sector has developed significantly since 1975. Domestic electricity consumption in the country increased from less than 1,000 GWh in the early 1990s to 4,239 GWh in 2015 (with a peak demand of 760 MW). Vientiane, the capital and surrounding areas, represent approximately 37% of the total national consumption. Demand in other regions of the country has increased as electricity access rates rise— more than 96% of households now have access to electricity (MEM 2015b; 2018; Phongsavath 2019). Total electricity generation (for export and domestic consumption) increased from 834 GWh/year to more than 16,500 GWh/year in the period from 1991 to 2015. This rise in total generation is a result of efforts to meet domestic demand and export electricity for regional demand (MEM 2015b).

In early 2005, the NSEDP identified key targets to further develop the country's power sector:

1. Provide a source of foreign exchange to fund economic and social development and alleviate poverty
2. Meet the commitments for cross-border power trade under intergovernmental memoranda of understanding and agreements with Thailand, Vietnam, and others
3. Extend electrification to promote better socioeconomic development and reach the government target of 70% and 90% by 2010 and 2020, respectively
4. Integrate the power sector and maintain its economic development as a whole with international communities through its power exchange programs and foreign direct investment (Laspho 2016).

With increased economic development and access to electricity, further growth in domestic electricity consumption is projected. By 2030, domestic consumption is forecast to reach a level between 21,844 GWh and 33,024 GWh for low- and high-growth scenarios, respectively, which follow recent GDP

growth forecasts.[5] The low- and high-growth scenarios correspond to peak demand levels between 4,312 MW/year and 6,358 MW/year, respectively (MEM 2015a).

Total domestic generation capacity was approximately 6,391 MW in 2017. The majority of this capacity was hydropower. There is one coal-fired power plant (1,878 MW), and a smaller share of capacity from biomass gasification with sugarcane and solar PV systems. In 2017, EDL owned approximately 12% of total generation assets (738.5 MW), and independent power producers (IPPs) owned the remaining capacity, or 88% of installed capacity (5,652.45 MW) To meet domestic demand and support power export plans, the Lao PDR intends to reach 14,000 MW of total installed domestic generation by 2020 (MEM 2015b; Laotian Times 2017). A majority of this capacity will come from hydropower. Fifty-three hydropower plants were under construction or in the planning stage in 2017, which will bring the total number of hydropower plants to more than 90 (Laotian Times 2017). The country plans to establish and implement a new five-year Power Development Plan (PDP) and, as a result, the current hydropower-dominated generation mix is likely to become more diversified with both renewable and nonrenewable resources to complement existing hydropower in the medium to long term.

The Institute of Renewable Energy Promotion, within MEM, is the primary agency responsible for developing and promoting renewable energy in the Lao PDR. Total installed capacity from renewable power sources (excluding large hydropower) in Lao PDR for 2015 was 140 MW, comprising microhydro (80 MW), solar photovoltaic (PV) (22 MW), and wind (6 MW). Plans for future renewable power production would bring the total installed capacity to 728 MW by 2025, which includes microhydro (400 MW), solar PV (33 MW), and wind (73 MW) (ADB 2015).

Power-sector planning, which until recently consisted of a national power-development planning process, is now moving toward an integrated resource and resilience planning (IRRP) approach. The DEPP of MEM is currently undertaking the first iteration of this IRRP, which includes developing multiple demand and supply scenarios for the power sector and the identification of a least-regrets pathway for power-sector development. The first IRRP may be completed in 2019 with the support of the USAID Clean Power Asia Program.

Transmission lines are a critical element of any power sector because these lines allow for domestic transmission and distribution as well as international electricity import and export. Transmission will provide a crucial link for Lao PDR as the country moves toward an integrated power grid. In 2017, the country had approximately 53,000 km of high-voltage power lines (150 kV and above) and 53 high-voltage electrical substations (Laotian Times 2017).These transmission lines create the potential for growing regional interconnectivity as the country explores opportunities for further power import and export with neighboring countries (ADB 2015). Currently, Lao PDR is interconnected with neighboring Cambodia, China, Thailand, and Vietnam (EDL 2015), allowing for electricity imports and exports. Thailand remains the source of the dominant share of electricity imports (1,748 GWh in 2015) and exports (10,842 GWh in 2015). Imported electricity primarily supplies demand around the capital, Vientiane; however, a share of imports also supplies the southern provinces of Khammuane and Savannakhet. Exported electricity is primarily provided by IPPs with direct transmission interconnections to Thailand or other neighbors (MEM 2015b).

Currently, most bilateral cross-border connections exist under power purchase agreements (PPAs) on which the financing for hydropower investment usually rests. Under such arrangements, the hydropower plants are operated to meet the demands of the power purchaser. This creates a situation where dams and power grids have limited flexibility in their operations—ultimately affecting the efficiency of the entire power system. With changes in the regional climate, participating in a regional power market may become increasingly important as an option to improve energy security and power-sector resilience if hydropower resource shortages occur. The Lao PDR is involved in Greater Mekong Subregion planning to improve regional interconnectedness and the competitive market (Wijayatunga 2016).

[5] The low, medium, and high scenarios are based on different GDP growth rates of 6.5%, 7%, and 7.5%, respectively, and additional assumptions about demand growth for different regions in the country (MEM 2015a).

2.3 Regional Climate, Climate Impacts, and Projected Climate Change

The Lao PDR has a tropical monsoon climate with:

- A northeastern monsoon driving a cool dry period from November to February
- A transitional hot dry season in March and April
- A southwestern monsoon driving the rainy season from May to October (Beilfuss and Triet 2014).

Lao PDR is affected by tropical typhoons and depressions that can bring extensive precipitation. Typhoons can lead to flash flooding in mountainous areas and river overflow in low-lying areas. Past typhoons have led to extensive infrastructure and property damage as well as loss of life. The areas most affected by typhoons are sometimes inaccessible for weeks after the event (GFDRR 2014).

The country's weather can also be affected by other global climate dynamics, such as the El Niño-Southern Oscillation (ENSO). During El Niño years, Lao PDR experiences below-average rainfall while La Niña years are associated with above-average rainfall (ICEM 2013).

Lao PDR has three climate zones:

- A northern mountainous area with elevations above 1,000m has average temperatures less than 25ºC and annual precipitation ranges generally from 1,500 millimeters (mm) to 2,000 mm
- A central zone that has higher temperatures and usually more precipitation, ranging from 2,500 mm to 3,500 mm annually
- The southern lowlands and flood plains have annual precipitation that normally range from 1,500 mm to 2,000 mm (World Bank 2011).

Climate models have been used to project potential climate futures for Lao PDR. Although climate models vary considerably, there is a clear trend and consensus on the climate-change impacts for Lao PDR: "Expected climate change impacts include higher temperatures, longer dry seasons, severe and frequent rainfall, droughts, and floods" (ADB 2017). Each increasing hazard has potential impacts on the power sector in Lao PDR. Because hydropower is based on the environmental flows of water, the hydropower sector in Lao PDR is vulnerable to existing extremes and variability in climate, and climate change modeling predicts these extremes and variability may become more intense in the future under a range of greenhouse gas emission scenarios and pathways.

3 Methodology

This section describes the methodology applied in this work and provides guidance for relevant stakeholders who plan to perform a power-sector VA and develop a resilience action plan. This approach involves an eight-step process for conducting vulnerability assessments and resilience action planning in the power sector:

1. Collect information about hazards and hazard impacts
2. Assess vulnerabilities
3. Conduct planning to increase resilience in the power sector
4. Develop resilience actions
5. Implement resilience actions
6. Monitor and evaluate the effectiveness of resilience actions
7. Report on the impacts of hazards and the effectiveness of resilience actions
8. Adjust plans and measures for increasing resilience based on the results of monitoring and evaluation.

This guidance can be used by local and central executive bodies that collect climate and other hazard data, conduct VAs, engage in resilience planning, develop resilience actions, implement resilience actions, monitor and evaluate effectiveness of resilience actions, report on the impacts of hazards and effectiveness of resilience actions, and review and update plans and resilience actions. This methodological guidance can also be helpful for relevant committees and other governmental organizations as well as nongovernmental organizations that assist in power-sector resilience planning processes. In addition, this methodological guidance can be used by a wider audience, including experts, consultants, civil servants, teachers, students, trainers, and the general public. The following sections describe each step of this process.

3.1 Methodological Guidance on Collecting Information About Hazards and Hazard Impacts

Collecting information about hazards and hazard impacts ensures local and central executive bodies can conduct VAs and consider the impacts of hazards in their power-sector plans and programs.

The goal of this section is to introduce the types of hazard and hazard-impact information needed to conduct VA and resilience planning.

Hazard information includes data on:

- Current and past climate trends and events
- Forecasts of future changes in the climate
- Current and past impacts of climate
- Projected impacts of climate and weather events
- Current and past technological hazard events
- Current and past bad-actor or other human-caused events
- Impacts of technological and human-caused hazards.

Local and central executive bodies obtain climate and climate-impact information from governmental and nongovernmental bodies that gather or generate the information themselves. Technological and human-caused hazard information is often available from local and central executive bodies that track security and emergency events. Because information about one field of activity might also be useful for another (such as information on the water necessary for an assessment of the power sector), an interministerial collaboration and exchange of information would be useful. Ministries are therefore encouraged to cooperate and share information about hazards and hazard impacts as well as their ability to collect and analyze this type of information.

3.2 Types of Hazard and Hazard-Impact Information

Information on hazards and hazard impacts can include, but is not limited to:

- Current and past climate trends and events
- Forecasts of future changes in climate
- Current and past impacts of climate
- Projected impacts of climate change
- Current and past technological hazard events
- Current and past bad-actor or other human-caused events
- Impacts of technological and human-caused hazards.

See Table 1 for examples of the types of information in each of these categories.

Table 1. Types of Climate, Technological, and Human-Caused Hazard Information

	Historical Observations	Future Projections
Climate	• Daily temperature measurements • Hourly/daily/seasonal rainfall amounts • Hourly/daily/seasonal snowfall amounts • Incidence of windstorms • Streamflow • Extreme cold event frequency and intensity • Extreme heat event frequency and intensity • Drought frequency and intensity • Mudflow frequency and severity • Glacial lake outburst flood occurrence. *Information is typically quantitative.*	• Global climate model projections of changes in temperature, rainfall, and snowfall • Projections from paleoclimatic records, regional climate models, or other sources • Projections based on a physical understanding of global climate and/or atmospheric dynamics. *Information is typically quantitative but has significant associated uncertainty because of climate model assumptions and parameters; information also often includes nonquantitative physical understanding of climate dynamics, such as the Clausius-Clapeyron relationship.*
Technological Hazards	• Construction methods for power-sector assets • Material quality and type • Supervisory control and data acquisition (SCADA) • Other data monitoring processes.	• Changes in construction methods • Changes in availability and type of materials • Changes in software, monitoring, or acquisition of data.
Human-Caused Hazards	• Socioeconomic context • Political context • Accident statistics • Informal connection statistics.	• Changes in socioeconomic context • Evolving political context • Projected accident rates • Projected informal connection changes.
Impacts of Climate Hazards	• Effect of wind loads on power-sector assets • Infrastructure damage from a flooding event • Loss of lives from a dam-collapse event • Impacts to the economy from power outages because of extreme weather.	• Assessments by experts or local power-sector staff of effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure because of the climate and other hazard changes. • Examples include effects of climate-enhanced droughts, water availability for hydropower generation, effects of heat waves on power-system asset stress, and effects of high winds on transmission availability. *Information may be anecdotal or subjective judgments by experts.*

3.3 Required Information for a VA

Information needs for assessing vulnerability will vary by system within the power sector (or other sectors) and geographic region, based on other factors and conditions. In general, a qualitative understanding of how projected changes in climate and in hazards will affect the power sector will be necessary for assessing vulnerability. This information about the impacts of hazards and projected impacts of climate change is sometimes available from scientific and government agencies, but it is also crucial to develop a system-specific understanding of impacts.

VAs require six key types of information:

1. Scientific assessment of the existing information on the current and past impacts of climate
2. Scientific assessment of forecasts of future changes in climate
3. Projected impacts of climate change
4. Scientific assessment of other natural-hazard (such as earthquakes) information on the current and past impacts of natural-hazard events
5. Assessment of other hazard data (such as the number of accidents causing outages) and the associated impacts
6. Assessment of the changing conditions under which human-caused hazards exist within the power sector.

A participatory exercise with local power-sector experts can identify and describe the impacts of changing conditions. Section 4 describes this participatory exercise in the Lao PDR.

3.4 Methodological Guidance for Power-Sector VAs

This section provides background on the recommended processes and practices for conducting a VA to support resilience action planning.

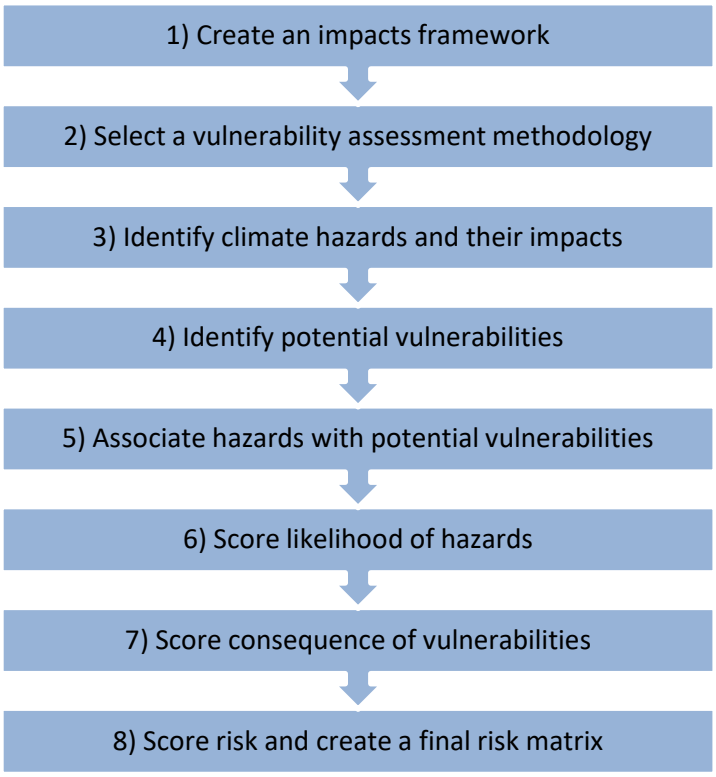

Figure 1. Vulnerability Assessment process

The goal of a VA is to identify the highest-risk vulnerabilities in the power sector. This prioritized list of vulnerabilities provides the foundation for subsequent tasks in the resilience planning process. A VA describes where and how hazards may affect the power sector and, subsequently, lives, livelihoods, health, ecosystems, economies, societies, cultures, and services.

VAs should be conducted by the central executive bodies, utilities, and grid operators that manage the power sector and its related components.

A VA consists of an eight-step process (Figure 1). Each step is described in detail below. In summary, the purpose of a VA is to gather information about hazards and system vulnerabilities and rank them to determine which vulnerabilities pose the greatest risks. These highest-risk vulnerabilities are typically the first issues addressed in a resilience action plan.

3.4.1 Step 1: Create an Impacts Framework

An impacts framework provides a structure for identifying potential vulnerabilities in the power sector. As a general guide, it is important to identify and include the key goals or objectives of the power sector and the key components or resources of the power sector. Resilience experts can develop a draft impacts framework, but knowledge and buy-in from high-level managers in the power sector is critical. The impacts framework serves two primary purposes: First, to facilitate a conversation with high-level power-sector managers about the scope of the VA, and second, to guide discussions about potential vulnerabilities with the full range of stakeholders involved in the VA. Section 4 presents the impacts framework developed with Lao PDR stakeholders.

There is no such thing as a right or wrong impacts framework. The impacts framework is simply meant to be a useful way to categorize vulnerabilities. The following recommendations may increase the usefulness of an impacts framework:

- **Build the impacts framework using input from key stakeholders**. Early commitment from managers makes it more likely that organizations will adopt the resilience actions that emerge from the VA and resilience action planning process.
- **Rely as much as possible on existing, verified, and accepted materials**. This will save time, facilitate ownership and support, and ensure organizations can endorse, implement, and integrate solutions. This may involve relying on existing strategic plans, programs of territorial development, various state and governmental programs, or previously conducted analyses of the power sector.
- **Plan sufficient time to build the framework**. Expect the process of developing the framework to take time and involve iterations and discussion. Typically, an impacts framework will take shape over multiple discussions among resilience experts and high-level managers.
- **Revise the impacts framework, if necessary**. As the VA progresses, it may become apparent that some of the impacts framework categories are not useful or appropriate. Remain open to changing the impacts framework based on this experience instead of sticking with a difficult impacts framework category.
- **Tailor the power-sector impacts framework to reflect its unique internal processes and goals**. Every organization is different, and a generic impacts framework should not be applied across all organizations.

3.4.2 Step 2: Develop a VA Methodology

After creating the impacts framework, it is important to develop the VA methodology. This includes identifying the stakeholders who will participate in the subsequent steps of the VA. In some cases, only a small group of experts will participate in a VA; however, in most cases, a VA benefits from broad engagement of stakeholders with detailed knowledge of the power sector. It is also important to note that VAs should be conducted by the authorized bodies that manage the power sector. But a VA could be conducted exclusively within a single department or ministry and may require input from stakeholders from other departments or ministries, nongovernmental organizations, private industry, or academic institutions.

The reasons for engaging stakeholders are to:

1. Identify hazards by discussing how participants experience hazards in their work and how these hazards affect, or could affect, the ability of the power sector to meet objectives
2. Draw on stakeholders' expertise to identify potential vulnerabilities to hazards that can affect key power-sector objectives and components
3. Associate hazards with potential vulnerabilities
4. Describe and score the likelihood that these potential vulnerabilities will be realized and the severity of these potential vulnerabilities.

3.4.3 Step 3: Identify Hazards and Their Impacts

Identifying hazards for the power sector is a relatively simple but important task. Stakeholders should start by identifying hazards that have affected the power sector in the past. A second aspect of identifying changing hazard conditions is to explicitly consider climate change. While many climate hazards are the result of extreme weather, climate change may add new climate hazards or significantly alter the severity of current climate hazards. To successfully conduct a VA, stakeholders should be provided with basic information about climate change. A common, broad understanding of climate change science is essential to identifying the different ways certain aspects of climate change (e.g., higher temperatures, increased fire risk) might affect the power sector.

Through a three-day workshop and assessment process, the VA Stakeholder Group and the Resilience Team determined that extreme precipitation, flooding, landslides, and extreme temperatures pose the greatest risks to power-sector activities in the Lao PDR and expose important vulnerabilities. Section 4 shows the full list of identified power-sector hazards in the Lao PDR.

3.4.4 Step 4: Identify Potential Vulnerabilities

By discussing hazards and hazard impacts, stakeholders can define vulnerabilities associated with each hazard and its potential impacts. This involves considering the climate hazards identified in Step 3 and their interactions with the key objectives and resources identified in the impacts framework developed in Step 1. Each vulnerability statement should identify a problem that could lead to one or more specific solutions. For example, over the course of a three-day VA workshop, the Resilience Team and the VA Stakeholder Group collaborated to assess high-risk vulnerabilities to the Lao PDR power sector. Section 4 presents the full list of vulnerability statements the VA Stakeholder Group developed for the Lao PDR. It is important to note that it is possible to define more than one vulnerability based on the potential impacts associated with each hazard.

3.4.5 Step 5: Associate Hazards with Potential Vulnerabilities

Next, it is important to identify which hazards can affect or expose each potential vulnerability. A simple yes or no input format (Table 2) can be sufficient for completing this exercise. The purpose of this exercise is to help stakeholders understand which hazards they need to assess and associate with the potential vulnerabilities.

Table 2. Subset of Potential Vulnerabilities Associated with a Subset of Hazards from a VA of the Lao PDR Power Sector

Hazards	Vulnerabilities					
	Power system rules, regulations, and technical standards do not meet current and changing environmental conditions	Corruption leads to code violations	Dam construction does not follow design specifications	Installation does not follow design specifications	Lack of compliance with codes in design	System operations are not flexible enough to respond to changes in demand and supply
Extreme Precipitation	Yes	No	Yes	Yes	Yes	Yes
Extreme Temperatures	Yes	No	No	No	No	Yes
Flooding	Yes	No	Yes	Yes	Yes	Yes
Landslides	Yes	No	Yes	Yes	Yes	No
Wildlife Interactions	No	No	No	No	No	No
Wind	Yes	No	No	No	No	Yes
Human Actions: Bad Actors	No	Yes	Yes	Yes	No	No
Human Actions: Accidents	No	No	Yes	Yes	No	No
Technological Design	Yes	No	Yes	Yes	Yes	Yes

3.4.6 Step 6: Score Likelihood of Hazards

In this step, stakeholder group members have to determine how likely it is that the hazard will occur. There are multiple ways to score the likelihood of hazard occurrence. The Lao PDR VA methodology used the scores and thresholds shown in Table 3. Section 4 presents the full list of hazards and their likelihood scores for the Lao PDR Power Sector VA.

Table 3. Hazard Likelihood Scores and Threshold Descriptions

Hazard Likelihood Scores		Threshold Descriptions
Qualitative	Quantitative	
High	9	Almost certain to occur. Historic and frequent occurrences.
Medium-High	7	More likely to occur than not.
Medium	5	May occur.
Low-Medium	3	Slightly elevated level of occurrence. Possible, but more likely not to occur.
Low	1	Very low probability of occurrence. An event has the potential to occur but is still very rare.

Table adapted from (Stout et al. 2019)

3.4.7 Step 7: Score Severity of Vulnerabilities

A severity score is then assigned to each potential vulnerability. Using the key resources in the impacts framework from Step 1, the stakeholder group identifies categories of severity. The categories describe the potential impact, effect, or other indicators of severity. For example, this might include the number of people impacted, the impact to the local or national economy, or the effect on operating systems. Table 4 presents a theoretical list of criteria for assessing the severity of a potential vulnerability.

Table 4. Qualitative Vulnerability Severity Scores and Threshold Descriptions

Vulnerability Severity Score		Threshold Descriptions
Qualitative	Quantitative	
High	9	Highest consequence. Entire power system would be impacted. Extreme financial impacts would exist.
Medium-High	7	Significant consequences to the organization. Majority of population served would be impacted. Staff tasks would be switched to emergency and critical operations. Significant financial impacts would exist.
Medium	5	Medium consequence. The organization would be somewhat affected. Specific systems or functions would be substantially interrupted, but not all. Financial impacts would be expected to change budgeting plans or require reallocation of funds.
Low-Medium	3	Slightly elevated consequence to the organization. The power sector may need to temporarily transition operations to backup systems to resolve failure. Limited financial impacts may become apparent.
Low	1	Lowest consequence to the organization. The power sector would experience little to no affect, or an in-place backup system would resolve the failure.

Table adapted from (Stout et al. 2019).

3.4.8 Step 8: Score Risk and Create a Final Risk Matrix

Risk describes the interaction between the likelihood that a hazard will occur and the severity of the consequence if a potential vulnerability is realized. In other words, risk equals likelihood multiplied by severity (Equation 1). This approach reveals that vulnerabilities with a relatively high severity that may be triggered by high-likelihood hazards could occur frequently and could have dire consequences. Addressing these vulnerabilities will likely be a priority in the resilience planning process. This approach also reveals that vulnerabilities with a relatively low severity that may be triggered by low-likelihood hazards are unlikely to be priorities in the resilience planning process.

Severity Score	**x**	**Hazard Likelihood Score**	**=**	**Risk Score**	Risk Score = High, Medium-to High, Medium, Low-to-Medium, or Low

Equation 1.

It is interesting to note the areas where risk scoring can lead to important questions about an organization's risk tolerance. For example, a high-consequence vulnerability triggered by a low-likelihood hazard could lead to extremely unlikely yet catastrophic consequences (such as a glacial lake outburst flooding a town or village). But the risk score for this might only be medium. Similarly, a low-consequence vulnerability triggered by a high-likelihood hazard may be easy to ignore but could lead to significant costs over time (e.g., nuisance flooding that has small effects on the economy but occurs regularly). The risk score for this might also be medium. Despite their common risk score, it may be very important to understand the difference between these two types of risks.

The final step in scoring each potential vulnerability is to assess it for risk. This is a technical exercise and does not typically require stakeholder involvement. Nevertheless, it is recommended that stakeholders review how the risks rank in relation to one another and provide feedback on whether the rankings make sense. The risk score is a combination of the climate hazard likelihood score (Step 6) and the severity score (Step 7), illustrated in Equation 1. The risk score matrix (Table 5) shows the relationship between the severity and likelihood and resulting risk scores.

Stakeholders can identify the highest-risk vulnerabilities by defining a threshold that determines which vulnerabilities will be considered in subsequent resilience planning steps. There are multiple ways to rank vulnerabilities, but a simple numerical assignment of scores (where 1 = low, 3 = low-to-medium, 5 = medium, 7 = medium-to-high, and 9 = high) can often facilitate risk scoring by associating qualitative likelihood and severity scores with a numerical risk score.

Table 5. Risk Score Matrix

Vulnerability Severity Score	***Low***	***Low-to-medium***	***Medium***	***Medium-to-high***	***High***
High	Medium	Medium-to-high	Medium-to-high	High	High
Medium-to-high	Medium	Medium	Medium-to-high	Medium-to-high	High
Medium	Low-to-medium	Medium	Medium	Medium-to-high	Medium-to-high
Low-to-medium	Low-to-medium	Low-to-medium	Medium	Medium	Medium-to-high
Low	Low	Low-to-medium	Low-to-medium	Medium	Medium

Hazard Likelihood Score

Note: Red indicates high risk, dark orange indicates medium-to-high risk, gray indicates medium risk, gold indicates low-to-medium risk, and yellow indicates low risk.

3.5 Develop Outputs for the VA

Next, the VA process should develop outputs necessary for the next steps of the resilience planning. Specifically, the Stakeholder Group will need to determine which vulnerabilities will be considered in resilience planning and the development of resilience actions. Sometimes it is appropriate to develop a comprehensive public report on this process and other times an internal white paper or technical report is adequate. In many cases, a well-organized spreadsheet containing the outputs from each step of the VA is sufficient. This information will be necessary for carrying out subsequent steps of the resilience planning process.

3.6 Monitor and Evaluate Potential Vulnerabilities

Assessing vulnerabilities should be an ongoing and iterative process. Vulnerabilities may change as conditions change. Changes in climate and nonclimate hazards, and changes in the physical, social, economic, or natural environment affect the results of a VA and the priorities that emerge. Therefore, monitoring and evaluating vulnerabilities, and responding to changes through an adaptive management protocol, ensures that a VA remains relevant over time. This may include periodically revisiting the entire VA process, revisiting the highest-priority vulnerabilities, addressing a second tier of vulnerabilities as the highest-risk vulnerabilities are addressed, or identifying new or emerging vulnerabilities.

3.7 Methodological Guidance for Resilience Action Planning

It is often unnecessary and infeasible to address all vulnerabilities identified in the VA process. Therefore, the resilience action planning process typically addresses only the highest-priority vulnerabilities. Section 5 presents a list of the prioritized vulnerabilities addressed in the Lao PDR Resilience Action Plan.

Like the VA process, the resilience action planning process is typically stakeholder-driven with input from subject matter experts, as necessary. In the Lao PDR resilience planning process, stakeholder engagement began with a meeting of the VA Advisory Group in November 2018. The objectives of this meeting were to review the selected high- and medium-high risk vulnerabilities and to determine the criteria for evaluating resilience actions.

The following subsections describe the four main tasks of the resilience action planning process:

1. Identify Resilience Solutions
2. Score and Prioritize Resilience Solutions
3. Group Resilience Solutions into Resilience Actions for Implementation
4. Finalize Resilience Action Plan.

3.7.1 Identify Resilience Solutions

The first step in developing a resilience action plan is to develop a broad list of potential resilience solutions. These solutions are based on stakeholder knowledge of the power sector and its vulnerabilities; stakeholder understanding of technical, social, and political contexts; input from resilience subject matter experts; and case studies from resilience activities in similar contexts.

In the Lao PDR power sector, a stakeholder workshop convened multiple members of the Lao PDR power sector, as well as resilience subject matter experts, to develop potential solutions to address one or more of the prioritized high-risk vulnerabilities. In total, the stakeholder group developed 42 potential resilience strategies and mapped them to the specific vulnerabilities that they could address. Section 5 describes these solutions in detail.

3.7.2 Score and Prioritize Resilience Solutions

The next step in the resilience action planning process is to score and prioritize resilience solutions. This consists of two tasks:

1. Evaluating the resilience solutions based on selected criteria
2. Ranking the resilience solutions based on their evaluation scores.

Manager-level stakeholders who understand the political, financial, and other contexts that affect implementation of resilience actions should select criteria for evaluating potential resilience actions. Stakeholders then rank resilience solutions as good, fair, or poor to determine the degree to which they meet the selected criteria. Table 6 shows an example of this weighting for the Lao PDR.

In the Lao PDR, evaluation criteria included cost and finance availability, feasibility (both technical and political), effectiveness of the strategy, and implementation timing. Section 5 defines these criteria in more detail and presents the results of the Resilience Stakeholder Group's evaluations of resilience solutions.

Table 6. Resilience Strategy Evaluation Criteria and Defined-Level Scores for the Lao PDR

Criteria	Defined-Level Scores		
	Good	**Fair**	**Poor**
Cost or finance availability	• Less than $500,000 in capital costs • Low operations and maintenance costs • Financing is readily available.	• Between USD $500,000 and $1,000,000 in capital costs • Significant operations and maintenance costs • Some financing may be available.	• Greater than USD $1,000,000 in capital costs • High operations and maintenance costs • Little or no financing is available.
Implementation timing	0–2 years to complete implementation	From 2–5 years to complete implementation	More than 5 years to complete implementation
Feasibility (technical and political)	• Local staff have necessary expertise • Local design and manufacturing services available • Strategy consistent with the Lao PDR power development plan and five-year national socio-economic development plan	• Southeast Asian, Indonesian, Indian, or Chinese expertise may be necessary • Regional design and manufacturing services needed • There is some political support even if not in the power development plan or five-year national socio-economic development plan.	• Western or European expertise needed • World-class design and manufacturing services required • Strategy inconsistent with power development plan or five-year national socio-economic development plan.
Effectiveness	• Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for many vulnerabilities • Addresses a high-priority vulnerability.	• Reduces significant risk for a vulnerability (approximately 50% reduction in risk) • Reduces some risk for multiple vulnerabilities • Addresses a medium-priority vulnerability.	• Reduces only a little risk for a vulnerability (less than 30% reduction in risk) • Reduces risk for only one vulnerability • Addresses a low-priority vulnerability.

The Resilience Stakeholder Group then scored each proposed resilience strategy using the established evaluation criteria. Because the Resilience Stakeholder Group determined that effectiveness was the most important evaluation criterion, participants first assessed the effectiveness of each resilience strategy in addressing high-risk vulnerabilities. The goal of this exercise was to determine whether, and the extent to which, each strategy was effective in reducing one or more high-risk vulnerabilities. After assessing the effectiveness of each strategy, the Resilience Stakeholder Group scored the strategy using the remaining criteria. Section 5 presents the results of the scoring process.

The Resilience Team used the final scores to evaluate the implementation priority of each strategy, with the following weighting of criteria: 1) Effectiveness, 2) Feasibility (both technical and political), 3) Cost or finance availability, and 4) Implementation timing. The team then assigned each strategy one of three descriptive priority levels:

Implement—Applies to least-regret strategies that decision-makers should consider pursuing at this time. These strategies have favorable scores on the evaluation criteria and could provide benefits under current conditions as well as potential future conditions. A least-regret strategy will reduce risks to existing threats while increasing resilience to future threats, ensuring the investment is worthwhile regardless of which future scenario unfolds. A least-regret strategy may also involve some cost that is not fully justified under current conditions, but the costs are generally low and likely a less-significant factor in the decision.

Evaluate—Applies to strategies that need further information (such as additional information on effectiveness, cost, or other criteria) before they are ready for implementation or for removal from consideration.

Remove from consideration—Applies to strategies that are untenable for one or more reasons (such as not sufficiently effective, too expensive, or technically or politically infeasible) given the current criteria under current and potential future conditions. Although these strategies may not be attractive at this time, they may be evaluated differently in future planning activities given different conditions or understanding of future scenarios.

This scoring process resulted in 26 high-priority solutions with favorable scores (Implement). Appendix C shows the priority levels assigned to each resilience strategy.

3.7.3 Group Resilience Solutions into Resilience Actions for Implementation

It is often expedient to address vulnerabilities through coordinated resilience actions. Therefore, individual resilience solutions may be consolidated into categories to address vulnerabilities more comprehensively. Resilience solutions may be grouped according to the vulnerabilities they address, the implementing agency, or other criteria. The Resilience Team grouped the Resilience Stakeholder Group's solutions into four categories to support coordinated implementation across systematic themes. Each group of resilience strategies addresses multiple related power sector vulnerabilities. Section 5 presents the results of grouping resilience solutions into broader resilience action categories.

3.7.4 Finalize Resilience Action Plan

A resilience action plan outlines a step-by-step process for implementing resilience actions. The plan should identify the implementing lead, describe costs and financing of solutions, and clearly define all intermediate steps in resilience solution implementation. Section 5 presents the resilience action plan for the Lao PDR power sector.

4 Lao Power Sector VA

The Resilience Team's approach to identifying the power sector's highest-risk vulnerabilities builds on extensive past experience with engaging stakeholders in the VA process and is tailored to the context of the Lao PDR power sector. This section provides a general description of the technical approach and the stakeholder engagement activities involved in each VA task.

The Resilience Team engaged two groups in the VA: a VA Advisory Group and a VA Stakeholder Group. The VA Advisory Group was a group of nine upper-level power-sector directors and managers from the MEM, EDL, and EDL-Generation Public Company (EDL-Gen) who helped scope and frame the VA and ensure the subsequent engagement with the Stakeholder Group was meaningful and productive. The Resilience Team held a half-day meeting with the VA Advisory Group before conducting the VA with the VA Stakeholder Group during a three-day workshop. The objectives of the VA Advisory Group meeting were to:

1. Determine the scope of the Lao power-sector VA
2. Ensure buy-in from power-sector decision-makers who can give permission to and encourage their staff to participate in two stakeholder workshops—the VA workshop and a second resilience-action planning workshop.

The VA Advisory Group also reviewed a draft of the VA report (Section 4 of this report) and provided technical feedback that was incorporated into this final draft by the Resilience Team.

The VA Stakeholder Group was a larger group of 23 stakeholders with expertise to support power-sector planning and decision-making in the Lao PDR. Participants represented various departments in the MEM, as well as other ministries and organizations, including the Ministry of Industry and Commerce, Ministry of Science and Technology, Ministry of Natural Resources and Environment, Lao Holding State Enterprise, EDL, and EDL-Gen. This group of stakeholders provided diverse perspectives on the power sector, from long-range planning and capital improvements to operations and maintenance. The Resilience Team met with the VA Stakeholder Group for three consecutive days to conduct a participatory VA in August 2018. The objectives of the VA Stakeholder Group workshop included:

1. Draw on stakeholders' expertise to identify potential vulnerabilities to climate and nonclimate hazards that can affect key power-sector components and activities
2. Discuss how participants experience climate and nonclimate hazards in their work, and how these hazards affect, or could affect, their ability to meet power-sector objectives
3. Describe the severity of these potential vulnerabilities and assess their overall risk to the sector.

The remainder of this section describes the task-by-task outcomes of the VA process.

4.1 Task 1: Developing and Reviewing an Impacts Framework

In advance of conducting the VA stakeholder engagement activities, the Resilience Team developed an impacts framework to organize thinking about the power-sector VA. The impacts framework served two primary purposes: To facilitate a conversation with the VA Advisory Group about the scope of the VA and to guide discussions about potential vulnerabilities with the VA Stakeholder Group.

The impacts framework cross-references the power sector's key objectives with the sector's components. Key objectives include the formal or practical objectives of the power authority (such as energy-sector security, reliability, and affordability, among others). The sector components are aspects of the power system that could experience impacts from natural and unnatural hazard components (such as electricity generation, transmission and distribution, and demand, among others).

The Resilience Team developed a generalized impacts framework based on desktop research on the Lao PDR power sector. The team discussed the draft framework with the VA Advisory Group and then revised it to more accurately reflect the context of the Lao PDR power sector. The VA Advisory Group recommended eliminating some power-sector objectives that were not important or relevant and revising some components and objectives to better describe the Lao PDR power sector.

For example, the VA Advisory Group recommended removing fuel, fuel transport, and fuel storage from the original list of power-sector components because the dominant power source in the Lao PDR is hydropower, which does not require fuel, fuel transport, or fuel storage. In addition, the VA Advisory Group determined that cybersecurity, government subsidies, and air and water pollution were not important objectives to consider in the VA.

The final impacts framework agreed on by the Resilience Team and the VA Advisory Group is shown in Table 7. The impacts framework was used to engage the VA Stakeholder Group in a discussion about how natural and human and technical hazards might affect the power sector. The relevant hazards considered are listed in Table 8. The output of applying the impacts framework is a set of narrative descriptions of potential vulnerabilities, as listed in Table 9.

Table 7. Final Lao PDR Power-Sector Impacts Framework

Objectives		Power System Components										
		Hydro Generation	Thermal generation	Generator step up transformer	Transmission lines	Substation step-down transformer	Distribution lines	Point of common coupling	Residential demand	Small commercial demand	Large commercial and industrial demand	Grid operations/ management
Reliability and security	Availability											
	Continuity of service											
	Good power quality											
	Skilled workforce											
Affordability	Appropriate rates											

4.2 Task 2: Identify Hazards and Their Impacts to the Lao PDR Power Sector

The Resilience Team presented a list of potential hazards to the VA Advisory Group to prompt discussion about the most important hazards and to determine which hazards to consider in the VA. This discussion began with a brief explanation of definitions. A hazard is a condition or occurrence that is outside the control of power-sector planners and system operators (e.g., typhoons). Threat is often used interchangeably with the term hazard. An impact is the interaction of a hazard with the power system (e.g., a typhoon causes wind damage to transmission lines).

Because this VA is comprehensive and intends to address all major hazards, the Resilience Team introduced hazard categories that describe different types of hazards to the Lao PDR power sector. The Resilience Team broadly categorized power-sector hazards into natural hazards and human or technical hazards. Natural hazards include both climate and nonclimate hazards. Unnatural hazards include human-caused and technological hazards.

The VA Advisory Group engaged in a small-group participatory exercise to discuss all potential hazards that the Resilience Team introduced. Each group discussed the following questions for each hazard:

1. What impacts does the hazard have on the power sector?
2. How have you experienced the hazard in your work in the power sector?
3. If the hazard becomes more intense or frequent, what impacts do you anticipate in the future?

From this discussion, the VA Advisory Group identified the most important hazards and impacts on the Lao PDR power sector and narrowed the range of hazards that the VA Stakeholder Group would consider in the VA workshop. Table 8 presents the final list of hazards.

Table 8. Final List of Hazards Selected by the VA Advisory Group

Natural Hazards
Cyclone (including extreme precipitation, landslides, and wind)
Drought
Extreme heat and cold
Lightning
Unnatural Hazards
Technological (design, workmanship, low-quality, and defective materials)
Wildlife interactions
Human-caused accidents

The Resilience Team introduced this final list of hazards to the VA Stakeholder Group on the first day of the VA workshop. Working in small groups, the VA Stakeholder Group discussed how each of these hazards could impact the Lao PDR power sector, and each group developed a detailed list of the potential impacts associated with each hazard.

4.3 Task 3: Developing a List of Potential Vulnerabilities

The Resilience Team used the VA Stakeholder Group's list of impacts to define vulnerabilities associated with each hazard and its potential impact. For example, the VA Stakeholder Group described how lightning could strike power-sector infrastructure and cause damage and fires. An example of a vulnerability associated with lightning strikes that damage infrastructure could be, "Inadequate infrastructure or power-system protection from lightning strikes." It is possible to define more than one vulnerability based on the potential impacts associated with each hazard.

During the workshop, the Resilience Team modeled the process for defining several vulnerabilities associated with the hazards and impacts that the VA Stakeholder Group had discussed. The Resilience Team developed a full list of potential vulnerabilities based on the outputs of the first day of the VA Stakeholder Group meeting. The VA Stakeholder Group validated and revised the list on workshop Day 2 with the VA Stakeholder Group. Table 9 presents the full list of potential vulnerabilities.

Table 9. List of Potential Vulnerabilities

Number	Vulnerability	Lao Translation
1	Animals nest on power system assets.	ສັດທີ່ມີຜນກະທົບຕໍ່ລະບົບໄຟຟ້າ (ສັດປີກ)
2	Limited numbers of skilled workers to carry out daily activities.	ບຸກຄະລາກອນທີ່ມີຄວາມຮູ້ຄວາມສາມາດໃນການປະຕິບັດວຽກງານປະຈຳວັນມີຈຳນວນຈຳກັດ
3	Transmission equipment susceptible to lightning strikes.	ລະບົບສາຍສົ່ງສ່ຽງຕໍ່ການຖືກຟ້າຜ່າ
4	Theft of power (illegal connections) and power-system components is common.	ການລັກອຸປະກອນໄຟຟ້າ ແລະ ການລັກໃຊ້ໄຟຟ້າ
5	Large industry (mining, cement, and economic zones) constitutes approximately 40% of demand and revenue.	ຄວາມຕ້ອງການໄຟໃນອຸດສະຫະກຳຂະໜາດໃຫຍ່ (ບໍ່ແຮ່, ຊີມັງ, ເຂດເສດຖະກິດພິເສດ)ກວມເອົາ40%ຂອງຄວາມຕ້ອງການ
6	Civil work occurs near transmission infrastructure.	ການກໍ່ສ້າງໃກ້ກັບລະບົບສົ່ງ ແລະ ລະບົບຈຳໜ່າຍໄຟຟ້າ
7	Heavy power-sector reliance on hydro generation.	ການເອື່ອຍອີງພະລັງງານໄຟຟ້ານ້ຳຕົກເປັນສ່ວນໃຫຍ່
8	Hunting and shooting in proximity to infrastructure.	ການຂ້າ ແລະ ການລ່າສັດບໍລິເວນໃກ້ຄຽງກັບ T&D
9	Trees are close to distribution lines.	ຕົ້ນໄມ້ ໃກ້ກັບສາຍສົ່ງ
10	Distribution equipment susceptible to lightning strikes.	ສະຖານີຈ່າຍ ແລະ ສົ່ງ ໄຟຟ້າ ສ່ຽງຕໍ່ການຖືກຟ້າຜ່າ
11	Animal access to distribution lines/substations.	ສັດເຂົ້າໄປສະຖານີໄຟຟ້າ
12	Lack of compliance with codes in design.	ບໍ່ປະຕິບັດຕາມມາດຕະຖານ ແລະ ເຕັກນິກການອອກແບບ
13	Dam construction does not follow design specifications.	ການກໍ່ສ້າງບໍ່ເປັນໄປຕາມການອອກແບບ
14	Transmission equipment located in zones prone to landslides.	ອຸປະກອນສາຍສົ່ງໄປຕັ້ງຢູ່ເຂດຄວາມສ່ຽງດິນເຈື່ອນ
15	Poor coordination between dam operators.	ຂາດການປະສານງານລະຫວ່າງຜູ້ປະຕິບັດການປະຈຳເຂື່ອນ
16	Corruption leads to code violations.	ການສໍ້ໂກງ ຫຼ ລະເມີດລະບຽບການກໍ່ສ້າງທີ່ໄດ້ກຳນົດໄວ້
17	Demand forecasting is not responsive to changing load conditions.	ການຄາດຄະເນຄວາມຕ້ອງການຊົມໃຊ້ໄຟຟ້າລາຍວັນ ແລະ ອະນາຄົດ ຍັງບໍ່ທັນແທດເໝາະກັບສະພາບການປ່ຽນແປງໃນປະຈຸບັນ
18	Transmission equipment in zones prone to flooding.	ອຸປະກອນສາຍສົ່ງທີ່ຢູ່ໃນເຂດມີຄວາມສ່ຽງນ້ຳຖ້ວມ
19	Distribution equipment located in zones prone to landslides.	ອຸປະກອນພາກຈຳໜ່າຍລະບົບໄຟຟ້າຕັ້ງໃນເຂດທີ່ມີຄວາມສ່ຽງທີ່ຈະເກີດດິນເຈື່ອນ
20	System operations are not flexible enough to respond to changes in demand and supply.	ການບໍລິຫານລະບົບໄຟຟ້າທີ່ບໍ່ຕອບສະໜອງກັບການປ່ຽນແປງ ຂອງການຊົມໃຊ້ ແລະ ການຜະລິດໄຟ
21	Installation did not follow design specifications.	ການຕິດຕັ້ງອຸປະກອນທີ່ບໍ່ເປັນໄປຕາມການອອກແບບໄວ້
22	Hydro generation reservoir is too small for drought conditions.[6]	ຄວາມສາມາດໃນການກັກເກັບນ້ຳໃນອ່າງເກັບນ້ຳບໍ່ພຽງພໍ ສຳລັບການຜະລິດໃນລະດູແລ້ງ
23	Transmission infrastructure located in wildfire-prone areas.	ໂຄງສ້າງພື້ນຖານຂອງລະບົບໄຟຟ້າຕັ້ງຢູ່ໃນເຂດທີ່ມີຄວາມສ່ຽງທີ່ຈະເກີດໄຟໄໝ້

[6] This is based on the discussion with stakeholders during the workshop; however, representatives from EDL provided their perspective that storage volumes of all dams and reservoirs are normally available and sufficient in the dry season because these dams and reservoirs will be emptied after the end of the rainy season (November and December) to prepare maximum available storing volume at the beginning of a dry season (January and February).

Number	Vulnerability	Lao Translation
24	Distribution equipment located in zones prone to flooding.	ອຸປະກອນຂອງສາຍຈຳໜ່າຍໄຟຟ້າຕັ້ງຢູ່ໃນເຂດທີ່ນ້ຳຖ້ວມ /ມີຄວາມສ່ຽງສູງທີ່ຈະເກີດນ້ຳຖ້ວມ
25	High level of turbidity and siltation affect hydro generation.	ລະດັບຄວາມຂຸ່ນຂອງນ້ຳມີຜົນຕໍ່ກັງຫັນພະລັງນ້ຳ
26	Transportation impacts occur with power-sector impacts.	ຂໍ້ບົກຜ່ອງດ້ານຄົມມະນາຄົມຈະສົ່ງຜົນໃຫ້ເກີດມີຈຸດອ່ອນໃ ນຂະແໜງການພະລັງງານເຊັ່ນດຽວກັນ
27	Population's reaction to extreme weather results in unpredictable power loads.	ໃນກໍລະນີມີຜົນຫຼາຍ ຈະສົ່ງຜົນຕໍ່ການຊົມໃຊ້ໄຟຟ້າຂອງປະຊາຊົນມີການປ່ຽນແ ປງ
28	Critical staff may be unavailable during extreme events.	ຂີດຈຳກັດທາງດ້ານແຮງງານບໍ່ພຽງພໍເພື່ອຕອບສະໜອງຕໍ່ ເຫດການສຸກເສີນຮຸນແຮງ
29	Rules, regulations, and technical standards do not meet current and changing environmental conditions.	ລະບຽບການ, ມາດຕະຖານທາງດ້ານເຕັກນິກບໍ່ສອດຄ່ອງກັບເງື່ອນໄຂສະ ພາບການ ແລະ ການປ່ຽນແປງທາງດ້ານສິ່ງແວດລ້ອມໃນປະຈຸບັນ
30	Communication and SCADA systems between power-system components lack certain functions.	ລະບົບ SCADA ຂາດ ຟັງຊັ່ນບາງຢ່າງທີ່ເຮັດໃຫ້ບໍ່ຄົບອົງປະກອບໃນການໃຊ້ງານ
31	Inadequate domestic generation capacity requires costly energy imports.	ຂີດຄວາມສາມາດໃນການສ້າງພະລັງງານພາຍໃນບໍ່ພຽງພໍ ເຊິ່ງຮຽກຮ້ອງໃຫ້ມີການນຳເຂົ້າພະລັງງານ ທີ່ມີຄ່າໃຊ້ຈ່າຍສູງ
32	Unreliable and/or inadequate meteorological, hydrological, and climate change data for decision-making.	ຂໍ້ມູນກ່ຽວກັບປະລິມານຜົນຕົກ ແລະ ການປ່ຽນແປງຂອງສະພາບອາກາດ ມີບໍ່ພຽງພໍ ເພື່ອນຳໃຊ້ໃນການຕັດສິນໃຈ

4.4 Task 4: Associate Hazards with Potential Vulnerabilities

The Resilience Team presented the full list of potential vulnerabilities to the VA Stakeholder Group for review and validation on workshop Day 2. To validate the list of vulnerabilities that the Resilience Team developed, the VA Stakeholder Group worked in small groups to discuss the specific intersection of each vulnerability with the entire suite of potential hazards. The stakeholders suggested some revisions to finalize the list (Table 9 presents this final list). The groups recorded the key points of their discussions about the correlation between vulnerabilities and hazards to inform the risk analysis in the next step of the VA process. Table 10 shows an example of a subset of the vulnerabilities and hazards that the working groups discussed.

Table 10. Subset of Potential Vulnerabilities Associated with a Subset of Hazards

Hazards	Vulnerabilities					
	Power system rules, regulations, and technical standards do not meet current and changing environmental conditions	Corruption leads to code violations	Dam construction does not follow design specifications	Installation does not follow design specifications	Lack of compliance with codes in design	System operations are not flexible enough to respond to changes in demand and supply
Extreme precipitation	Yes	No	Yes	Yes	Yes	Yes
Extreme temperatures	Yes	No	No	No	No	Yes
Flooding	Yes	No	Yes	Yes	Yes	Yes
Landslides	Yes	No	Yes	Yes	Yes	No
Wildlife interactions	No	No	No	No	No	No
Wind	Yes	No	No	No	No	Yes
Human actions: Bad actors	No	Yes	Yes	Yes	No	No
Human actions: Accidents	No	No	Yes	Yes	No	No
Technological design	Yes	No	Yes	Yes	Yes	Yes

4.5 Task 5: Score Severity of Potential Vulnerabilities

Severity scores of each vulnerability reflect the magnitude of the consequence of realizing each vulnerability or the extent to which each vulnerability could negatively impact the power sector. The VA approach involves ranking the severity from low to high. Table 4 (Section 3.4.7) shows the qualitative scores used to assign the vulnerability scores. A threshold description of each score provides a guideline for assigning an appropriate score. The score for each vulnerability accounts for the following considerations:

- Effect on delivery of power—the percentage of service disrupted, effects on power quality, etc.
- Effect on capital and operating costs—additional costs for the reliable operation of the power system
- Extent of health and safety impacts to the population—metrics of health and safety for the population
- Extent of environmental effects—metrics of the release of toxic materials, effects on biodiversity, changes to an area's ecosystem, impacts on historic sites, and others.

After the Resilience Team introduced this scoring methodology on Day 2 of the workshop, the VA Stakeholder Group worked in small groups to assign a severity score to a subset of the vulnerabilities. The small work groups then reviewed one another's scores to ensure the severity scores reflected the consensus of the full group. Table 11 presents the final consequence scores.

Table 11. Vulnerability Severity Scores for Lao Power-Sector Vulnerabilities

Severity Score	Vulnerability	Number
High	Power-system rules, regulations, and technical standards do not meet current and changing environmental conditions.	29
High	Corruption leads to code violations.	16
High	Dam construction does not follow design specifications.	13
High	Installation does not follow design specifications.	21
High	Lack of compliance with codes in design.	12
Medium-High	System operations are not flexible enough to respond to changes in demand and supply.	20
Medium-High	Demand forecasting is not responsive to changing load conditions.	17
Medium-High	Heavy power-sector reliance on hydro generation.	7
Medium-High	Inadequate domestic generation capacity requires costly energy imports.	31
Medium-High	Hydro generation reservoir is too small for drought conditions.	22
Medium-High	Large industry (mining, cement, and economic zones) constitutes approximately 40% of demand and revenue.	5
Medium-High	Poor coordination between dam operators.	15
Medium-High	Transmission infrastructure located in wildfire-prone areas.	23
Medium-High	Transmission equipment located in zones prone to flooding.	18
Medium-High	Transmission equipment located in zones prone to landslides.	14
Medium-High	Transmission equipment susceptible to lightning strikes.	3
Medium-High	Transportation impacts occur with power-sector impacts.	26
Medium-High	Unreliable and or inadequate meteorological, hydrological, and climate change data for decision-making.	32
Medium	Civil works occur near transmission infrastructure.	6
Medium	Distribution equipment located in zones prone to landslides.	19
Medium	Distribution equipment located in zone prone to flooding.	24
Medium	Distribution equipment susceptible to lightning strikes.	10
Medium	High levels of turbidity and siltation affect hydro generation.	25
Medium	Communication and SCADA systems between power-system components lack certain functions.	30
Medium	Limited number of skilled workers to carry out daily activities.	2
Medium	Critical staff may be unavailable during extreme events.	28
Low-Medium	Theft of power and power-system equipment is common.	4
Low-Medium	Population's reaction to extreme weather results in unpredictable power loads.	27
Low-Medium	Trees are close to distribution lines.	9
Low	Animal access to distribution lines.	11
Low	Animals nest on power-system assets.	1
Low	Hunting and shooting in proximity to infrastructure.	8

4.6 Task 6: Score Likelihood of Hazards

In addition to scoring the severity of each vulnerability, the VA approach also involves scoring the likelihood that each hazard may occur. Like the severity scores, likelihood scores range from low to high. Table 3 (Section 3.4.6) shows the qualitative and quantitative likelihood scores and threshold descriptions to guide scoring.

Likelihood scores did not represent simply the likelihood of the hazard occurring, but rather the likelihood of the hazard affecting the power sector. For example, lightning is almost certain to occur, but this information is not useful to our analysis. What we care about is the likelihood of lightning interacting with the power sector to cause an impact. After the workshop activities on Day 2, the Resilience Team assigned preliminary likelihood scores to each hazard based on understanding of each hazard in the Lao PDR context.

On Day 3 of the workshop, the VA Stakeholder Group reviewed and revised the preliminary likelihood scores in small working groups and discussed these as a full group to reach a consensus on the final scores to include in the VA. Table 12 shows the final hazard likelihood scores across natural and unnatural hazards.

Table 12. Natural and Unnatural Hazard Likelihood Scores for the Lao Power Sector

Hazard	Likelihood score
Natural Hazards	
Extreme precipitation	Medium-High
Flooding	Medium-High
Extreme temperatures	Medium-High
Landslides	Medium-High
Wind	Medium
Drought	Low-Medium
Lightning	Low-Medium
Unnatural Hazards	
Human bad actors	Medium
Technological poor design	Medium
Technological poor materials	Medium
Human accidents	Low-Medium
Technological poor workmanship	Low-Medium
Wildlife interaction	Low-Medium

4.7 Task 7: Score Risk and Create Final Risk Matrix

The final step of the VA involved entering the vulnerability severity scores and hazard likelihood scores into a spreadsheet tool to generate a risk matrix. The Resilience Team presented the risk matrix to the stakeholder group on workshop Day 3 to explain this scoring method and the final step of the VA process. Table 13 presents the final matrix for the Lao power-sector VA.

Table 13. Final Risk Matrix for the Lao Power-Sector VA

Vulnerability	Severity Score	Extreme Precipitation	Flooding	Extreme Temperatures	Landslides	Wind	Human Actions: Bad Actors	Technological Design	Technological Materials	Drought	Wildlife interactions	Human Actions: Accidents	Technological Workmanship	Lightning
Likelihood score		7	7	7	7	5	5	5	5	3	3	3	3	3
Power system rules, regulations, and technical standards do not meet current and changing environmental conditions	9	63	63	63	63	45		45	45	27				27
Corruption leads to code violations	9						45							
Dam construction does not follow design specifications	9	63	63		63		45	45	45			27	27	
Installation does not follow design specifications	9	63	63		63		45	45				27	27	
Lack of compliance with codes in design	9	63	63		63			45	45				27	27
System operations are not flexible enough to respond to changes in demand and	7	49	49	49		35		35		21				21
Demand forecasting is not responsive to changing load conditions	7	49		49				35		21				
Heavy power sector reliance on hydro generation	7	49	49	49				35		21				
Inadequate domestic generation capacity requires costly energy imports	7	49	49	49						21				
Hydro generation reservoir is too small for drought conditions	7			49				35		21				
Large industry (mining, cement, and economic zones) constitutes approx. 40perc of demand and revenue	7	49	49	49				35		21				
Poor coordination between dam operators	7	49	49	49						21				
Transmission infrastructure located in wildfire prone areas	7			49						21				21
Transmission equipment located in zones prone to flooding	7	49	49		49			35						
Transmission equipment located in zones prone to landslides	7				49			35						
Transmission equipment susceptible to lightning strikes	7							35						21
Transportation impacts occur with power sector impacts	7	49	49		49	35								
Unreliable and or inadequate meteorological, hydrological, and climate change data for decision making	7	49	49	49	49	35		35		21				21
Civil works occur near transmission infrastructure	5											15		
Distribution equipment located in zones prone to landslides	5	35	35		35			25						
Distribution equipment located in zones prone to flooding	5	35	35					25						
Distribution equipment susceptible to lightning strikes	5							25						15
High levels of turbidity and siltation affect hydro generation	5	35	35		35			25		15				
Communication and scada systems between power system components lack certain	5						25	25	25					
Limited number of skilled workers to carry out daily activities	5								25				15	
Critical staff may be unavailable during extreme events	5	35	35	35	35	25	25	25			15			
Theft of power and power system equipment is common	3						15					9		
Population's reaction to extreme weather results in power unpredictable loads	3	21	21			15	15	15				9		
Animals access to distribution lines	1							5	5		3			
Animals nest on power system assets	1							5	5		3			
Hunting and shooting in proximity to infrastructure	1										3	3		
Trees are close to distribution lines	1					5		5				3	3	3

The colored cells in the matrix represent all risk combinations that the stakeholder group believed could be linked; blank cells represent vulnerabilities that are not associated with the hazard in that column and, therefore, present no risk. Brightly colored cells represent threat and vulnerability combinations that met the criteria to be considered high or medium-high risk; gray cells represent lower-risk vulnerabilities. Table 14 highlights the highest-risk vulnerabilities to the Lao power sector.

Table 14. Highest-Risk Vulnerabilities Risk Matrix for the Lao Power-Sector VA

Vulnerability	Severity Score	Extreme Precipitation	Flooding	Extreme Temperatures	Landslides	Wind	Human Actions: Bad Actors	Technological Design	Technological Materials
Likelihood score		7	7	7	7	5	5	5	5
Power system rules, regulations, and technical standards do not meet current and changing environmental conditions	9	63	63	63	63	45		45	45
Corruption leads to code violations	9						45		
Dam construction does not follow design specifications	9	63	63		63		45	45	45
Installation does not follow design specifications	9	63	63		63		45	45	
Lack of compliance with codes in design	9	63	63		63			45	45
System operations are not flexible enough to respond to changes in demand and	7	49	49	49		35		35	
Demand forecasting is not responsive to changing load conditions	7	49		49				35	
Heavy power sector reliance on hydro generation	7	49	49	49				35	
Inadequate domestic generation capacity requires costly energy imports	7	49	49	49					
Hydro generation reservoir is too small for drought conditions	7			49				35	
Large industry (mining, cement, and economic zones) constitutes approx. 40perc of demand and revenue	7	49	49	49				35	
Poor coordination between dam operators	7	49	49	49					
Transmission infrastructure located in wildfire prone areas	7			49					
Transmission equipment located in zones prone to flooding	7	49	49		49			35	
Transmission equipment located in zones prone to landslides	7				49			35	
Transmission equipment susceptible to lightning strikes	7							35	
Transportation impacts occur with power sector impacts	7	49	49		49	35			
Unreliable and or inadequate meteorological, hydrological, and climate change data for decision making	7	49	49	49	49	35		35	

Finally, the Resilience Team assigned a qualitative risk score to each highest-risk vulnerability for ease of discussion. These are shown in Table 15 and were assigned based on the numerical scores in Table 14. A vulnerability that scored 50 or higher for any hazard was considered high risk, and a vulnerability that scored between 40 and 50 for any hazard was considered medium-high. Vulnerabilities scoring below 40 were excluded from the highest-risk vulnerabilities.

Table 15. Highest-Risk Vulnerabilities and Risk Scores for the Lao Power-Sector VA

Risk Score*	Vulnerability (and Vulnerability Number)	
High	Power-system rules, regulations, and technical standards do not meet current and changing environmental conditions.	V29
	Dam construction does not follow design specifications.	V13
	Installation does not follow design specifications.	V21
	Lack of compliance with codes in design.	V12
Medium-High	Corruption leads to code violations.[7]	V16
	System operations are not flexible enough to respond to changes in demand and supply.	V20
	Demand forecasting is not responsive to changing load conditions.	V17
	Heavy power-sector reliance on hydro generation.	V7
	Inadequate domestic generation capacity requires costly energy imports.	V31
	Hydro generation reservoir is too small for drought conditions.	V22
	Large industry (mining, cement, and economic zones) constitutes approximately 40% of demand and revenue.	V5
	Poor coordination between dam operators.	V15
	Transmission infrastructure located in wildfire-prone areas.	V23
	Transmission equipment located in zones prone to flooding.	V18
	Transmission equipment located in zones prone to landslides.	V14
	Transportation impacts occur with power-sector impacts.	V26
	Unreliable and/or inadequate meteorological, hydrological, and climate change data for decision-making.	V32

*For additional details on these Risk Score Vulnerabilities for the Lao PDR, see (Vogel et al. 2018).

4.8 VA Conclusions and Next Steps

Reducing the matrix view to focus on the highest-risk vulnerabilities (Table 14) reveals that extreme precipitation, flooding, and landslides (which are often correlated) are the hazards that most expose vulnerabilities. The top four vulnerabilities have severe exposure to these hazards and earn the highest risk scores within the VA. Extreme temperatures also contribute to one of the high-risk vulnerabilities and many of the medium-high-risk vulnerabilities. These final risk scores suggest that the resilience action plan must focus on vulnerabilities associated with extreme precipitation, flooding, landslides, and extreme temperatures.

Through this VA process, the Resilience Team, VA Advisory Group, and VA Stakeholder Group collaborated to systematically identify and describe the highest-risk vulnerabilities of the Lao PDR power sector. The next steps of this work, which are described in Section 5 of this report, focused on identifying the most appropriate resilience actions to address high-risk vulnerabilities.

[7] Although the Stakeholder Group agreed that "Corruption leads to code violations" is one of the high-risk vulnerabilities in the power sector, members agreed to map this vulnerability to other strategies, noting that they did not have the authority to address this issue directly through resilience strategies. Therefore, the Advisory Group or other high-level decision-makers may need to address this issue in a different setting.

5 Lao Power-Sector Resilience Action Plan

The purpose of this activity was to develop a power-sector resilience action plan, to address high-risk vulnerabilities of the Lao power sector, through a stakeholder-driven resilience action planning approach. This section summarizes the power-sector resilience planning approach. Section 3 provides additional details about the resilience action planning approach and the high-risk vulnerabilities to the Lao Power Sector, which were assessed using the approach described in Section 4.

Stakeholder engagement is an important component of any comprehensive power-sector resilience planning process. To develop the power-sector resilience action plan, two in-country stakeholder groups engaged in workshops and meetings with a power-sector resilience planning team.

1. A **Vulnerability Assessment Advisory Group (VA Advisory Group)** provided knowledge and guidance for linking the resilience action plan to the preceding vulnerability assessment and ensured meaningful and productive engagement with the Resilience Stakeholder Group. The Advisory Group included eight upper-level power-sector directors and managers from the MEM, EDL, and EDL-Gen. Appendix A lists the members of the VA Advisory Group.
2. A **Resilience Stakeholder Group** drew from the diverse experience and perspectives of its members to develop resilience actions to address critical power-sector vulnerabilities. The Resilience Stakeholder Group included 26 stakeholders from various departments of the MEM, as well as other ministries and organizations, including the Ministry of Industry and Commerce, Ministry of Science and Technology, Ministry of Natural Resources and Environment, Ministry of Finance, Ministry of Labor and Social Welfare, Lao Holding State Enterprise, Central Bank of Lao PDR, Laos Women Union, EDL, and EDL-Gen. Appendix F lists the members of the Resilience Stakeholder Group.

The resilience action planning approach consisted of four main tasks. Figure 2 summarizes these four tasks and the process of developing a resilience action plan. Section 3 describes this process in detail.

1. Identify Resilience Solutions
    - The Resilience Stakeholder Group reviewed the previously identified high-risk vulnerabilities for the Lao Power Sector.
    - The Resilience Stakeholder Group identified an initial, broad set of 42 resilience solutions to address these high-risk vulnerabilities in the Lao power sector.
2. Score and Prioritize Resilience Solutions
    - The VA Advisory Group selected a set of four criteria (effectiveness of the solution, feasibility of the solution, cost or financing availability of the solution, and implementation timing of the solution) to score and prioritize the resilience solutions.
    - The Resilience Stakeholder Group refined the criteria and the thresholds for scoring the alternatives.
    - The Resilience Stakeholder Group scored the resilience solutions on each of these criteria.
    - The Resilience Stakeholder Group developed detailed action plans to address the high-priority resilience solutions.
    - The Resilience Team evaluated the resilience solutions and prioritized the solutions based on the scoring of the Resilience Stakeholder Group (implement the solution, evaluate the solution further, or remove the solution from consideration).
    - The Resilience Team then identified 26 resilience solutions to implement.
3. Group Resilience Solutions into Resilience Actions for implementation
    - The Resilience Team consolidated related resilience solutions into four main resilience actions to help coordinate implementation.
      Finalize Resilience Action Plan
    - The Resilience Team developed a resilience action plan for the four main resilience actions with 16 activities for implementation.

- The VA Advisory Group reviewed and provided feedback on the Power-Sector Resilience Action Plan.

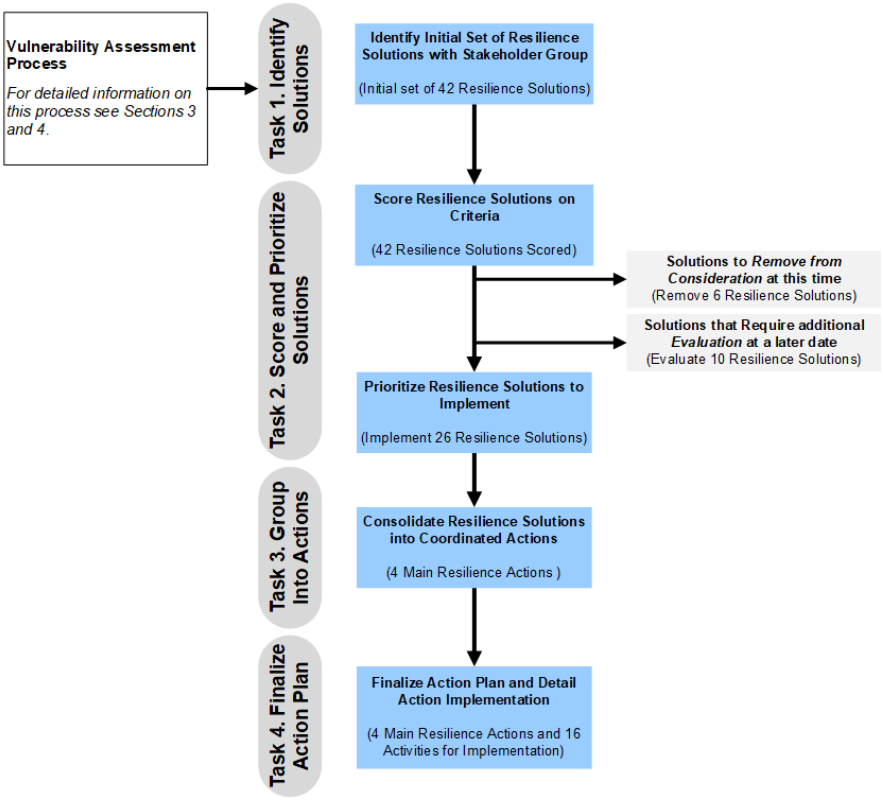

Figure 2. Identification of power-sector resilience actions

The Resilience Team consolidated the resilience solutions into four main resilience actions to support coordinated implementation. These resilience actions group solutions according to their scores on the criteria of cost or finance availability, feasibility (both technical and political), effectiveness of the solution, and implementation timing. Appendix C shows the scores for each resilience solution.

Table 16 presents the four overarching actions identified through the VA process (Sections 3 and 4), potential lead entities, the proposed activities under each action, and potential funding sources for each action. By combining resilience solutions into a coordinated action plan, implementing authorities may address multiple vulnerabilities cost-effectively and efficiently through cross-cutting resilience actions. Power-sector managers could implement the actions in Table 16 as a coordinated set of activities that address multiple vulnerabilities.[8] The following sections describe these actions and respective activities. Sections 3 and 4 provide detailed information about the VA process to identify the resilience actions in this table.

[8] Individual activities do not represent coordinated, cross-cutting resilience action and are therefore less effective when implemented alone. Each activity is not meant to represent a single resilience solution or to address a single vulnerability.

Table 16. Action Plans for Grouped Resilience Strategies

Resilience Action	Public or Private Sector	Lead Entities	Description of Activities (and Approximate Implementation Timing)	Potential Funding Sources
1. Implement Resilient Power System Policies (R7, R13, R15, R17, R23, R24, R26, R27, R29, R33, R36, R37, R40, R41)	Public and Private	• MEM • EDL • National Disaster Management Office (Ministry of Labor and Social Welfare) • Department of Disaster Management and Climate Change - Ministry of Natural Resources and the Environment (MoNRE)	Activity 1.1: Develop standard operating procedures and continuity of operation plans for extreme events—including staffing plans, prioritized repowering of networks, and aid agreements with neighboring countries (Months 1-16) Activity 1.2: Develop climate projections and geospatial data for hydropower (Months 1-24) Activity 1.3: Develop standards and enforcement mechanisms for power reliability (Months 13-23) Activity 1.4: Improve community readiness for extreme events that may impact the power sector (Months 13-23) Activity 1.5: Improve enforcement of dam design and construction codes—including planning for expected hazards (e.g., floods, high winds, landslides) where these cannot be avoided (Months 7-18) Activity 1.6: Include resilience provisions within annual operating budgets of relevant agencies (Months 7-18).	• Funding for policy development from government funds (i.e., MEM and EDL) • Development Bank or other international donor (e.g., World Bank or Asian Development Bank) • Government budget (Ministries and EDL)
2. Improve Power System Flexibility (R18, R26, R28, R30, R31, R32)	Public and Private	• MEM • EDL • Ministry of Planning and Investment • Ministry of Industry and Commerce	Activity 2.1: Consider multiple demand and supply scenarios for power-system growth in the power development plan and related planning activities (Months 1-11) Activity 2.2: Reduce dependence on hydropower by diversifying energy mix (Months 7-12) Activity 2.3: Introduce flexibility solutions into power-system operations (Months 7-17) Activity 2.4: Improve power-system planning for future scenarios—including education for dispatch scenarios, weather forecasting for variable renewable energy, and knowledge of demand forecasting methods (Months 7-17) Activity 2.5: Develop and implement a demand-side management program to address electricity demand during peak periods, such as time-of-use tariffs, industry and large customer programs, or public awareness and educational campaigns (Month 7 beyond month 25) Activity 2.6: Establish a binding contract or agreement within an interconnection procedure to ensure commitment of new large electrical customers, such as large industrial loads (Months 7-17).	• Government budget (MEM and EDL) • Development Bank or other international donor (e.g., World Bank or Asian Development Bank)
3. Improve Coordination across Hydropower Dam Operations (R1, R2)	Public and Private	• MEM • EDL • EDL-Gen • IPPs	Activity 3.1: Establish protocol for data collection at all hydropower dams, including data types, collection frequency, and data format for sharing (Months 1-11) Activity 3.2: Mandate data sharing between hydropower dam operators (Months 7 beyond month 25).	• Funding for policy development from MEM • Funding for data collection from EDL and private developers • Development Bank or other international donor (e.g., World Bank or Asian Development Bank)

Resilience Action	Public or Private Sector	• Lead Entities	Description of Activities (and Approximate Implementation Timing)	• Potential Funding Sources
4. Facilitate Better Sedimentation Management in Hydropower Watersheds (R6, R9, R10, R11, R12)	Public	• MEM • Ministry of Agriculture and Forestry • MoNRE	Activity 4.1: Develop incentive and enforcement structures to ensure users or areas that are upstream from hydropower dams protect watersheds located upstream from hydropower dams (Months 1-22) Activity 4.2: Create educational campaign and community awareness for watershed protection upstream from hydropower dams (Month 13 beyond month 25).	• Government budget (Ministries) • EDL or private developer budgets • Development Bank or other international donor (e.g., World Bank or Asian Development Bank)

5.1 Resilience Actions

This section details the resilience actions and their respective activities.

Feedback on the resilience actions from the VA Advisory Group is presented in Appendix E.

5.1.1 ACTION 1: Implement Resilient Power-System Policies

An overarching policy or set of policies is needed to support improved power-sector resilience in the Lao PDR. Development of these policies may facilitate the further implementation of other resilience actions. The next sections detail activities associated with developing and implementing these policies.

5.1.1.1 ACTIVITY 1.1: Develop Standard Operating Procedures and Continuity of Operation Plans for Extreme Events

Lead Entities

- MEM
- National Disaster Management Office—Ministry of Labor and Social Welfare

Timeline

Months 1-16 of Resilience Action Plan

Key Activities

- Review relevant organizations and establish a working group
- Conduct comprehensive analysis of current operating procedures and guidelines as they relate to extreme events and cross-coordination between EDL and relevant disaster response agencies to identify potential gaps
- Develop, approve, and disseminate best-practice operating procedures and continuity-of-operations plans and guidelines for extreme events that address existing gaps
- Coordinate with neighboring countries to render aid in the event of major power disruptions.

The Resilience Stakeholder Group noted that the current structure of power-service operations lacks a comprehensive plan for maintaining operations during responses to extreme events. This includes lack of planning for staff in critical roles, coordination with nonpower-specific entities responsible for disaster response, or agreements with neighboring countries for aid during or after major events. The first step in developing a comprehensive plan is to review the current practices, operating procedures, and agreements related to cross-coordination for extreme-event responses. This includes a review of current agreements between MEM, EDL, and other Lao PDR agencies; evaluation of power-sector responses to past outages and extreme events to understand areas of opportunity; and the initiation of a dialogue about coordinated responses with neighboring countries.

This information will facilitate the development of best practices and a continuity-of-operations plan.

A continuity-of-operations plan will detail the roles, responsibilities, actions, and response times of power-sector stakeholders in extreme events. The goal of this plan is to enable a smooth transition of operations from one resource to another during a disaster scenario. For example, the National Control Center may need to shift control of power dispatch to one of the regional control centers during a major event impacting the capital, Vientiane. The continuity-of-operations plan may present multiple scenarios for responding to events that vary in geographic scale. This type of plan should also include provisions for cross-training staff in critical roles. The Stakeholder Group noted that some critical staff may be unavailable during extreme events. The continuity-of-operations plan should therefore

increase staffing flexibility by training multiple staff members in the completion of critical procedures.

Finally, this operating procedure could consider inclusion of international agreements—most likely in the form of Memorandums of Understanding (MOUs) with regional partners. This will facilitate delivery of aid between nations in the event of a nationwide extreme event that requires more resources than the affected country can provide. This type of agreement has historically been enacted in response to major natural disasters such as typhoons or earthquakes.

Additional Resources:

- Security Guideline for the Electricity Sector: Continuity of Business Processes and Operations Operational Functions (NERC 2007)
- Model Intergovernmental and Host Government Agreements for Cross-Border Electricity Projects (Energy Charter Secretariat 2015)
- Understanding the Electric Power Industry's Response and Restoration Process (EEI 2013)
- Historic Storms, Historic Responses (EEI 2017).

5.1.1.2 ACTIVITY 1.2: Develop Climate Projections and Geospatial Data for Hydropower

Lead Entities
- MEM
- MoNRE

Timeline
Months 1-24 of Resilience Action Plan

Key Activities
- Analyze potential hydropower development for future climate predictions
- Map watersheds and water flows
- Develop national hazard zone map
- Gather potential data and determine zones with acceptable hydropower development risk
- Incorporate this data in comprehensive, publicly available maps for hydropower resources.

Hydropower provides the majority of Lao PDR power, both current and planned. Therefore, hydropower resources must be accurately characterized and prioritized for development while still meeting safety standards and avoiding unnecessary hazards.

Analysis of energy development potential of hydropower resources in the Lao PDR should account for climate projections. These climate projections will inform generation projections as well as changes in hazards that could negatively affect dams. This will require multiple levels of mapping and analysis. First, accurate mapping of watersheds and water flows should be developed; these maps are most useful when they include temporal characterization of water flows. Automated flow gauges that include data on localized precipitation, stream depth, and flow rates can be deployed on key watershed resources to better characterize these flows. Second, developing a national map of hazard zones will inform siting of systems. This mapping may include hazards such as flood plains, landslide-prone slopes, soil type (for understanding of soil stability), and land cover. Third, current and future climate projections should be geographically overlaid with watershed and hazard data. These overlays will help power-sector planners understand projected changes in watersheds under various climate scenarios. This will allow prioritization of watersheds based on energy generation and

safe siting of dams. This mapping may require limited support from outside agencies and could involve continued development of vulnerability and risk assessment maps in Lao PDR as well as determining an acceptable level of risk for power-sector projects. Decision-makers in the Lao PDR power sector should determine acceptable risk limits and develop standardized risk assessment protocols for all new power-system projects. These protocols could include review of expected hazards, characterization of risks, and acceptable risk thresholds for projects.

In general, networks should not be constructed in zones where risks exceed established thresholds (such as zones with high exposure to hazards); however, the purpose of distribution networks is to deliver power to end users, and this may require construction of limited networks in hazard zones in certain instances. Therefore, standard procedures should minimize risk for these distribution network projects. For example, distribution networks in zones with high winds and significant amounts of vegetation, which could fall and damage distribution networks, may be placed underground to reduce the risk of damage to distribution lines. Similarly, network components in areas prone to flooding may be placed above flood lines (i.e., the maximum elevation that water may reach based on historic or projected events) to reduce risk of water damage.

Additional Resources:

- U.S. Geological Survey: Water Data for the Nation (USGS 2019)
- Environmental, Health, and Safety Approaches for Hydropower Projects (IFC 2018)
- Hydropower Resource Assessment and Characterization (DOE 2018b).

5.1.1.3 ACTIVITY 1.3: Develop Standards and Enforcement Mechanisms for Power Reliability

Lead Entities
- MEM
- EDL

Timeline
Months 13-23 of Resilience Action Plan

Key Activities
- Determine current reliability statistics and challenges
- Set standards for reliability
- Develop enforcement mechanisms.

The Resilience Stakeholder Group noted that power reliability can be a problem in the Lao PDR. They also noted that no mandated standard currently exists for reliability. Additionally, there is no mechanism for enforcement of any developed standards. The first step in setting standards is to understand the current reliability of power delivery in the Lao PDR then address specific challenges to improving reliability. The Resilience Stakeholder Group noted a need for a study to understand reliability challenges because these are currently not well-characterized.

With better understanding of these barriers to greater reliability, the Lao PDR may set goals for reliability improvements. Institute of Electrical and Electronics Engineers (IEEE) Standard 1366 is the international code for classifying reliability. This standard includes System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and the Customer Average Interruption Duration Index (CAIDI). The Lao PDR may choose to develop enforcement

mechanisms for ensuring compliance with standards. Imposing fines for failing to meet reliability goals is a common approach to enforcement.

Additional Resources:

- IEEE 1366-2012 - IEEE Guide for Electric Power Distribution Reliability Indices (IEEE 2012)
- Performance Benchmarking for Electricity Distribution Utilities (Sharma 2017).

5.1.1.4 ACTIVITY 1.4: Improve Community Readiness for Extreme Events That May Impact the Power Sector

Lead Entity
MEM

Timeline
Months 13-23 of Resilience Action Plan

Key Activities
- Review existing community readiness plans for EDL, EDL-Gen, and IPPs
- Develop a curriculum and plan for community engagement and training that includes key messages for various stakeholders for community readiness
- Conduct training on community readiness.

The Resilience Stakeholder Group also noted that the population of the Lao PDR often does not understand how to respond when natural disasters affect the power sector. Widespread public outreach efforts to build awareness about power-sector resilience and effective public response to disasters will enable power-sector managers to communicate more effectively with their users and encourage appropriate end-user behavior during extreme events. An effective engagement plan will need to include key messages to different stakeholder groups, including government entities, residential customers, small commercial customers, and large commercial and industrial customers.

Additional Resources:

- Community Guidelines for Energy Emergencies (DOE 2018a).

5.1.1.5 ACTIVITY 1.5: Improve Enforcement of Hydropower Dam Design and Construction Codes

Lead Entity
MEM

Timeline
Months 7-18 of Resilience Action Plan

Key Activities
- Review existing enforcement guidelines
- Develop or improve guidelines and options for enforcement of construction codes
- Train relevant staff to support the enforcement of guidelines.

The Resilience Stakeholder Group reported that lack of enforcement of construction and safety codes remains an issue in the Lao PDR. They attribute this to a combination of confusion and lack of code awareness on the part of construction laborers, and possible corruption in the supply chain for dam construction materials. These two issues must be addressed separately. First, construction laborers should receive training to help them spot faulty or substandard equipment and materials. Second, adoption of new standards can help ensure compliance with international safety codes and environmental standards. Finally, developing an enforcement mechanism can ensure compliance with codes. This type of mechanism most often involves penalties such as fines and financial penalties; ramifications for developers or companies that build, operate, or maintain power-system components and repeatedly disregard codes and standards; and plans for continuous monitoring of power-sector construction and operations by independent monitoring entities.

Additional Resources:

- Regulatory Frameworks for Dam Safety (Bradlow, Palmieri, and Salman 2002).

5.1.1.6 ACTIVITY 1.6: Include Resilience Provisions Within Annual Operating Budgets of Relevant Agencies

Lead Entity
MEM

Timeline
Months 7-18 of Resilience Action Plan (to occur annually and follow the budgeting processes of the Lao PDR government)

Key Activities
- Develop work plan and estimate budget for implementation
- Discuss with relevant agencies
- Report to the Lao Ministry of Finance for approval.

Finally, no overarching resilience policy supporting this action plan is effective without budgetary support for implementation. MEM will likely need to work within the national budgetary process to develop a budget to develop and implement this policy.

5.1.2 ACTION 2: Improve Power-System Flexibility

Increasing power-system flexibility will be key to improving power-sector resilience by addressing vulnerabilities related to changes in power supply and demand. Improving power-system flexibility requires significant planning (such as the IRRP process) to optimize investments and ensure applicable power-system requirements are met. Options to improve power-system flexibility exist across the physical and institutional elements of the system and include demand-side resources, generation, transmission systems, and system operations (Cochran et al. 2014; Katz, Milligan, and Cochran 2015).

The sections that follow provide information about activities that may support power-system flexibility and enhance overall system resilience for the Lao power sector.

5.1.2.1 ACTIVITY 2.1: Consider Multiple Demand and Supply Scenarios for Power-System Growth in the Power Development Plan and Related Planning Activities

Lead Entities
- MEM
- EDL

Timeline
Months 1-11 of Resilience Action Plan

Key Activities
- Review existing Lao power-system modeling work with USAID, the Japan International Cooperation Agency, Asian Development Bank, the World Bank, and others
- Incorporate relevant considerations into the IRRP and Lao National Power Development Plan updates
- Identify and develop multiple demand growth scenarios and supply scenarios in power development planning activities
- Submit the National Power Development Plan to the Lao National Assembly for approval.

The Resilience Stakeholder Group noted that long-term demand and supply scenarios, which are necessary to support power development planning, do not always present an accurate picture of Lao power-sector growth. Therefore, a first step to increasing power-system flexibility is considering multiple scenarios for power-system growth in planning processes such as the IRRP. This includes multiple demand development scenarios (such as low, medium, or high growth) and multiple supply development scenarios (such as increased generation, additional energy imports, additional or new generation technologies, and diversification).

Energy demand forecasts are inherently uncertain and relying on a single demand and supply scenario for long-term planning provides limited information on possible future scenarios. Considering multiple demand forecasts and potential supply scenarios helps to address uncertainty and improve the robustness of planning. Scenario-based planning is a best practice and generally consists of developing reasonable energy demand and supply scenarios that account for different plausible power-system development pathways. These different pathways may arise because of financial, economic, regulatory, technical, or other impacts on power demand and supply options. Having multiple demand scenarios also allows planners to consider a diverse set of supply-side options to meet demand and identify robust plans. These also provide decision-makers with the flexibility to adjust to future demand (such as increased residential demand or uncertainty in large industrial demand) or supply conditions (such as decreased hydropower resource availability).

Additional Resources:

- Insights on Planning for Power System Regulators (IRENA 2018)
- Best Practices Guide: Integrated Resource Planning for Electricity (The Tellus Institute 2010)
- Best Practices in Electric Utility integrated Resource Planning: Examples of State Regulations and Recent Utility Plans (Wilson and Biewald 2013).

5.1.2.2 ACTIVITY 2.2: Reduce Dependence on Hydropower by Diversifying Energy Mix

Lead Entities
- MEM
- EDL

Timeline
Months 7-12 of Resilience Action Plan

Key Activities
- Identify targets that increase geographic, fuel-supply, and water-use diversification in the national electricity generation mix
- Develop power-sector policies that incentivize diversification of the electricity generation mix
- Incorporate targets into medium- and long-term planning through the development of supply-side scenarios
- Integrate renewables and other technologies (such as coal) into the system
- Follow National Power Development Plan targets and MEM strategies.

The Resilience Stakeholder Group identified heavy power-sector reliance on hydropower generation as a high-risk vulnerability for the power sector and noted the need to increase diversification in the power system (Sections 3 and 4 provide additional details on the VA). A diverse portfolio of electricity generation—including renewable energy generation—helps to increase reliability and to mitigate and resolve service disruptions. Multiple dimensions of generation diversity should be considered:

- **Geography**—Planning to ensure geographically dispersed conventional (thermal or large hydro) and renewable-energy-based generation allows for the effective management of responses to short-term or chronic climate impacts. Managers can compensate for changes in resource availability (e.g., hydropower) in one region with assets in other regions of the country in the face of hazards (e.g., cyclones or flooding). Diversifying generation geographically across the power system can also help address demand and supply fluctuations, facilitate integration of variable renewable energy, and decrease potential vulnerabilities to hazards.
- **Fuel supply**—Hazards (e.g., cyclones, drought, or human-caused accidents) can impact fuel supplies (e.g., coal) and energy resource availability (hydropower resources) that can place traditional generation at greater risk than generation that has onsite fuel supply (e.g., wind and solar resources). Diversifying the fuel supply of generation portfolios and including renewable energy technologies that use onsite fuel resources can enable resilience and ensure power provision when traditional generation may be impacted.
- **Water use**—Traditional generation (e.g., hydropower and thermal technologies) are dependent on water resources for power production, cooling, and other functions and could be impacted by water availability or temperature in certain regions. Diversifying generation portfolios with technologies with low-water requirements (e.g., wind and solar PV) could provide a technical solution for the Lao PDR, which currently depends on hydro and thermal technologies (coal-fired power) and may face hazards that impact water availability in the future (Cox et al. 2017).

Decision-makers can set diversification targets, such as targets to lower the share of hydropower in the total generation mix and increase the share of additional generation, including renewables, such as wind and solar, for the Lao PDR. New policies could incentivize diversification and ensure targets are

met and incorporated into planning. Diversification requires that regions throughout the country have adequate transmission access. This requires close coordination with power and transmission development planning (Wang et al. 2016).

Additional Resources:

- Bridging Climate Change Resilience and Mitigation in the Electricity Sector Through Renewable Energy and Energy Efficiency: Emerging Climate Change and Development Topics for Energy Sector Transformation (Cox et al. 2017)
- Enhancing Power Sector Resilience: Emerging Practices to Manage Weather and Geological Risks (Wang et al. 2016)
- Chapter 4: Energy Supply and Use. Climate Change Impacts in the United States: The Third National Climate Assessment (Dell et al. 2014).

5.1.2.3 ACTIVITY 2.3: Improve Power-System Flexibility Through Forecasting and Dispatch

Lead Entities
- MEM
- EDL

Timeline
Months 7-17 of Resilience Action Plan

Key Activities
- Review existing power-system operation and demand, and supply forecasting approaches
- Research and implement improved demand and supply forecasting approaches
- Research and move to subhourly dispatch intervals for system operations (National Control Center).

Operational flexibility refers to a power system's ability to respond to changes in supply and demand. Implementing improved operational practices can often unlock significant flexibility in power systems at lower costs than actual changes to the physical system (Katz, Milligan, and Cochran 2015). Improved generation forecasting and shorter dispatch intervals are relevant operational practices that could help increase flexibility in the Lao power system.

- **Improved Generation Forecasting**—To ensure the continuous balance of electricity supply and demand and reduce inherent uncertainties in demand and generation, power-system operators rely on forecasts of demand and generation. Accurate forecasts support reliable system operation and cost-effective operation through improved generation scheduling. They also provide operators with a clearer understanding of available resources to anticipate and address disruptions and support resilience. Bringing forecast periods closer to real-time system deployment (subhourly) and providing resources to improve forecast accuracy increases forecast benefits for system operators. Options for achieving this include:
    - Developing an enabling policy environment for forecasting
    - Enhancing forecast accuracy and utilization in system operations (EDL and IPPs).
- **Shorter Dispatch Intervals**—With improved demand and supply forecasts, the system operator can move toward sub hourly dispatch and intrahourly scheduling of generation (ensuring operators can make actionable dispatch decisions at this interval). These shorter time intervals allow for more efficient responses from grid operators because demand and supply forecasts are more accurate and closer to actual dispatch. Shorter intervals also provide

operators more flexibility and clearer options for rapidly responding to power-system disruptions.

Researching and deploying improved demand and supply forecasting approaches and shifting to shorter dispatch intervals would provide the National Control Center-EDL with improved data for decision-making and additional flexibility in preparing for and responding to potential hazards. Other methods for procuring flexibility are available in the list below.

Additional Resources:

- Flexibility in 21st Century Power Systems (Cochran et al. 2014)
- Flexible Generation and Forecasting topics from greeningthegrid.org (NREL 2019).

5.1.2.4 ACTIVITY 2.4: Improve Power-System Planning for Future Scenarios

Lead Entities
- MEM (Department of Energy Policy and Planning)
- EDL

Timeline
Months 7-17 of Resilience Action Plan

Key Activities
- Organize training activities focused on advanced forecasting approaches (for variable renewable energy technologies and rapid dispatch) for power-systems operations staff (EDL and IPPs)
- Conduct training on energy demand and supply scenario development for long-term power-sector planning for power-sector planning staff (MEM) as part of ongoing IRRP work.

The Resilience Stakeholder Group identified lack of training and capacity building as key limitations to enhancing power-sector planning and operations. As the Lao PDR diversifies its generation mix, technical staff will need training to ensure the economic and reliable dispatch of power. Unlocking flexibility in power-system operations requires knowledgeable and capable technical staff that can ensure systems respond to changes in demand and supply. Staff require training in the planning, design, and operation of resilient power systems to ensure they make well-informed decisions based on best practices and high-quality, robust data. This includes training on approaches that allow staff to make operational changes closer to real time—allowing for dispatch decisions that are based on improved (shorter-term) demand and supply (e.g., wind and solar) forecasts. Staff also need training to ensure they can apply best practices in designing and considering multiple demand and supply scenarios to support longer-term power-sector planning.

Training may be a component of the larger power-sector resilience policy (see Action 1) or may be implemented by relevant power-sector organizations, such as EDL, to support improved power-system flexibility. The most important training needs in the short- to medium-term to support Lao power-sector resilience are: Advanced forecasting approaches (for variable renewable energy technologies and rapid dispatch) and scenario design for power-sector planning. These training activities will enhance the resilience action plan.

Additional Resources:

- Integration topics on greeningthegrid.org (NREL 2019)
- Insights on Planning for Power System Regulators (IRENA 2018).

5.1.2.5 ACTIVITY 2.5: Develop and Implement a Demand-Side Management Program to Reduce Peak Electricity Demand

Lead Entities
- MEM
- EDL

Timeline
Month 7 beyond month 25

Key Activities
- Research and develop a demand-side management program that addresses peak electricity demands and supports power-system flexibility
- Implement demand response regulations and a program with a first focus on large industrial demands.

The Resilience Stakeholder Group expressed concerns regarding a lack of demand-side resources (e.g., coordination with large industrial loads) available to support power-system flexibility and resilience. Demand-side management refers to a set of formal approaches for changing the amount and timing of customer electricity use to shift, reduce, or increase demand during specific periods—providing utilities and system operators with more flexibility in balancing supply and demand (Gagne et al. 2018). Increasing demand responsiveness through demand-side management programs with price signals, contractual agreements, or remote system operator control can help to increase power-system flexibility. Demand response programs can be inexpensive, effective ways to increase flexibility in the power system; however, these programs require strict regulations for response time, magnitudes of allowable interruptible load, reliability, and verification of demand-side resources (Katz, Milligan, and Cochran 2015; Katz, Cochran, and Miller 2015). Price signals and contractual agreements are two demand-response approaches that could be considered in the Lao PDR to address peak electricity demand concerns and provide additional flexibility.

- Price signals—Incentives to reduce demand during peak periods could be implemented through price signals that encourage use of power at nonpeak times through a multitiered rate structure program. This rate structure would incentivize load shifts with onpeak and offpeak (demand and energy) rates. Customers would have the option to join the program, voluntarily adjusting consumption habits to save money on their utility bills.
- Contractual agreements—These are typically bilateral contracts with large industry or commercial customers that have controllable loads. They provide interruptible load (or automated load control by the system operator) to shift demand to offpeak periods, offering demand-side flexibility during extreme situations. Agreements allow for quick control of a large portion of demand through contracts with a small set of customers. Agreements should specify limits to the frequency, number, time duration, and amount of interruptible load. Contracts can also be established with smaller customers in the commercial, agricultural, and residential sectors allowing direct control of energy-intensive devises (Katz, Cochran, and Miller 2015).

Researching and implementing a demand-side management program and implementing demand response approaches with a focus on large industrial load in the short term could provide additional demand-side resources for system planning and operations.

Additional Resources:

- Demand Response and Storage topic from greeningthegrid.org (NREL 2019)

- Demand Response Compensation Methodologies: Case Studies for Mexico (Gagne et al. 2018)
- Effective Mechanisms to Increase the Use of Demand-Side Resources (Crossley 2013).

5.1.2.6 ACTIVITY 2.6: Establish a Binding Contract or Agreement Within an Interconnection Procedure for Large Industrial Electricity Customers

Lead Entities
- MEM
- EDL
- Ministry of Planning and Investment
- Ministry of Industry and Commerce

Timeline
- Months 7-17 of Resilience Action Plan

Key Activities
- Research binding contract or applicable agreement within industrial load interconnection procedures to ensure levels of commitment for these new, large electrical customers
- Develop binding contracts of commitment process that align with existing grid codes and regulations (between large industries and EDL).

The Resilience Stakeholder Group determined that large industrial customers (mining, cement, and economic zones) constituting approximately 40% of electricity demand and revenue in the power sector are a high-risk vulnerability to the power sector. There is also uncertainty regarding new interconnections and demand from large industrial customers that complicates medium- to long-term planning, including the planning and construction of interconnections and supply.

Research and development of a binding contract or applicable agreement process within industrial load interconnection procedures by MEM, EDL, and the Ministry of Industry and Commerce would help to ensure levels of commitment for these new, large electrical customers and reduce uncertainty for planning. A binding contract or applicable agreement process would help to postpone planning and construction decisions to ensure commitment from the load and avoid the loss of time to unnecessary interconnection studies, and loss of investment in unneeded generation. This may be part of a tiered approach that begins with a prefeasibility note of interest from potential industrial loads and a high-level assessment conducted by EDL. Next, a connection query would initiate the formal connection process and would require initial review from EDL to ensure compliance with the national grid code or regulations. The next step would involve completing an application to connect from the load, which could be accompanied by a fee that would demonstrate sufficient financial commitment. The final offer to connect from EDL could include a binding contract that ensures commitment prior to actual grid connection.

Additional Resources:

- Connection Process (TransGrid 2019).

5.1.3 ACTION 3: Improve Coordination Across Hydropower Operations

The Resilience Stakeholder Group noted that coordination among dam operators remains a challenge in the Lao PDR. The lack of coordination results in the release of water that negatively impacts local populations and can also lead to a lack of hydropower resources and inefficient dispatch of power. To address this problem, decision-makers may consider power-sector regulation that sets a standardized

format for data collection and dissemination and ensures coordination among dam operators (both nationally and internationally).

5.1.3.1 ACTIVITY 3.1: Establish Protocol for Data Collection at all Hydropower Dams

Lead Entity
MEM

Timeline
Months 1-11 of Resilience Action Plan

Key Activities

- Review existing protocols and identify needed improvements and timeline for development of revised protocols
- Identify key data necessary to support coordination among dam operators
- Establish a protocol for the standardized collection, management, and sharing of these data by dam operators and other data sources
- Discuss protocol with relevant agencies prior to approval and dissemination.

Standardized data collection may stipulate the type of data collected, timescale of data, and formatting for data management and sharing. The timely sharing of hydropower data through a centralized database would support dam operators and the National Control Center of EDL in daily operations and during responses to extreme events.

The MEM and other stakeholders will have to identify the specific data sets that would support improved hydropower coordination in the Lao PDR; however, these data will likely include data related to real-time river flows, current and forecast reservoir dam levels, weather forecasts, and generation and water release plans. Data sources may include the Lao Department of Meteorology and Hydrology, which could provide close to real-time data on river flows and predictions of high-water flows, as well as warnings for high sediment levels (coordinate with Action 4 on sedimentation management) caused by landslides and related events. Dam operators—including EDL and IPPs—would also be key sources of data and could share their real-time and forecast data on river flows, current and forecast reservoir levels, and plans for generation and water release.

Data sharing should be standardized and automated to remove the possibility of human error in the process. It should also be shared and managed through a centralized database to ensure transparency and access. The National Control Center or a similar institution that already has experience managing the Lao PDR power system could lead efforts to improve coordination and communication among dam operators and other data sources.

Additional Resources:

- Enhancing Power Sector Resilience: Emerging Practices to Manage Weather and Geological Risks (Wang et al. 2016).

5.1.3.2 ACTIVITY 3.2: Mandate Data Sharing Between Hydropower Dam Operators

Lead Entities
- MEM
- EDL
- EDL-Gen
- IPPs

Timeline
Month 7 to beyond month 25

Key Activities
- Conduct study and site visits with relevant agencies for hydropower dam data sharing
- Develop guidelines to mandate data sharing between hydropower dam operators
- Discuss guidelines with relevant agencies prior to approval and dissemination.

A policy guaranteeing the timely sharing of accurate data would ensure the necessary data are available to support planning, operations, and emergency responses, in addition to instilling confidence in data users. Building on the established protocol for the collection, management, and sharing of key data on hydropower system operations, MEM and EDL could develop and enforce a policy that requires the sharing of these data. A national policy would ensure data collection and sharing follow the requirements set in the protocol (responsibilities, format, frequency, accuracy, and so on). The policy would establish an approach for the vetting of data and penalties for noncompliance by responsible parties.

5.1.4 ACTION 4: Facilitate Better Sedimentation Management in Hydropower Watersheds

Another key aspect of power-sector resilience in the Lao PDR is ensuring efficient operation of existing hydropower stations. The Resilience Stakeholder Group decided that an overarching watershed management policy would help advance this goal. The objective of the policy would be to reduce sedimentation in the watersheds that serve hydropower generators. The goal of these activities is to reduce sediment impacts on hydropower generators, including the pitting of turbines and silting of reservoirs that reduces available hydraulic head (potential energy). This, in turn, reduces operations and maintenance requirements for dam turbines and extends the lifespan of generators.

5.1.4.1 ACTIVITY 4.1: Develop Incentive and Enforcement Structures to Improve Watershed Protection

Lead Entities
MEM

Timeline
Months 1-22 of Resilience Action Plan

Key Activities
- Understand upstream sedimentation activities and existing enforcement policies
- Develop best-practice sedimentation reduction plans and train relevant staff
- Develop and promote incentives and enforcement of sedimentation reduction plans.

The Lao PDR is heavily reliant on hydropower systems. Therefore, maintaining the integrity of the hydro resource is critically important to building resilience in the power sector. This includes extending the life of hydropower components, such as turbines, by reducing turbidity and extending the life of the reservoir through reducing sedimentation. Upstream activity affects both priorities. Therefore, analysis of upstream activities that increase sedimentation could help determine the points of greatest impact. After identifying these points, sedimentation-reduction programs should design and implement activities to stabilize soils along riverbeds, reduce farm animal watering on vulnerable soils, stabilize slopes in landslide-prone zones, and encourage changes in construction practices on roads near rivers. Upstream users will likely need incentives to adopt behaviors that reduce sedimentation. MEM will need to work closely with other agencies and ministries to develop sedimentation reduction policies that are coordinated with other industries.

Additional Resources:

- Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs and Watersheds for Sustainable Use (Morris and Fan 1998)
- Sediment Management Strategies (IHA 2019b).

5.1.4.2 ACTIVITY 4.2: Create Educational Campaign and Community Awareness for Watershed Protection Upstream from Hydropower Dams

Lead Entities
- MEM
- MoNRE
- Ministry of Agriculture and Forestry

Timeline
Month 13 to beyond 25 of Resilience Action Plan

Key Activities
- Evaluate current community awareness
- Develop engagement plan that includes educational campaign and guidelines for upstream communities and discuss with stakeholders
- Implement and promote engagement plan for community awareness.

The successful implementation of a sedimentation reduction plan will require significant buy-in from upstream communities. An education campaign should be developed to aid these communities in understanding the benefits of reducing sedimentation activities. This engagement will likely include community engagement and listening sessions for the communities to voice concerns, developing educational materials, and obtaining long-term cooperation to ensure continued support of the programs.

Additional Resources:

- Communications and Consultation (IHA 2019a)

5.2 Proposed Timeline for the Resilience Action Plan

The Resilience Team developed a coordinated power-sector resilience action plan for these grouped resilience strategies. Figure 3 shows the relative timelines for this action plan. The sections that follow detail the steps to implement these resilience actions.

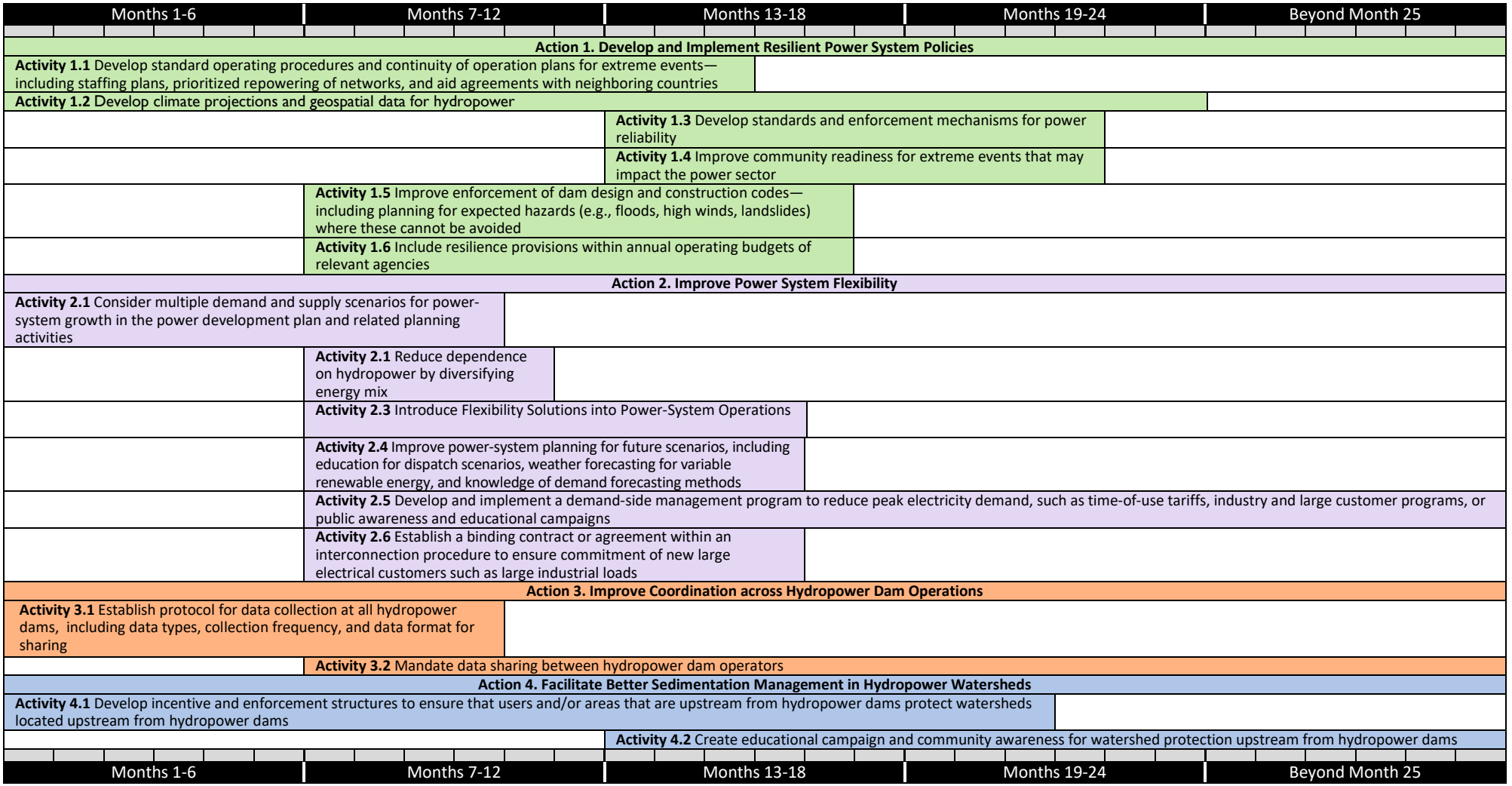

Figure 3. Timeline for implementation of key resilience actions

5.3 Using the Action Plan

This resilience action plan is not the final step in improving Lao power-sector resilience. Power-sector decision-makers will work to incorporate these actions, as appropriate, into the ongoing IRRP process and share this action plan with a wider stakeholder group. In addition, immediate, medium-term, and long-term steps in this action plan will enable decision-makers to address high-risk vulnerabilities and improve power-sector resilience for the long term.

Immediate Steps (1-24 Months)

- Address the immediate resilience actions detailed in this plan (Section 5) to develop a solid foundation for longer-term resilience solutions. These immediate actions will build capacity and support subsequent resilience actions.
- Incorporate the outcomes of this action plan and the preceding VA into ongoing IRRP activities (and subsequent power development plans) to support the identification of the best power development pathways for the country. The actions identified here are most effective when incorporated into comprehensive power development plans that establish appropriate institutional capacities and authorities to implement and sustain resilience activities in the long term.
- Review existing power-sector policies to ensure they are properly enforced and help the Lao power-sector construct, operate, and maintain systems (generation, transmission, and distribution) that follow existing codes and standards. This will help improve the technical resilience of systems and infrastructure as well as the organizational aspects that also support resilience.
- Disseminate this resilience action plan to a wider stakeholder audience and strengthen working relationships on resilience with local governments and other key actors in the Lao PDR to improve communications and responses in extreme events.
- Work with the VA Advisory Group to develop a plan to monitor the implementation of the power-sector resilience action plan.
- Work with the VA Advisory Group to identify sources of funding for plan implementation.

Medium-Term Steps (24-36 Months)

- Focus on the medium-term actions described in this plan (Section 5). Building resilience requires coordination between the power sector and the broader community. Many of the medium-term steps build on the foundation set in earlier steps and involve a more diverse stakeholder group in developing power-sector resilience through community outreach, education, and involvement.
- Consider the main themes of this resilience action plan in the development of a comprehensive power-sector resilience policy. A comprehensive resilience policy can increase the political feasibility of resilience actions and empower agencies to achieve the country's vision for power-sector resilience.
- Engage the Resilience Stakeholder Group in further review of the resilience strategies that received a priority level of Evaluate.
- Periodically review and update standard operating procedures, codes and standards, regulations, and power-system maintenance issues (such as those in resilience strategy R13) to ensure applicability of current practices to changing environmental conditions.

Long-Term Steps (Beyond 36 Months)

- The MEM and Advisory Group members took significant action in establishing the first broad Resilience Stakeholder Group to support power-sector resilience planning in the Lao PDR as part of this work. Ensure these stakeholders, and potentially additional stakeholders, remain

involved in resilience planning to build local technical capacity and ensure expert engagement in periodic evaluations and updates to the resilience action plan.

- Continued evaluation of the effectiveness of implemented actions would provide an opportunity to revise approaches and ensure the efficacy and relevance of any technical or operational measures.
- As environmental and political conditions change and the power system continues to develop, revise and update the action plan to reflect current vulnerabilities and develop the necessary resilience strategies.

6 Next Steps

Power-sector resilience is a dynamic concept and will not be achieved through ad hoc technical measures; however, the Lao PDR has the opportunity to develop comprehensive policies that increase its power-sector resilience incrementally over time. As power-sector decision-makers work to implement the actions detailed in Section 5 of this report, they may wish to explore the value of developing comprehensive resilience policies and strategies that also improve institutional and organizational capacity for implementing and managing other technical solutions. Policies and strategies can establish the range of appropriate and feasible options for addressing high-risk vulnerabilities; assign responsibilities to key power-sector actors; and detail government oversight and enforcement mechanisms that ensure implementation of these actions.

New lessons and innovative power-sector resilience strategies will evolve and emerge as the Lao PDR and other countries build experience addressing high-risk power-sector vulnerabilities. It will be crucial for Lao PDR to continually assess its vulnerabilities and incorporate novel resilience strategies under a continual power-sector planning framework (Cox et al. 2017). Extensive engagement of diverse stakeholders will help identify, evaluate, and implement the most appropriate new strategies and lessons in the planning process. The ongoing IRRP activity is an opportunity for the Lao PDR to ensure resilience strategies from this and future resilience action plans are incorporated into the country's power-sector planning framework.

Building power-sector resilience will require a balanced approach that builds both technical and institutional capacity into resilience policies, strategies, and actions. Infrastructure and system design (technical capacity) may help to overcome disruptions; however, power-sector managers' and operators' capability to anticipate and react quickly and appropriately (institutional capacity) is an essential component to resilience. Technical measures may be more familiar to the technical staff at the MEM and EDL and may include diversifying the generation mix, reforesting areas prone to erosion, building redundancy into transmission and distribution systems, and setting up backup power systems. Implementing institutional measures to enhance resilience may include improving change readiness (ability to anticipate hazards and adapt and learn from the implementation of resilience strategies), soft networks (partnerships, communication channels, and cooperation at different government levels), capability and knowledge (ensuring informed, trained technical staff utilize high-quality data in their decision-making), in addition to leadership and culture (larger organizations' approach to address challenges, adapt, innovate, and seek new opportunities). These institutional aspects often play a larger role in improving power-sector resilience than purely technical measures (Wang et al. 2016).

References

ADB. 2015. “Renewable Energy Developments and Potential in the Greater Mekong Subregion.” Manila: Asian Development Bank (ADB). http://hdl.handle.net/11540/5054.

———. 2017. “Lao People’s Democratic Republic, 2017–2020 — More Inclusive and Sustainable Economic Growth.” Country Partnership Strategy. Manila, Philippines: Asian Development Bank (ADB). https://www.adb.org/sites/default/files/institutional-document/360121/cps-lao-2017-2020.pdf.

———. 2019. “Asian Development Outlook (ADO) Supplement.” Manila, Philippines: Asian Development Bank (ADB). https://data.adb.org/dataset/gdp-growth-asia-and-pacific-asian-development-outlook.

Beilfuss, Richard, and Tran Triet. 2014. “A Scoping Study on Climate Change and Hydropower in the Mekong River Basin: A Synthesis of Research.” Deutsche Gesellschaft Für Internationale Zusammenarbeit GmbH (GIZ). https://www.giz.de/en/downloads/giz2014-en-study-climate-change-hydropower-mekong.pdf.

Bradlow, Daniel D., Alessandro Palmieri, and Salman M.A. Salman. 2002. “Regulatory Frameworks for Dam Safety: A Comparative Study.” 25069 Law, Justice, and Development Series. Washington, D.C.: World Bank. http://documents.worldbank.org/curated/en/785201468763768736/pdf/multi0page.pdf.

Cochran, Jaquelin, Mackay Miller, Owen Zinaman, Michael Milligan, Doug Arent, Bryan Palmintier, Mark O’Malley, et al. 2014. “Flexibility in 21st Century Power Systems.” NREL/TP-6A20-61721. Golden, CO: 21st Century Power Partnership. https://www.nrel.gov/docs/fy14osti/61721.pdf.

Cox, Sadie, Eliza Hotchkiss, Dan Bilello, Andrea Watson, Alison Holm, and Jennifer Leisch. 2017. “Bridging Climate Change Resilience and Mitigation in the Electricity Sector Through Renewable Energy and Energy Efficiency: Emerging Climate Change and Development Topics for Energy Sector Transformation.” Technical Report NREL/TP-6A20-67040. Golden, CO: National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy18osti/67040.pdf.

Crossley, David. 2013. “Effective Mechanisms to Increase the Use of Demand-Side Resources.” The Global Power Best Practices Series. Washington, D.C.: Regulatory Assistance Project (RAP). https://www.raponline.org/knowledge-center/effective-mechanisms-to-increase-the-use-of-demand-side-resources/.

Dell, Jan, Susan Tierney, Richard G. Newell, Rich Richels, John Weyant, and Thomas J. Wilbanks. 2014. “Ch. 4: Energy Supply and Use.” In *Climate Change Impacts in the United States: The Third National Climate Assessment*, edited by Jerry M. Melillo, Terese (T.C.) Richmond, and Gary W. Yohe. Washington, D.C.: U.S. Global Change Research Program. https://nca2014.globalchange.gov/downloads.

DOE. 2018a. “Community Guidelines for Energy Emergencies.” Washington, D.C.: U.S. Department of Energy (DOE). https://www.energy.gov/ceser/community-guidelines-energy-emergencies.

———. 2018b. “Hydropower Resource Assessment and Characterization.” Washington, D.C.: U.S. Department of Energy (DOE). https://www.energy.gov/eere/water/hydropower-resource-assessment-and-characterization.

EDL. 2015. “Annual Report 2015.” Vientiane: Électricité du Laos (EDL). http://www.edl.com.la/ckfinder/userfiles/files/Annual%20report/Annual%20Report%202015%20Okay%20.pdf.

EEI. 2013. “Understanding the Electric Power Industry’s Response and Restoration Process.” Washington, D.C.: Edison Electric Institute (EEI). https://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/MA_101FINAL.pdf.

———. 2017. “Historic Storms, Historic Responses.” Washington, D.C.: Edison Electric Institute (EEI). https://www.energy.gov/sites/prod/files/2018/02/f49/1_Mutual%20Assistance%20Agreements%20-%20David%20Bonenberger%2C%20EEI.pdf.

Energy Charter Secretariat. 2015. “Model Intergovernmental and Host Government Agreements for Cross-Border Electricity Projects.” Brussels: Energy Charter Secretariat. https://energycharter.org/fileadmin/DocumentsMedia/Legal/EMAs_en.pdf.

Gagne, Doug, Edward Settle, Alexandra Aznar, and Riccardo Bracho. 2018. “Demand Response Compensation Methodologies: Case Studies for Mexico.” NREL/ TP-7A40-71431. Golden, CO: 21st Century Power Partnership. https://www.nrel.gov/docs/fy18osti/71431.pdf.

GFDRR. 2014. “Lao PDR: Strengthening Institutional Capacities for Resilient Recovery.” Country Case Study Series Disaster Recovery Framework Guide. Washington, D.C.: Global Facility for Disaster Reduction and Recovery (GFDRR). https://www.gfdrr.org/en/publication/lao-pdr-strengthening-institutional-capacities-resilient-recovery.

ICEM. 2013. “USAID Mekong ARCC Climate Change Impact and Adaptation Study for the Lower Mekong Basin: Main Report.” Bangkok: USAID Mekong ARCC Project: Prepared for the United States Agency for International Development by the International Centre for Environmental Management (ICEM). https://www.climatelinks.org/sites/default/files/asset/document/mekong_arcc_main_report_printed_-_final.pdf.

IEEE. 2012. “IEEE 1366-2012 - IEEE Guide for Electric Power Distribution Reliability Indices.” https://standards.ieee.org/standard/1366-2012.html.

IFC. 2018. “Environmental, Health, and Safety Approaches for Hydropower Projects.” Washington, D.C.: International Finance Corporation (IFC). https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/publications/publications_gpn_EHSHydropwer.

IHA. 2019a. “Communications and Consultation.” International Hydropower Association (IHA). 2019. https://www.hydropower.org/topics/environmental-and-social/communicationsandconsultation.

———. 2019b. “Sediment Management Strategies.” International Hydropower Association (IHA). 2019. https://www.hydropower.org/sediment-management/about/sediment-management-strategies.

IRENA. 2018. “Insights on Planning for Power System Regulators.” Abu Dhabi: International Renewable Energy Agency (IRENA). https://www.irena.org/publications/2018/Jun/Insights-on-planning-for-power-system-regulators.

Katz, Jessica, Jaquelin Cochran, and Mackay Miller. 2015. “Methods for Procuring Power System Flexibility.” NREL/FS-6A20-63040. Golden, CO: National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy15osti/63040.pdf.

Katz, Jessica, Michael Milligan, and Jaquelin Cochran. 2015. “Sources of Operational Flexibility.” NREL/FS-6A20-63039. Golden, CO: National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy15osti/63039.pdf.

Lao Ministry of Planning and Investment. 2016. “Lao PDR, 8th Five-Year National Socio-Economic Development Plan (2016-2020).” Vientiane: Lao Ministry of Planning and Investment. http://www.la.one.un.org/images/publications/8th_NSEDP_2016-2020.pdf.

Laotian Times. 2017. “Laos: Electricity Facts.” Vientiane: Laotian Times. https://laotiantimes.com/2017/01/10/laos-latest-electricity-facts/.

Laspho, Litthanoulok. 2016. “Electricity Access in Lao PDR: Ministry of Energy and Mines (MEM), Department of Energy Policy and Planning, Lao PDR.” Presentation presented at the Seminar

on Supporting Sustainable Development Goals, UNCC, Bangkok, Thailand, June 21. https://unosd.un.org.

Lee, Nathan, and Sherry Stout. 2018. "Planning a Resilient Power Sector: Ensuring Reliable, Secure, Safe, and Affordable Electricity (English Version)." Technical Report NREL/TP-7A40-71543. Golden, CO: National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy18osti/71543.pdf.

———. 2019. "ການວາງແຜນສິ່ງເສີມການປັບຄືນສະພາບເອົາໃຫ້ອອກຂະແໜງພະລັງງານ: ການຮັບປະກັນໄຟຟ້າໃຫ້ມີຄວາມສະຖຽນ, ໝັ້ນຄົງ, ປອດໄພ ແລະ ໃນລາຄາທີ່ສາມາດຊື້ໄດ້ (Lao Version) (Planning a Resilient Power Sector: Ensuring Reliable, Secure, Safe, and Affordable Electricity)." Technical Report NREL/TP-7A40-72792. Golden, CO: National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy19osti/72792.pdf.

MEM. 2015a. "Demand Forecast 2016-2030: Main Report." Vientiane: Lao Ministry of Energy and Mines (MEM).

———. 2015b. "Electricity Statistics Yearbook 2015 of Lao PDR." Vientiane: Lao PDR Ministry of Energy and Mines (MEM). http://www.laoenergy.la/download_file.php?id_ph=143.

———. 2018. "Lao PDR Energy Statistics 2018." Vientiane: Lao Ministry of Energy and Mines (MEM) with the support of the Economic Research Institute for ASEAN and East Asia.

Morris, Gregory L., and Jiahua Fan. 1998. *Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs and Watersheds for Sustainable Use*. New York: McGraw-Hill. https://www.hydropower.org/sediment-management/resources/publication-reservoir-sedimentation-handbook.

NERC. 2007. "Security Guideline for the Electricity Sector: Continuity of Business Processes and Operations Operational Functions." Washington, D.C.: North American Electric Reliability Corporation (NERC). https://www.nerc.com/comm/CIPC_Security_Guidelines_DL/WTRMRK-Continuity_Business_Operational_Functions-Retired.pdf.

NREL. 2019. "Greening the Grid." Greening the Grid from the US Agency for International Development (USAID) and the US Department of Energy's National Renewable Energy Laboratory (NREL). 2019. http://greeningthegrid.org/.

Phongsavath, Anousak. 2019. "Policy of Renewable Energy Promotion and Rural Electrification in Lao PDR." Presentation presented at the Workshop on SDG7 Implementation in Asia and the Pacific. March 19 to 21, 2019, Bangkok. https://www.unescap.org/events/workshop-sdg7-implementation-asia-and-pacific.

Sharma, Ashutosh. 2017. "Performance Benchmarking for Electricity Distribution Utilities." Presentation presented at the 11th Capacity Building Programme for Officers of Electricity Regulatory Commissions, Singapore. https://www.iitk.ac.in/ime/anoops/FOR-17/FOR_17_photos/PPTs/Singapore_Day_5/DNV_GL_Benchmarking.pdf.

Stout, Sherry, Nathan Lee, Sadie Cox, James Elsworth, and Jennifer Leisch. 2019. "Power Sector Resilience Planning Guidebook: A Self-Guided Reference for Practitioners." Technical Report NREL/TP-7A40-73489. Golden, CO: National Renewable Energy Laboratory (NREL). https://www.nrel.gov/docs/fy19osti/73489.pdf.

The Tellus Institute. 2010. "Best Practices Guide: Integrated Resource Planning for Electricity." Washington, D.C.: The Tellus Institute and The Energy Group Institute of International Education. https://pdf.usaid.gov/pdf_docs/PNACQ960.pdf.

TransGrid. 2019. "Connection Process." TransGrid. 2019. https://www.transgrid.com.au/what-we-do/our-network/connections-and-modifications/connection-process/Pages/default.aspx.

USGS. 2019. "U.S. Geological Survey Water Data for the Nation." U.S. Geological Survey (USGS). 2019. https://waterdata.usgs.gov/nwis.

Vogel, Jason, Lorine Giangola, Sherry Stout, and Nathan Lee. 2018. "A Comprehensive Vulnerability Assessment of the Lao PDR Power Sector." Unpublished, Citation-Only Report. Washington, D.C.: United States Agency for International Development (USAID).

Wang, Xiaoping, Ray Brown, Guillaume Prudent-Richard, and Katrina O'Mara. 2016. "Enhancing Power Sector Resilience Emerging Practices to Manage Weather and Geological Risks." Washington DC 20433: International Bank for Reconstruction and Development / The World Bank. https://openknowledge.worldbank.org/handle/10986/26382.

Wijayatunga, Priyantha. 2016. "Power Trade in Greater Mekong Sub-Region." Presentation presented at the Workshop on Sustainable Development of Power Sector and Enhancement of Electricity Trade in South Asia Region: Policy, Regulatory Issues/Challenges and the Way Forward. January 15, 2016, New Delhi. https://sari-energy.org/wp-content/uploads/2016/03/Session-3-Dr-Priyantha-Wijayatunga-GMS.pdf.

Wilson, Rachel, and Bruce Biewald. 2013. "Best Practices in Electric Utility Integrated Resource Planning: Examples of State Regulations and Recent Utility Plans." Montpelier, Vermont: Prepared by Synapse Energy Economics for the Regulatory Assistance Project. https://www.raponline.org/wp-content/uploads/2016/05/rapsynapse-wilsonbiewald-bestpracticesinirp-2013-jun-21.pdf.

World Bank. 2011. "Climate Risk and Adaptation Country Profile: Lao PDR." Washington, D.C.: World Bank and Global Facility for Disaster Reduction and Recovery (GFDRR). https://www.gfdrr.org/en/publication/climate-risk-and-adaptation-country-profile-lao-pdr.

Appendix A: Members of VA Advisory Group

Table A-1. Members of the Lao PDR VA Advisory Group

Name		Organization	Position
Sanhya	Somvichit	Department of Energy Policy and Planning, MEM	Deputy Director General
Litthanoulok	Laspho	Power Generation Division, Department of Energy Policy and Planning, MEM	Chief of Division
Davanhny	Xaneth	Energy Policy and Planning Division, Department of Energy Policy and Planning, MEM	Chief of Division
Soukvilai	Phimmasene	System Planning Division, Department of Energy Policy and Planning, MEM	Technical Officer
Chitpanya	Phamisith	Power Development Plan Office, EDL	Deputy Chief of Office
Hongsakoun	Kongsup	Department of Transmission System Planning, EDL	Technical Officer
Phetsamone	Bounnouvong	National Control Center, EDL	Deputy Chief of Unit
Vinalong	Phonekeo	Project Study Division, Department of Business Development, EDL-Gen	Technical Officer

Appendix B: Members of the VA Stakeholder Group

Table B-1 lists all stakeholders who participated in the workshop on Assessing Vulnerabilities in the Lao PDR Power Sector, August 21-23, 2018, in Vientiane, Lao PDR.

Table B-1. Lao PDR VA Stakeholder Group Members

Name		Organization	Position
Dr. Daovong	Phonekeo	MEM	Permanent Secretary, Cabinet Office
Sanhya	Somvichit	Department of Energy Policy and Planning, MEM	Deputy Director-General
Davanhny	Xaneth	Energy Policy and Planning Division, MEM	Chief of Division
Chansamone	Xaiyalath	Energy Policy and Planning Division, MEM	Deputy Chief of Division
Phaysone	Phouthonesy	Energy Policy and Planning Division, MEM	Technical Officer
Yevang	Nhiavue	Energy Policy and Planning Division, MEM	Technical Officer
Khamphan	Lasachak	Energy Policy and Planning Division, MEM	Technical Officer
Soukvilay	Phimmasen	Power System Planning Division, MEM	Deputy Chief of Division
Anousith	Bounsou	Information Division, MEM	Technical Officer
Chitpanya	Phamisith	Power System Planning Office, EDL	Deputy Chief
Phetsamone	Bounnouvong	National Control Centre, EDL	Deputy Chief of Planning Team
Vinalong	Phonekeo	Department of Business Development, EDL-Gen	Technical Officer
Thippavanh	Mamphousay	EDL-Gen	Technical Officer
Noumay	Souvannaphoum	Project Division Lao Holding State Enterprise	Deputy Chief
Mona	Sychanthongthip	Department of Planning and Cooperation, Ministry of Industry and Commerce	Technical Officer
Kongsin	Saiyalin	Alternative Energy Division, Ministry of Science and Technology	Deputy Chief of Division
Boupha	Phiathep	Department of Natural Resource and Environmental Policy, Ministry of Natural Resource and Environment	Technical Officer
Vimala	Bulyaphol	Department of Planning and Cooperation, MEM	Technical Officer
Phayvanh	Phasiboriboun	Ministry of Labor and Social Welfare	
Phonesamay	Phaxay	Central Bank of Lao PDR	Deputy of Division
Lay	Phommalin	Department of Energy Management, MEM	
Alounzay	Inthilath	MEM	Technical Officer
Vilakone	Maniphousay		Officer
Mixaykone	Phongsavath		Officer

Appendix C: Resilience Technical Work

C.1 Identify Resilience Solutions

The Resilience Team facilitated an activity with the Resilience Stakeholder Group to develop broad power-sector resilience solutions that address high- and medium-high-risk vulnerabilities in the Lao power sector. After the workshop, the Resilience Team reviewed this initial set of solutions, combined solutions that overlapped significantly, and developed a final set of solutions for aggregation into the action plan. Table 15 (section 4.7) presents the list of high-risk vulnerabilities and their risk scores, and Table C-1 presents the final set of 42 resilience solutions and the vulnerabilities that they address. The solutions may address one or more vulnerabilities and some vulnerabilities could be addressed by multiple resilience solutions.

Table C-1. Power-Sector Resilience Solutions for Lao PDR

Resilience Solution (and Resilience Solution Number)		Specific Vulnerabilities Addressed
R1	Establish protocol for data collection at all hydropower dams.	V32
R2	Develop policy to improve communications and require data sharing between hydropower dam operators.	V15, V32
R3	Improve ability to collect and make use of data (meteorological, hydrological, and climate change data).	V32
R4	Construct protection systems, underground lines, or redundant lines for important transmission and/or distribution lines or substations.	V19, V24
R5	Improve survey and spatial data on landslide-prone areas to support siting of distribution systems.	V19, V29
R6	Reforest landslide-prone areas near distribution systems.	V19, V29
R7	Develop policy and enforcement mechanisms to ensure that design and construction of distribution systems in hazard zones (flood-prone and landslide-prone zones) adhere to adequate standards and codes.	V19, V24, V29
R8	Incorporate sediment mitigation actions in construction and operation of hydropower dams.	V25, V29
R9	Incentivize users or areas that are upstream from hydropower dams to reduce sedimentation.	V25
R10	Conduct educational campaign or community awareness for watershed protection upstream from hydropower dams.	V25, V29
R11	Improve and develop policies or procedures for sediment management in watersheds located upstream from hydropower dams.	V25, V29
R12	Enforce any existing sediment and water management plans to protect watersheds located upstream from hydropower dams.	V25, V29
R13	Develop standard operating procedures and contingency plan for extreme events.	V28, V29, V23, V18, V14
R14	Develop an early warning system to notify critical staff in the case of an extreme event.	V27, V28
R15	Increase staff training of critical skills to respond in case of an extreme event.	V15, V26, V28
R16	Ensure large industry electricity customers aid in creating system flexibility.	V5
R17	Develop a law or regulation that requires a commitment in the form of a contract or other agreement between electricity customers, Ministry of Industry and Commerce, and EDL (or other applicable utility).	V5
R18	Improve policy and regulation to facility building of transmission lines that may allow for separate circuits for medium-sized factories.	V5, V20
R19	Increase automation in hydropower system to support coordination among operators.	V15

Resilience Solution (and Resilience Solution Number)		Specific Vulnerabilities Addressed
R20	Provide incentives and recognition for good coordination between hydropower dam operators.	V15
R21	Prepare portable equipment and tools to allow for a rapid response in the event of an extreme event.	V26, V28
R22	Develop approaches to facilitate customer reporting of power-system problems (such as posting a photo and location on social media).	V26
R23	Conduct community outreach and education to encourage appropriate end-user behavior during extreme events to better prepare the community for extreme events that may impact the power sector.	V26
R24	Ensure the monitoring and enforcement of power-system standards and codes, which may include fines and penalties for developers.	V12, V13, V16, V21, V29
R25	Automate power system (i.e., generation and dispatch) responses, where possible.	V15, V17, V20
R26	Implement planning and policy to diversify the electricity generation mix to reduce dependence on hydropower.	V7, V20, V29, V31
R27	Ensure inclusion of upgrades and maintenance activities for generation, transmission, and distribution systems within annual operating budgets, including those that increase system control and flexibility.	V17, V20, V29, V31
R28	Consider multiple demand and supply scenarios for power-system growth in the power development plan and related planning activities.	V17, V7
R29	Develop regulation and/or an enforcement mechanism that requires EDL (and other potential utilities) to provide reliable power (such as a fine or penalty for unreliable power).	V20
R30	Build technical capacity for effective dispatching and controlling of power generators by National Control Center staff.	V5, V15, V17, V20
R31	Increase technical knowledge of staff on demand-forecasting methods for planning at the MEM and EDL.	V17
R32	Develop and implement a demand-side management program to reduce peak electricity demand (such as time-of-use tariffs, industry and large customer programs, or public awareness and education campaigns).	V5, V17, , V31
R33	Develop resilient power-system standards for the specifications and operation of equipment and systems.	V3, V9, V10, V11, V14, V18, V19, V23, V24, V29
R34	Increase the installed capacity of distributed generation and backup power systems.	V5, V7, V19, V24, V29, V31
R35	Expand and build redundant transmission and distribution systems.	V5, V7
R36	Standardize risk-assessment protocols for all new power-system projects.	V13, V21, V29
R37	Develop process for compensating losses that result from using inferior or nonstandard equipment.	V13, V21
R38	Improve system monitoring and forecasting of short-term electricity demand for power-system operation.	V7, V15, V29
R39	Create a hotline for reporting poor construction or installation of equipment or systems.	V13, V21
R40	Create regulation that mandates improved hydropower dam siting.	V13, V29
R41	Develop an enforcement mechanism that allows for the recovery of government funds from failed power-system projects that do not adhere to applicable codes and standards.	V13, V21, V29
R42	Increase workforce knowledge and understanding of correct construction processes and operations (such as implementing workforce qualification or certification programs).	V12, V13, V21, V29

See Section 4 of this report for additional details on the vulnerabilities addressed.

C.2 Score and Prioritize Solutions

Some of the methodologies for scoring and prioritizing resilience solutions are discussed in Section 3 of this report. Table 6 (section 3.7.2) shows the criteria and scoring thresholds that the Resilience Stakeholder Group established. The Resilience Stakeholder Group and the Resilience Team applied these criteria to score each of the power-sector resilience solutions shown in Table C-2. The resilience solutions received a priority level of Implement, where two or more criteria received a score of Good and the remaining criteria scored at least Fair. Resilience solutions that received a Poor score for effectiveness were removed from evaluation. Any solutions that received two or more scores of Poor on criteria were removed from consideration. All other solutions were determined to require additional evaluation before either implementation or removal from consideration.

Table C-2. Scoring of Resilience Strategies on Criteria and Priority-Level Evaluation

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R1	Establish protocol for data collection at all hydropower dams.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Local staff have necessary expertise • Consistent with Lao PDR power development plan (PDP) and other policies.	• Good • Less than USD $500,000 in capital costs.	• Good • Less than 2 years to complete.	Implement
R2	Develop policy to improve communications and require data sharing between hydropower dam operators.	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk).	• Good • Local technical experts available.	• Good • Less than USD $500,000 in capital costs.	• Fair • 3 years for implementation.	Implement
R3	Improve ability to collect and use data (meteorological, hydrological, and climate change data).	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk).	• Fair • Local and Southeast Asian technical expertise.	• Fair • Between USD $500,000 and USD $1,000,000 in capital costs.	• Fair • 3 years for implementation.	Evaluate
R4	Construct protection systems, underground lines, or redundant lines for important transmission and/or distribution lines and/or substations.	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk).	• Good • Local technical staff available.	• Poor • Greater than USD $1,000,000 in capital costs.	• Poor • More than 5 years to complete implementation.	Evaluate

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R5	Improve survey and spatial data on landslide-prone hazard areas to support siting of distribution systems.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Local staff have necessary expertise.	• Poor • Greater than USD $1,000,000 in capital costs.	• Fair • 3 years for implementation.	Evaluate
R6	Reforest landslide-prone areas near distribution systems.*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk).	• Good • Local staff have necessary expertise.	• Fair • Between USD $500,000 and USD $1,000,000 in capital costs.	• Fair • 2-5 years to plant trees to decrease erosion.	Implement
R7	Develop policy and enforcement mechanism to ensure that design and construction of distribution systems in hazard zones (flood-prone and landslide-prone zones) adhere to adequate standards and codes.	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Enables other resilience strategies.	• Good • Local technical experts available.	• Good • Less than USD $500,000 in capital costs.	• Fair • 2-5 years for implementation.	Implement
R8	Incorporate sediment mitigation actions in construction and operation of hydropower dams.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Fair • Local and SE Asian technical expertise.	• Poor • Greater than USD $1,000,000 in capital costs.	• Poor • More than 5 years to complete implementation.	Remove from Consideration
R9	Incentivize users or areas that are upstream from hydropower dams to reduce sedimentation.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Local staff have necessary expertise.	• Good • Less than USD $500,000 in capital costs.	• Good • Less than 2 years to complete.	Implement

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R10	Conduct educational campaign or community awareness for watershed protection upstream from hydropower dams.	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Local staff have necessary expertise.	• Good • Less than USD $500,000 in capital costs.	• Fair • From 2 to 5 years to complete implementation.	Implement
R11	Improve or develop policies or procedures for sediment management in watersheds located upstream from hydropower dams.*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk).	• Good • Local technical experts available. •	• Good • Less than USD $500,000 in capital costs.	• Fair • From 2 to 5 years to complete implementation.	Implement
R12	Enforce any existing sediment and/or water management plans to protect watersheds located upstream from hydropower dams.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Local staff have necessary expertise.	• Good • Less than USD $500,000 in capital costs.	• Good • Less than 2 years to complete.	Implement
R13	Develop standard operating procedures and continuity-of-operation plans for extreme events.	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Local staff have necessary expertise.	• Good • Less than USD $500,000 in capital costs.	• Fair • From 2-5 years to complete implementation.	Implement
R14	Develop an early warning system to notify critical staff in the case of an extreme event.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Fair • Local and SE Asian technical expertise.	• Fair • Between USD $500,000 and USD $1,000,000 in capital costs.	• Fair • From 2-5 years to complete implementation.	Evaluate
R15	Increase staff training of critical skills to respond in case of an extreme event.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Fair • Local and SE Asian technical expertise.	• Good • Less than USD $500,000 to implement.	• Good • Less than 2 years for implementation.	Implement

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R16	Ensure large industry electricity customers aid in creating system flexibility.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Fair • Local and SE Asian technical expertise • May be resistant to participation in demand-response programs.	• Fair • Between USD $500,000 and USD $1,000,000 in capital costs.	• Fair • From 2-5 years to complete implementation.	Evaluate
R17	Develop a law or regulation that requires a commitment in the form of a contract or other agreement between electricity customers, Ministry of Industry and Commerce, and EDL (or other applicable utility).	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Internal consultant available with technical capabilities.	• Good • Less than USD $500,000 to implement.	• Fair • 3 years for implementation.	Implement
R18	Improve policy and regulation to facility building of transmission lines that may allow for separate circuits for medium-sized factories.	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for multiple vulnerabilities.	• Fair • Requires technical experts from China and/or India or depends on conditions of a loan.	• Good • Less than USD $500,000 to implement.	• Good • 2 years for implementation.	Implement
R19	Increase automation in hydropower system to support coordination among operators.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Poor • Requires foreign technical experts • Full automation of power system is beyond technical capabilities of Lao PDR grid technology at this time.	• Poor • Greater than USD $1,000,000 in capital costs.	• Poor • More than 5 years to complete implementation.	Remove from Consideration
R20	Provide incentives or recognition for good coordination between hydropower dam operators.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Fair • Requires foreign technical experts.	• Fair • Between USD $500,000 and USD $1,000,000 in capital costs.	• Fair • 3-5 years for implementation.	Evaluate

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R21	Prepare portable equipment and tools to allow for a rapid response in the event of an extreme event.*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk).	• Fair • Requires foreign technical experts.	• Poor • Greater than USD $1,000,000 in capital costs.	• Fair • 3-5 years for implementation.	Evaluate
R22	Develop approaches to facilitate customer reporting of power system problems (i.e., posting a photo and location on social media).*	• Poor • Reduces only a little risk for a vulnerability (less than 30% reduction in risk) • Reduces risk for only one vulnerability.	• Fair • Local staff have necessary expertise • May not be consistent with Lao PDR PDP and other policies.	• Good • Less than USD $500,000 to implement.	• Fair • 3-5 years for implementation.	Remove from Consideration
R23	Improve community readiness for extreme events that may impact the power sector.	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Local staff have necessary expertise.	• Good • Less than USD $200,000 to implement.	• Fair • 3-5 years for implementation.	Implement
R24	Ensure the monitoring and enforcement of power-system standards and codes that may include fines and penalties for developers.	• Good • Technically effective due to the risk of fines or other penalties.	• Fair • Requires third-party consultant to implement.	• Good • Approximately USD $200,000 to implement • Budget from developer already includes funds to monitor work.	• Good • Less than 2 years for implementation • Regulation is already available; however, time is needed to train staff.	Implement
R25	Automate power responses system (i.e., generation and dispatch) where possible.*	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk). • May introduce new vulnerabilities related to cyber operations.	• Poor • Requires foreign technical experts • Full automation of power system is beyond technical capabilities of Lao PDR grid technology at this time.	• Poor • Greater than USD $1,000,000 in capital costs.	• Fair • 2-5 years for implementation.	Remove from Consideration

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R26	Implement planning and policy to diversify the electricity generation mix to reduce dependence on hydropower.*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for multiple vulnerabilities.	• Good • Consistent with Lao PDR PDP and other policies • Requires foreign experts.	• Good • Less than USD $200,000 to implement • Incorporate into ongoing planning activities.	• Fair • 2-5 years for implementation.	Implement
R27	Ensure inclusion of resilience activities and appropriate upgrades and maintenance activities for generation, transmission, and distribution systems within annual operating budgets.*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for multiple vulnerabilities.	• Fair • Initially requires foreign technical experts.	• Good • Less than USD $500,000 to implement.	• Fair • 2-5 years for implementation.	Implement
R28	Consider multiple demand and supply scenarios for power-system growth in the PDP and related planning activities.	• Fair • Not entirely sure that more scenarios would resolve vulnerabilities • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Have technical staff that work on the Lao PDP • Strategy consistent with the Lao PDP.	• Good • Less than USD $200,000 to implement • Already have a model and just need to dedicate time to develop more scenarios.	• Good • 1 year to implement and regularly update the Lao PDP every 5 years.	Implement
R29	Develop regulation or an enforcement mechanism that requires EDL (and other potential utilities) to provide reliable power (such as a fine or penalty for unreliable power).	• Good • Technically effective due to the risk of fines or other penalties and allows for increased control of utilities.	• Fair • There may be some resistance to fines or penalties from existing utilities.	• Good • Less than USD $200,000 to implement (minimal cost).	• Good • Less than 2 years to implement • Requires a short amount of time to improve weakness of existing rules.	Implement
R30	Build technical capacity for generator management of National Control Center staff.*	• Good • Reduces risk for multiple vulnerabilities.	• Fair • Initially requires foreign technical experts.	• Good • Less than USD $500,000 to implement.	• Good • Less than 2 years to implement.	Implement

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R31	Increase technical knowledge of staff on demand forecasting methods for planning at MEM and EDL.*	• Fair • Not entirely certain that new demand forecasting methods would resolve vulnerabilities • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Fair • Initially requires foreign technical experts.	• Good • Less than USD $500,000 to implement.	• Good • Less than 2 years to implement.	Implement
R32	Develop and implement a demand-side management program to reduce peak electricity demand (such as time-of-use tariffs, industry and large customer programs, or public awareness and education campaigns).	• Good • Reduces risk for multiple vulnerabilities.	• Good • Strategy consistent with the Lao PDP.	• Good • Up to USD $400,000 to implement.	• Good • No more than 2 years to implement.	Implement
R33	Develop resilient power-system standards for the specifications and operation of equipment and systems.*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for multiple vulnerabilities.	• Fair • Requires foreign technical experts.	• Good • Less than USD $500,000 in capital costs.	• Fair • From 2-5 years to complete implementation.	Implement
R34	Increase the installed capacity of distributed generation and backup power systems.	• Good • Reduces risk for multiple vulnerabilities.	• Fair • No policy for distributed generation in current PDP • Requires foreign experts.	• Poor • Greater than USD $1,000,000 in capital costs.	• Fair • 2-5 years for implementation.	Evaluate

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R35	Expand or build redundant transmission or distribution systems.	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for multiple vulnerabilities.	• Poor • Strategy does not align with goal of transmission expansion in Lao PDP, which is focused on electricity access and not redundant systems.	• Poor • Large amount of investment • Greater than USD $1,000,000 in capital costs.	• Poor • More than 5 years to expand and build systems.	Remove from Consideration
R36	Standardize risk assessment protocols for all new power-system projects.*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for multiple vulnerabilities.	• Fair • Requires foreign experts.	• Good • Less than USD $500,000 to implement.	• Good • Less than 2 years for implementation.	Implement
R37	Develop process for compensating losses because of bad equipment.	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Internal consultant available with technical capabilities.	• Good • Less than USD $500,000 to implement.	• Good • Less than 2 years for implementation.	Implement
R38	Improve system monitoring and forecasting of short-term electricity demand for power-system operation.	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk) • Reduces some risk for multiple vulnerabilities.	• Poor • Requires foreign experts • Strategy does not align with goal of transmission expansion in Lao PDP, which is focused on electricity access and not redundant systems.	• Fair • Greater than USD $500,000 in capital costs. • Likely requires more equipment and staff than currently available.	• Fair • 2-5 years for implementation.	Evaluate

Resilience Solution		Criteria				Priority Level
		Effectiveness	Feasibility (technical and political)	Cost and/or Finance Availability	Implementation timing	
R39	Create a hotline for reporting poor construction or installation of equipment or systems.*	• Poor • Reduces only a little risk for a vulnerability (less than 30% reduction in risk).	• Poor • Requires foreign technical experts or third-party consultants to implement • There may be some resistance to fines or penalties from existing utilities.	• Good • Less than USD $500,000 to implement.	• Good • Less than 2 years for implementation.	Remove from Consideration
R40	Create regulation that mandates improved hydropower dam siting.*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for multiple vulnerabilities.	• Fair • Requires foreign technical experts or third-party consultants to implement.	• Good • Less than USD $500,000 to implement.	• Fair • From 2-5 years for implementation.	Implement
R41	Develop an enforcement mechanism that allows for the recovery of government funds from failed power-system projects that do not adhere to applicable codes and standards.	• Fair • Reduces significant risk for a vulnerability (approximately 50% reduction in risk).	• Good • Local staff have necessary expertise.	• Fair • Between USD $500,000 and USD $1,000,000 in capital costs.	• Good • Less than 2 years for implementation.	Implement
R42	Increase workforce knowledge and understanding of correct construction processes and operations (such as implementing workforce qualification or certification programs).*	• Good • Reduces the bulk of risk for a vulnerability (greater than 70% reduction in risk) • Reduces risk for multiple vulnerabilities.	• Fair • Requires foreign experts.	• Fair • Between USD $500,000 and USD $1,000,000 in capital costs.	• Fair • From 2-5 years for implementation.	Evaluate

*Evaluated by the Resilience Team after the Stakeholder Workshop

C.3 Group Solutions into Resilience Actions for Implementation

Prioritized solutions were consolidated into four groups of similar solutions to support their coordinated implementation. Table C-3 presents these groups of resilience strategies and the vulnerabilities that they address. The table shows only the strategies with an Implement priority level. It does not include strategies with a priority level of Evaluate or Remove from Consideration. These four Actions are described in more detail in Section 5 of this report.

Table C-3. Resilience Actions for Implementation

	Resilience Actions for Implementation	Specific Vulnerabilities Addressed*
Action 1. Develop and Implement Resilient Power-System Policies		
R7, R17, R13, R15, R23, R24, R27, R29, R33, R39, R36, R40, R41	Develop resilient power-system policy that includes: • System standards and specifications for construction, operation and maintenance (including standardized risk assessment) • Ensure government oversight and enforcement of power-system standards and codes • Extreme event planning to include continuity of operations, staff development, and community engagement • Appropriate siting regulations for all new power-system components (including generation, transmission, and distribution systems).	V5, V7, V12, V13, V14, V15, V16, V17, V18, V19, V20, V21, V22, V23, V24, V26, V28, V29, V31
Action 2. Improve Power-System Flexibility		
R18, R26, R28, R30, R31, R32	Improve power-system flexibility through implementing policy and planning that: • Diversifies the generation mix • Implements demand-side management programs • Increases capacities of technical power system staff (including dispatch scenarios, weather forecasting for variable renewable energy, and knowledge of demand forecasting methods) • Increases planning capabilities of technical staff to allow consideration of multiple future demand and supply scenarios.	V5, V7, V15, V17, V20, V29, V31
Action 3. Improve Coordination Across Hydropower Dam Operations		
R1, R2	Develop policy to improve communications and require data sharing between hydropower dam operators to facilitate greater coordination across the Lao hydropower sector to include protocol for data collection and sharing at all dam sites.	V15, V32
Action 4. Facilitate Better Sedimentation Management in Hydropower Watersheds		
R6, R9, R10, R11, R12	Develop watershed management policy to improve sediment management in watersheds located upstream from hydropower dams to include: • Procedures for sediment management in hydropower dam watersheds • Reforestation of areas prone to erosion • Educational campaigns for community awareness of watershed protection • Incentives for upstream users to reduce activities that cause sedimentation • Enforcement of policy and management plans to protect upstream watersheds.	V21, V25, V29

*See Vogel et al. (2018) for additional details on the vulnerabilities addressed.

Appendix D: Detailed Resilience Action Solutions

Table D-1 presents the individual solutions that the Resilience Stakeholder Group developed to address the high-priority (priority levels of Implement and Evaluate) resilience solutions (from Table C-2 in Appendix C). The Resilience Stakeholder Group did not complete all of the resilience solutions during the workshop; however, these are included in the table to allow stakeholders to complete them at a later time. Some details from the Resilience Team for these incomplete resilience solutions can be found in the resilience action plan.

Table D-1. Detailed Resilience Action Plans from Resilience Stakeholder Group

Resilience Solutions		Public or Private Sector Action	Lead Entity or Entities	Implementation Timing (approximate)	Geographic Scale	Description of Activities	Resilience Strategy Costs	Potential Funding Sources
R1	Establish protocol for data collection at all hydropower dams.							
R2	Develop policy to improve communications and require data sharing between hydropower dam operators.	Public	• MEM • EDL • Independent power producers (IPPs)	• 6 months to draft guidelines and forms for collecting information (MEM) • 3 months to approve the guidelines and relevant forms and disseminate information (MEM) • 3 months to finalize with approval from government (MEM) • 6 months for EDL and private developers to implement (EDL and private developers).	National	• Hydropower dam operators (EDL and private developers) collect data • Hydropower dam operators share and exchange information • Hydropower dam operators communicate and coordinate with relevant local authorities.	• Develop plan and budget for staff to collect information, follow up, and assess • Develop plan and budget for equipment and vehicles for the project work • Contingency fund.	• Funding for policy development from MEM • Funding for data collection from EDL and private developers.
R3	Improve ability to collect and make use of data (meteorological, hydrological, and climate change data).							
R4	Construct protection systems, underground lines, or redundant lines for important transmission and/or distribution lines and/or substations.	Private	EDL	• 18 months for survey and design of systems • 8-12 months to implement • 12-24 months for project tasks • Annual operation and maintenance.	Northern and central regions of Lao PDR	Enhance transmission and distribution systems with protective structures, underground lines, and/or redundant lines to ensure reliability of power.	• Survey and design: USD 50,000 • Project cost: USD $500,000 • Capital cost: USD $560,000	• Funding from international sources • Special priority loan from Lao bank.

Resilience Solutions		Public or Private Sector Action	Lead Entity or Entities	Implementation Timing (approximate)	Geographic Scale	Description of Activities	Resilience Strategy Costs	Potential Funding Sources
							• Operation and maintenance: USD/year $10,000	
R5	Improve survey and spatial data on landslide-prone hazard areas to support siting of distribution systems.							
R6	Reforest landslide-prone areas near distribution systems.	Public and Private	• Ministry of Agriculture and Forestry (MoAF) • Ministry of Natural Resources and the Environment (MoNRE) • MEM • EDL • IPPs	• 1 year for seeding and/or planting • 3 to 5 years of managed growth of reforested areas.	National as needed and affected areas	• Improve the land and forest areas in landslide-prone areas near distribution systems to be able to prevent landslides • Focus on areas that are upstream of hydropower dams to also improve watershed's ability to capture water and slow erosion.	• Reforestation: USD 100,000 • Managed growth: USD 50,000	• Government funds • Development Bank (such as Asian Development Bank).
R7	Develop policy and enforcement mechanism to ensure design and construction of distribution systems in hazard zones (flood-prone and landslide-prone zones) adhere to adequate standards and codes.	Public	• MEM • MoNRE • EDL • Ministry of Planning and Investment (MPI)	• 1 year for research • 6 months to draft policy • 2 years to complete policy • 1 year for the National Assembly to consider and finalize the policy.	National	• Encourage people to relocate to safe areas. • Educate people in the disaster-prone areas to understand about the potential disaster.	• Research: USD $200,000 • Draft policy: USD $20,000 • Complete policy: USD $100,000 • Disseminate: USD $100,000	• Government funds • Development Bank (such as Asian Development Bank) • EDL-Gen.
R8	Incorporate sediment mitigation actions in construction and operation of hydropower dams.							
R9	Incentivize users and/or areas that are upstream from hydropower dams to reduce sedimentation.							

Resilience Solutions		Public or Private Sector Action	Lead Entity or Entities	Implementation Timing (approximate)	Geographic Scale	Description of Activities	Resilience Strategy Costs	Potential Funding Sources
R10	Conduct educational campaign and/or community awareness for watershed protection upstream from hydropower dams.	Public and Private	• MEM • IPPs	• 3 months to draft an operational plan for educational and community awareness campaign • 1 month to coordinate with media (radio and TV) • 1 month to initiate cooperation with project developers • 1 month to prepare information for education and awareness activities.	National in project watershed areas	• Prepare staff for training on watershed management • Prepare equipment and vehicle for site surveys • Coordinate with relevant authorities • Conduct campaign to teach students and populations about the protection of watershed and forest areas.	• 10 staff members: USD $10,000 • Cost of plants: USD $20,000 • Equipment and vehicle: USD $50,000 • Media: $5,000 • Supporting the community with reforestation: USD $20,000 • Contingency: USD $20,000	None cited
R11	Improve and/or develop policies or procedures for sediment management in watersheds located upstream from hydropower dams.							
R12	Enforce any existing sediment and/or water management plans to protect watersheds located upstream from hydropower dams.							
R13	Develop standard operating procedures and continuity of operation plans for extreme events.	Private	EDL	• 6 months for a survey and research • 6 months for implementation • 1 month for dissemination of materials • 1 year for training • Evaluation every 3-12 months.	National	• Improve knowledge and skills of staff • Recruit staff • Engage community in raising awareness of emergency response.	• Survey and research: USD $30,000 • Implementation: USD $20,000 • Publication of materials: USD $10,000 • Training: USD $100,000 • Evaluation: USD $20,000	Budget of EDL or other utility
R14	Develop an early warning system to notify critical staff in the case of an extreme event.							

Resilience Solutions		Public or Private Sector Action	Lead Entity or Entities	Implementation Timing (approximate)	Geographic Scale	Description of Activities	Resilience Strategy Costs	Potential Funding Sources
R15	Increase staff training of critical skills to respond in case of an extreme event.							
R16	Ensure large industry electricity customers aid in creating system flexibility.							
R17	Develop a law or regulation that requires a commitment in the form of a contract or other agreement between electricity customers, Ministry of Industry and Commerce, and EDL (or other applicable utility).	Public	• MEM • MPI	• 2-3 years • Appoint working committees • Review existing laws • Draft law • Propose and share with relevant ministries for consideration • Propose to National Assembly for consideration and approval • Dissemination and implementation.	National	Propose the new law.	Total cost: USD $100,000 to $200,000	Government budget
R18	Improve policy and regulation to facility building of transmission lines that may allow for separate circuits for medium-sized factories.	Public and Private	• EDL	• 1 year • Load-flow analysis • Design of circuits • Installation.	National (implemented at the provincial level)	None provided.	Total cost: USD $2,000,000	Private-sector budget
R19	Increase automation in hydropower system to support coordination among operators.							
R20	Provide incentives or recognition for good coordination between hydropower dam operators.							
R21	Prepare portable equipment and tools to allow for a rapid response in the event of an extreme event.							

Resilience Solutions		Public or Private Sector Action	Lead Entity or Entities	Implementation Timing (approximate)	Geographic Scale	Description of Activities	Resilience Strategy Costs	Potential Funding Sources
R22	Develop approaches to facilitate customer reporting of power-system problems (such as posting a photo and location on social media).							
R23	Improve community readiness for extreme events that may impact the power sector.							
R24	Ensure the monitoring and enforcement of power system standards and codes, which may include fines and penalties for developers.	Public	• MEM	2-3 years	National	• Monitoring of construction • Monitoring of installation of equipment • Monitoring of operation and maintenance of equipment.	• Total cost: USD $100,000 to $300,000 • Inspector from government • Project consultant.	Project developer budget
R25	Automate power-response system (i.e., generation and dispatch) where possible.							
R26	Implement planning and policy to diversify the electricity generation mix to reduce dependence on hydropower.	Public and Private	• MEM • EDL • IPPs	• 2 years for planning • 5 years for implementation • 1 year for evaluation	National	• Planning: study the economic growth, demand for power sector in each year (potentially the duration of 30 years) • Study the potential energy resources and generation technologies including renewable energy • Develop strategy to identify the generation mix • Implementation: Develop policy and operational plan • Evaluation: review every 5 years to ensure generation mix is on target with plan.	• Planning: USD $200,000 • Implementation: USD $250,000 • Evaluation: USD $50,000	• Government budget (approximately 20%) • Donors such as the Japan International Cooperation Agency, Asian Development Bank, or World Bank (approximately 80%)
R27	Ensure inclusion of resilience activities and appropriate upgrades and maintenance activities for							

Resilience Solutions		Public or Private Sector Action	Lead Entity or Entities	Implementation Timing (approximate)	Geographic Scale	Description of Activities	Resilience Strategy Costs	Potential Funding Sources
	generation, transmission, and distribution systems within annual operating budgets.							
R28	Consider multiple demand and supply scenarios for power-system growth in the PDP and related planning activities.	Public	• MEM • EDL	• Less than 2 years • Collect information • Analyze information • Review information • Implementation.	National	• EDL is the implementing agency under the guidance of MEM, which is in charge of planning. • Considering multiple demand and supply scenarios will help provide more options to be considered for implementation by EDL.	• Planning (training for staff—using technology, analyses information detail): 40% of total cost • Implementation (capacity building, collect information, analyze and review): 30% of total cost • Operation (set up the system to follow up systematically, especially the process for collecting information, coordination and finance): 20% of total cost • Maintenance (capacity building for monitoring staff, must have regular report and must hire additional staff to follow up for problem solving): 10% of total cost.	Budget (and revenue) of EDL
R29	Develop regulation and/or an enforcement mechanism that requires EDL (and other potential utilities) to provide reliable power (such as a fine or penalty for unreliable power).							
R30	Build technical capacity for generator management of National Control Center staff.							

Resilience Solutions		Public or Private Sector Action	Lead Entity or Entities	Implementation Timing (approximate)	Geographic Scale	Description of Activities	Resilience Strategy Costs	Potential Funding Sources
R31	Increase technical knowledge of staff on demand forecasting methods for planning at MEM and EDL.							
R32	Develop and implement a demand-side management program to reduce peak electricity demand (such as time-of-use tariffs, industry and large customer programs, or public awareness and education campaigns).	Public	• MEM • EDL	• 6 months for planning • 1 year for implementation and operation • 6 months for evaluation and follow up.	National	• Planning: analyze current power consumption to identify which sector uses the most • Source funding: • Implementation and operation: • Improve the electricity price, could be the “Time of Use” • Request approval from government • Disseminate information to the public • Follow up: • Consumer questionnaire survey • Analyze the consumption after the demand-side management, how much does it decrease?	• Planning: USD $50,000 • Operation: USD $100,000 • Follow up: USD $30,000	• Government budget • Donors such as the World Bank.
R33	Develop resilient power system standards for the specifications and operation of equipment and systems.							
R34	Increase the installed capacity of distributed generation and backup power systems.							
R35	Expand and/or build redundant transmission and/or distribution systems.							

Resilience Solutions		Public or Private Sector Action	Lead Entity or Entities	Implementation Timing (approximate)	Geographic Scale	Description of Activities	Resilience Strategy Costs	Potential Funding Sources
R38	Improve system monitoring and forecasting of short-term electricity demand for power-system operation.	Public	EDL	• 3-5 years total: • Planning • Implementation • Operation • Maintenance	National	None provided	• Planning: 40% • Implementation: 30% • Operation: 20% • Maintenance: 10%	• EDL: 70% • Independent Power Producers: 20% • Donors: 10%
R39	Create a hotline for reporting poor construction and/or installation of equipment or systems.							
R40	Create regulation that mandates improved hydropower dam siting.							
R41	Develop an enforcement mechanism that allows for the recovery of government funds from failed power-system projects that do not adhere to applicable codes and standards.	Public	• MEM • EDL • Ministry of Finance (MOF) • Ministry of Justice	• 1-2 years total: • Appoint working committees • Stakeholder meeting costs • Consideration and approval process • Implementation • Evaluation • Based on agreements such as Power Purchase Agreements, Project Development Agreements, and Concession Agreement.	National	None provided	Less than USD $50,000	Government budget
R42	Increase workforce knowledge and understanding of correct construction processes and operations (such as implementing workforce qualification or certification programs).							

Appendix E. VA Advisory Group Review of the Power-Sector Resilience Action Plan

On April 4, 2019, the VA Advisory Group met to review the draft power-sector resilience action plan for the Lao PDR. This appendix presents the feedback received from the VA Advisory Group at this meeting. The Resilience Team reviewed this feedback and updated the current version of the action plan accordingly.

Meeting to Review Draft Resilience Action Plan for Lao PDR Power Sector

Purpose:

- Present and review draft resilience action report, which was built on inputs from the stakeholder workshop in November 2018
- Discuss the preparation for the consultative workshop for the VA and resilience action plan for Lao PDR's power sector.

Organizations:

- VA Advisory Group consisting of representatives from MEM, EDL, and EDL-Gen
- Technical staff from MEM.

Name(s) of Contact:

VA Advisory Group:

1. Phaysone Phouthonesy, Technical Officer, MEM
2. Phetsamone Bounnouvong, Deputy Chief of Planning team, EDL
3. Thanomsak Pholsena, Technical Officer, EDL
4. Vinalong Phonekeo, Technical Officer, EDL-Gen

Technical Staff:

1. Chansamone Xaiyalath, Deputy Chief of Energy Policy and Planning Division, MEM
2. Yevang Nhiavue, Technical Officer, MEM
3. Khamphan Lasachak, Technical Officer, MEM
4. Vatthana Vansyli, Technical Officer, MEM
5. Lamngeun Chanthavongsa, Technical Officer, MEM
6. Latsada Souvannalath, Technical Officer, MEM
7. Sengthong Pormuangpieng, Technical Officer, MEM
8. Sonexay Sengmany, Technical Officer, MEM

USAID/Lao PDR, USAID Clean Power Asia, and NREL:

1. Anders Imboden, Development Assistance Coordinator, USAID/Lao PDR
2. Pitoon Junthip, Renewable Energy Planning Specialist, USAID Clean Power Asia

3. Maythiwan Kiatgrajai, Renewable Energy Planning and Policy Specialist, USAID Clean Power Asia
4. Siphachanh Thythavy, Lao PDR Country Coordinator, USAID Clean Power Asia
5. Jason Vogel, Vulnerability Assessment Expert, USAID Clean Power Asia *(called in)*
6. Sherry Stout, Engineer, NREL *(called in)*
7. Nathan Lee, Postdoctoral Researcher, NREL *(called in)*

Meeting Notes:

- Expert team (Jason, Sherry, and Nathan) presented draft resilience action report:
    - Resilience Action Planning Approach: the draft report was built on stakeholders' input from the November 2018 workshop. Stakeholders identified 42 resilience solutions to address highest-risk vulnerabilities to the power sector. From those resilience solutions, 26 were selected using criteria developed during the workshop. Later, the expert team developed a draft action plan by consolidating those solutions into four coordinated actions and 16 activities.
    - Power Sector Resilience Action Plan Review: The resilience solutions were grouped into four main resilience actions to support implementation:
        - **Action 1—Implement Resilient Power System Policies:** consists of six activities, such as developing standard operating procedures and continuity-of-operation plans for extreme events, developing climate projections and geospatial data for hydropower and other generation planning, making these maps available publicly, and developing standards and enforcement mechanisms for power reliability.
        - **Action 2—Improve Power Systems Flexibility:** consists of six activities, such as considering multiple demand and supply scenarios for power-system growth in the PDP and related planning activities, reducing dependence on hydropower through diversification of the energy mix, and introducing flexibility solutions into power-system operations.
        - **Action 3—Improve Coordination Across Dam Operations:** consists of two activities, which are establishing protocol for data collection at all hydropower dams and mandating data sharing between hydropower dam operators.
        - **Action 4—Facilitate Better Sedimentation Management in Hydropower Watersheds:** consists of two activities which are developing incentive and enforcement structures to ensure that users and/or areas that are upstream from hydropower dams protect watersheds located upstream from hydropower dams and creating an educational campaign and community awareness for watershed protection upstream from hydropower dams.
- Key Takeaways and Using this Action Plan (Next Steps):
    - This resilience action plan is not the final step to improving Lao power-sector resilience. The action plan will be incorporated into the IRRP process. Further work is required to develop specific implementation plans for the actions identified in this plan.
    - This resilience action plan and VA should provide a working foundation for power-sector planning for many years; however, as climate conditions and the power sector evolve, it may be necessary to review and update both of these.

- Three suggested steps for this action plan: Immediate steps (Months 1-24), Medium-term steps (Months 24-36), and Long-term steps (Beyond month 36).

- Vinalong noticed that some lead entities presented in the action plans for grouped resilience strategies in Table 16 (section 5) on page 10 are different from those on page 15. The expert team informed that there could be some that are missing. They will review both tables.
- Phaysone and Yevang asked the expert team about a recommended implementation timeline, including when to begin and when to finish. The expert team explained that the starting time would mainly depend on when MEM or the Government of Lao PDR is ready to do so. It is highly recommended that the sooner it is started, the better, as this action plan was developed based on the current vulnerabilities and risks to the power sector as well as eligible implementing capacity of the country and available technologies. If the implementation is delayed, for example for four years, situations could change, and GOL might need to re-evaluate the plan before implementation.
- Maythiwan, with support from Pitoon and Siphachanh, led the discussion on reviewing the draft action plan. Participants were assigned into three groups. Each group was given 4-6 activities from the action plan. Participants were asked to verify assigned activities focusing on steps of implementation, lead entities, stakeholders, estimated timeline, and estimated cost and source of funding (if possible). Table E-1 shows the feedback from the VA Advisory Group.

Table E-1. VA Advisory Group Review of Power-Sector Resilience Actions

Actions/Activities*	Lead Entities	Estimated Timeline	Estimated Cost and Financial Source
Action 1. Implement Resilient Power-System Policies			
Activity 1.1 Develop standard operating procedures and continuity of operation plans for extreme events—including staffing plans, prioritized repowering of networks, and aid agreements with neighboring countries: • Review relevant organizations and set up working group • Review existing guidelines • Identify gap • Improve/develop guidelines that cover gap • Approve guidelines • Disseminate guidelines.	MEM, National Disaster Management office (Ministry of Labor and Social Welfare) Stakeholders: MoNRE, IPP, EDL	Months 1-16	
Activity 1.2 Develop climate projections and geospatial data for hydropower (Advisory group suggested to do only hydro resource to avoid duplicating activities under Action 2 (fuel mix diversification is already included in Action 2) • Analyze energy development for future climate prediction • Map watersheds and water flow • Develop national map of hazard zone • Gather potential data and determine zone with acceptable risk.	MEM, MoNRE (Department of Disaster Management and Climate Change)	Months 1-24	
Activity 1.3 Develop standards and enforcement mechanisms for power reliability • Determine current reliability statistics and challenges • Set standard for reliability • Develop enforcement mechanisms.	MEM, EDL	Months 13-23	
Activity 1.4 Improve community readiness for extreme events that may impact the power sector • Review existing plan (every IPP has its own readiness plan) • Develop training curriculum and other logistics • Conduct training.	MEM Stakeholders: EDL, EDL-Gen, Provincial Office, IPPs	Months 13-23	$15,000 USD
Activity 1.5 Improve enforcement of dam design and construction codes—including planning for expected hazards	MEM	Months 7-18	$30,000 USD (Government + Donor)

Actions/Activities*	Lead Entities	Estimated Timeline	Estimated Cost and Financial Source
Action 1. Implement Resilient Power-System Policies			
(e.g., floods, high winds, landslides) where these cannot be avoided • Review existing enforcement guidelines • Develop/improve enforcement guidelines, such as increase frequency of monitoring construction • Train relevant staff.	Stakeholders: EDL, EDL-Gen, IPP, MoNRE, Ministry of Agriculture and Forest		
Activity 1.6 Include resilience provisions within annual operating budgets of relevant agencies • Estimate work plan • Estimate budget • Discuss with relevant agencies • Report to MOF for approval.	MEM Stakeholders: MOF	6 months (this will happen once a year and must follow GOL budgeting process)	Government of Lao PDR (GOL) and donors
Action 2. Improve Power-Sector Flexibility			
Activity 2.1 Consider multiple demand and supply scenarios for power-system growth in the PDP and related planning activities • Review existing energy model from Japan International Cooperation Agency (JICA), USAID, ADB, World Bank • Incorporate into national PDP • Submit PDP to National Assembly for approval.	MEM (DEPP), EDL Stakeholders: EDL-Gen, IPP	Months 1-11	GOL and donors
Activity 2.2 Reduce dependence on hydropower by diversifying energy mix • Integrate renewable energy and other technologies (e.g., coal) into the system • Follow PDP target/MEM strategies.	MEM (DEPP), EDL Stakeholders: EDL-Gen	Months 7-12	GOL and donors
Activity 2.3 Introduce flexibility solutions into power-system operations • Review existing power-system operation • Improve demand and generation forecasting.	MEM (DEPP, DEM), EDL Stakeholders: EDL-Gen, IPP	Months 7-17	GOL and donors
Activity 2.4 Improve power-system planning for future scenarios, including education for dispatch scenarios, weather forecasting for variable renewable energy, and knowledge of demand forecasting methods • Capacity building/training for MEM staff.	MEM (DEPP), EDL	Months 7-17	Donors
Activity 2.5 Develop and implement a demand-side management program to address electricity demand during peak periods, such as time-of-use tariffs, industry and large customer programs, or public awareness and educational campaigns • Price incentive (energy saving on peak).	MEM, EDL Stakeholders:	Months 7-beyond 25	GOL and donors
Activity 2.6 Establish a binding contract or agreement within an interconnection procedure to ensure commitment of new large electrical customers, such as large industrial loads • Develop binding contracts of commitment process (large industries and EDL) • Review existing grid code and regulations to ensure they cover large industry.	MEM, EDL, MPI, Ministry of Industry and Commerce (MoIC)	Months 7-17	GOL and donors
Action 3. Improve Coordination across Hydropower Dam Operations			
Activity 3.1 Establish protocol for data collection at all hydropower dams, including data types, collection frequency, and data format for sharing • Review existing protocol • Improve protocol and develop timeline • Discuss and meet with relevant agencies • Approve protocol • Disseminate.	MEM Stakeholders: EDL/EDL-Gen, IPP, Lao Department of Meteorology and Hydrology, MoNRE	Months 1-11	$15,000 USD (GOL and donors)

Actions/Activities*	Lead Entities	Estimated Timeline	Estimated Cost and Financial Source
Action 1. Implement Resilient Power-System Policies			
Activity 3.2 Mandate data sharing between hydropower dam operators • Conduct study and site visit • Discuss and meet • Develop guidelines • Approve guidelines • Disseminate.	MEM, EDL, EDL-Gen, IPP Stakeholders: Department of Meteorology and Hydrology, MoNRE	Months 7-25	$12,500 USD (GOL and donors)
Action 4. Facilitate Better Sedimentation Management in Hydropower Watersheds			
Activity 4.1 Develop incentive and enforcement structures to ensure that users and/or areas that are upstream from hydropower dams protect watersheds located upstream from hydropower dams • Study existing enforcement structures • Discuss and train relevant staff • Publicize and promote incentive and enforcement structures.	MEM Stakeholders: MoNRE, Ministry of Agriculture and Forest, Department of Meteorology and Hydrology	Months 1-22	$13,000 USD (GOL and donors), excluding incentives
Activity 4.2 Create educational campaign and community awareness for watershed protection upstream from hydropower dams • Evaluate current community awareness • Discuss with stakeholders • Create educational campaign and guidelines • Publicize and promote (TV, radio, loudspeaker, brochure).	MEM, MoNRE, Ministry of Agriculture and Forest Stakeholders: EDL/EDL-Gen, IPP	Months 13-beyond 25	$30,000 USD (GOL and donors)

- Maythiwan and Siphachanh will share the above table with participants after the meeting. Participants can confirm the results and provide additional comments to the draft action plan within two weeks.[9]
- Some participants asked if USAID Clean Power Asia and NREL can provide technical and financial support for implementing this action plan. Maythiwan explained that the intention of developing this plan is to recommend what can be implemented in Lao PDR in order to improve resilience of the power sector. USAID Clean Power Asia and NREL are willing to support the GOL on implementing activities that match with their expertise. However, for those tasks that are beyond the scope of these two organizations, other donors might be able to support the GOL.
- Maythiwan informed participants that USAID Clean Power Asia and NREL are proposing to hold a forum to disseminate the vulnerability assessment and resilience action plan for Lao PDR's power sector. The forum can be a great opportunity for the GOL to seek support from other donors or international organizations. DEPP is asking for approval from Dr. Daovong to hold this event during the last week of May.

[9] The table was shared with participants by email on April 5, 2019, and 9 out of 12 participants confirmed it without any additional comment.

Appendix F: Members of the Resilience Stakeholder Group

Table F-1 lists all stakeholders who participated in the workshop on Developing a Resilience Action Plan for the Lao PDR Power Sector, November 15-16, 2018, in Vientiane, Lao PDR.

Table F-1. Lao PDR Resilience Stakeholder Group Members

Name		Organization	Position
Sanhya	Somvichit	Department of Energy Policy and Planning, MEM	Deputy Director-General
Davanhny	Xaneth	Department of Energy Policy and Planning, MEM	Chief of Division
Yevang	Nhiavue	Department of Energy Policy and Planning, MEM	Technical Officer
Khamphan	Lasachak	Department of Energy Policy and Planning, MEM	Technical Officer
Soukvilay	Phimmasen	Department of Energy Policy and Planning, MEM	Deputy Chief of Division
Alounzay	Inthilath	Department of Energy Policy and Planning, MEM	Technical Officer
Latsana	Souvannalath	Department of Energy Policy and Planning, MEM	
Vimala	Bulyaphol	Department of Planning and Cooperation, MEM	Technical Officer
Sayphin	Singphavanh	MEM	
Vongphet	Latsavong	MEM	
Phouttavanh	Phommachanh	Institute of Renewable Energy Promotion, MEM	
Anousith	Bounsou	MEM	Technical Officer
Chitpanya	Phamisith	Power System Planning Office, EDL	Deputy Chief
Hongsakoun	Kongsup	Power Development Plan Office, EDL	Deputy Chief of Division
Phetsamone	Bounnouvong	National Control Centre, EDL	Deputy Chief of Planning Team
Vinalong	Phonekeo	Department of Business Development, EDL-Gen	Technical Officer
Mona	Sychanthongthip	Department of Planning and Cooperation, Ministry of Industry and Commerce	Technical Officer
Kongsin	Saiyalin	Alternative Energy Division, Ministry of Science and Technology	Deputy Chief of Division
Tavanh	Kithiphone	Climate Change Department, Ministry of Natural Resources and Environment	Deputy Chief of Division
Peto	Monakhampao	Department of Meteorology and Hydrology, Ministry of Natural Resources and Environment	
Visanou	Vithanaly	Ministry of Natural Resources and Environment	
Lattany	Sisounavong	Department of State-Owned Enterprise Investment Management and Assurance, Ministry of Finance	
Noumay	Souvannaphoum	Lao Holding State Enterprise	Deputy Chief, Project Division
Kindavong	Kuangrath	Department of Social Work, Ministry of Labor and Social Welfare	Deputy Director
Phonesamay	Phaxay	Central Bank of Lao PDR	Deputy of Division
Nimala	Souksan	Laos Women Union	Officer

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The Resilient Energy Platform provides expertly curated resources, training, tools, and technical assistance to enhance power sector resilience. The Resilient Energy Platform is supported by the U.S. Agency for International Development.

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