ENHANCING POWER-SECTOR RESILIENCE: EMERGING PRACTICES TO MANAGE WEATHER AND GEOLOGICAL RISKS

EXECUTIVE SUMMARY

Over the past 20 years, natural disasters have become more frequent, and the costs of the associated damages and losses are rising. In 2012 alone, the 357 natural disasters recorded worldwide resulted in 9,655 fatalities, some 125 million victims, and US$157 billion in associated damages and losses. Far-flung power infrastructure—from upstream generation plants and transmission lines to downstream distribution networks and operational systems—may be particularly vulnerable to weather and geological events (e.g., earthquakes, tsunamis, volcanoes, cold spells, heat waves, storms, tropical cyclones, floods, droughts, and wildfires). In a changing climate, the impact of such events on power networks and energy services—on which all facets of the economy depend—may become more severe.

In a world that relies increasingly on electricity services, building the resilience of the power utilities is critical to providing reliable and sustainable services, energy security, economic well-being, and quality of life. In many developing countries, the power sector already faces a deficit in adapting to near-term weather and geological risks (e.g., weak and ageing infrastructure), making it difficult to additionally prepare for the slow onset of climate change consequences (box ES.1).

The World Bank Group's Energy Sector Management Assistance Program (ESMAP), in collaboration with AECOM and the Global Facility for Disaster Risk Reduction (GFDRR), undertook this study in 2015 to (i) raise awareness and enhance understanding about managing extreme weather and geological risks among utility-systems operators, owners, and planners in developing countries and (ii) enhance their capacity to take adaptive actions to cope with the impacts of these risks on the electricity value chain, including systems operations and demand.

The detailed study scope encompassed the risks faced by the power sector as a result of weather and geological hazards and the identification and documentation of a range of emerging practices for building resilience developed and implemented by power companies and their partners (e.g., investors and insurance companies) in both developed and developing countries. The study focuses on tangible weather and geological hazards of imminent concern to the utilities, which have drawn much less attention compared to the slow-onset impacts of climate change consequences (e.g., on hydropower generation). The power-production sources covered included conventional generation fuels (e.g., coal, oil, and gas) and weather-dependent renewables (e.g., hydropower, wind, and solar).

BOX ES.1 TERMINOLOGY CLARIFICATION

In this study, ***resilience*** is defined as the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through the preservation, restoration, or improvement of its basic structures and functions (IPCC 2012).

Weather refers to events caused by short-lived, small-to-meso-scale atmospheric processes (minutes to days), such as tropical cyclones, storms, and extreme cold or heat events.
Climate refers to events caused by long-lived, meso-to-macro-scale atmospheric processes (seasonal to multi-decadal variability), such as sea-level rise.

An ***integrated disaster risk management framework*** includes a set of disaster risk management (DRM) components that provide the foundation and organizational arrangements for designing, implementing, and evaluating strategies, policies, and measures to improve the understanding of disaster risk; foster disaster risk reduction and transfer; and promote continuous improvement in disaster preparedness, response, and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life, resilience, and sustainable development (IPCC 2012; ISO 31000 2009).

Standard (current) practices refer to existing design and process standards and guides, such as IEEC standards and guides. ***Emerging practices*** refer to (i) measures already being utilized by a small number of power companies that are not yet industry standards and (ii) power-industry measures relatively common in developed countries not yet established in developing countries. Practices common to other industries that are not yet established in the power sector are referred to as ***potential practices*** (e.g., city scorecard).

The study method included a detailed literature review, complemented by an online global industry survey. The survey respondents represented conventional and renewable-energy generation, transmission, and distribution businesses; systems operators; retailers; and enabling sectors (financial services providers and regulatory bodies). Validated written responses were supplemented by phone and in-person interviews, which provided further insights into responses on the risks imposed by weather and geological hazards on the power supply. Both the literature review and the industry survey examined risk-management processes and approaches used by the organizations or those over which they have influence (in the case of regulators and financial institutions), recovery and reconstruction approaches, and existing relationships and interactions between power-sector organizations related to natural hazard preparedness and recovery. In addition, survey participants were offered the opportunity to comment on useful emerging practices they had observed or would like to see that would help to develop greater power-sector resilience.

Out of 196 survey queries, the study received 45 valid responses. About one-third of the survey respondents were from developed countries, while two-thirds were from developing countries. The respondents represented a wide range of power utilities and a small sample of financial and regulatory institutions. About three-quarters were from the Pacific Ring region. About 50 percent were state-owned, while about the same percentage (not necessarily the same organizations) were vertically integrated. The most common hazards, reported by more than 40 respondents, were earthquakes, drought, wildfires, cyclones (including typhoons and hurricanes), extreme winter conditions, extreme heat events, lightning, and river and flash floods.

The survey results and the identified emerging practices were categorized into five pillars: (i) risk identification, (ii) risk reduction, (iii) preparedness, (iv) financial protection, and (v) resilient recovery. These pillars fit within the context of a typical risk management approach, aligned with the International Standards Organization (ISO) 31000 Risk Management Principles and Guidelines. The main steps are to establish the context (pillar i), analyze and evaluate the risks (pillars ii-v), and treat them.

Main Survey Findings

Awareness of natural hazard exposure and risk management standards is low in developing countries, possibly due to the cost of obtaining standards, lack of involvement in the standards development process, and lack of training and regulatory requirements. In developed countries, the application of risk management practices follows common standards or internal organizational practices based on those standards. The standards require a robust risk identification process in order to identify major risks. For most organizations, this process includes reviewing historical information to aid identifying future risks, conducting internal risk-review identification, and maintaining risk registers for natural hazards, including risk treatments and potential costs.

The survey results showed that DRM practices in the power sector of developing countries are weak. Only 25 percent of respondents, mainly from developed countries, confirmed that their organizations subscribe to policies and procedures aligned with ISO 31000 Risk Management Principles and Guidelines or other international risk management standards. Two-thirds of respondents were limited to informal or internal risk management processes.

The failure to fund and conduct maintenance often compromises the resilience capacity of the infrastructure investments made. Once risks are identified, the next step is to manage them through mechanisms designed to reduce the likelihood or consequences of the risk impacting their service delivery. The survey results highlight the lack of a maintenance culture in many developing countries. Risk reduction appears to be dominated by technical approaches that consider risks when planning new assets and retrofitting existing ones. At the same time, more than three-quarters of the survey respondents recognize the important role that pro-active maintenance practices can play in reducing risk. This finding is perhaps not surprising, given the long life span of power-sector assets.

Survey respondents also recognize the important role of educational approaches—both public education and internal capacity building—in reducing risk. The role of penalties, incentives, and auditing of service providers as risk-reduction mechanisms was recognized only by respondents in developed countries. This finding is not unexpected, given that many countries have vertically-integrated utilities with internal service providers.

The power sector needs to assign higher priority to the design of systems and processes rather than the design of supply equipment alone. The pillar of preparedness is about the ability of institutions, organizations, and communities to anticipate, prepare for, and enable response to power-supply interruptions. It is a particular class of governance approaches to risk management focused on systems, processes, and actions deployed by corporate functions within an organization, rather than solely technical or asset planning levels. Awareness of these approaches is often broadly distributed across all organizational functions; thus, it is not surprising that the preparedness plans reported by a majority of survey respondents included emergency management, contingency, communications plans, drills and response training, and forecasting and early warning systems. **Business**

continuity management, undertaken by a majority of respondents in developed countries, is an area of opportunity for developing countries.[1]

Preparedness focused on resilience strategies, not overly prescriptive solutions, can provide better protection at lower cost against uncertain events. Flexibility in adapting to unexpected conditions, including strong human resource and management processes that provide the tools for middle management to make timely decisions during a disaster, is more effective than excessive preparation against threats that rarely or may never occur. The challenge is to curtail the impact of disasters on the power system and carry out recovery actions so as to minimize social disruption.

Developing countries depend heavily on post-disaster financing, including donor assistance, while developed countries tend to rely on multiple layers of pre-disaster financing mechanisms, including insurance and credit-line instruments. All of the surveyed organizations, except for nine from developing countries, reported some form of financial protection to manage the cost impacts of recovery, restoration, and lost income associated with disaster events. Across the sector, asset insurance was the only established practice, accounting for 63 percent of all respondents. Two distribution companies (one from a developed country and the other from a developing country) used risk financing as their only form of insurance, while two distribution/transmission companies in developed countries had direct pass-through of costs. Eleven respondents reported using parametric insurance for financial protection. Eight organizations reported using an economic valuation of the energy supply lost during a power-system event, instead of the price of the energy lost (value of lost load), in cost-benefit analyses to make potential system improvements in the power supply; seven of those organizations also utilized automated demand-side management approaches.

Recovery is more resilient when support is provided for reconstruction planning. When a disaster occurs, the focus soon shifts to restoring electricity as part of recovery efforts and ultimately rebuilding infrastructure. Like risk-reduction approaches, recovery, restoration, and reconstruction comprise a range of methods, including planning, technical, financial, and education (information and communication). Response and/or recovery planning, stocking of spare parts, access to maintenance crews, and engagement with equipment manufacturers and suppliers are commonly used. Plans for post-disaster damage assessment, built-in redundancy in systems and supply, demand-side management, portable and other forms of temporary infrastructure, and automatic messaging to consumers are common, though redundancy and disaster science and management (DSM) are more prevalent in developed countries.

Partner relationships dominate the level of interaction between service providers and regulators. Collaboration across a diverse range of organizations during risk identification and management is quite high across the sector. Respondents commonly reported collaboration with scientific and national disaster relief agencies; however, only a few organizations in developing countries reported having a relationship with the WBG to identify and manage risks associated with natural disasters, suggesting there are good opportunities for building capacity based around project outcomes.

Relationships with insurance companies are much less common among developing countries, although the overall response was relatively high, at 21 percent. Collaboration between power-sector providers—both

[1] In the electric utilities of developed countries, planning in business continuity management (BCM) has had varying degrees of success. It would be useful to review experience and lessons learned from applying BCM principles to public utilities.

competitors and organizations in various parts of the supply chain—is strong. Where there is a competitive market, collaboration with other members of the electricity supply chain is common.

While there is strong collaboration between members of the power sector, the relationship between datasets is not established or shared. When there is collaboration between non-integrated competitors delivering the same function, they tend not to collaborate with other non-integrated organizations in other parts of the power supply chain. Similarly, non-integrated organizations that collaborate with various parts of the supply chain tend not to collaborate with non-integrated competitors. This may result from competition regulation precluding collaboration or a highly competitive market, even during disasters. Manufacturers and suppliers, public recovery and reconstruction authorities, and, to a lesser extent, private insurance companies are established stakeholders during recovery and restoration activities.

Among developing countries, weak organizational capacity is the dominant constraint to risk management implementation. The survey found that 54 percent of organizations in developing countries lack the available budget to support planning and risk-reduction activities, the necessary skills and experience to undertake risk-preparedness activities, or the ability to control other aspects of the power-sector supply chain to ensure coordination of planning, risk reduction, and recovery. Lack of support for planning and risk-reduction activities via the regulatory framework is also common.

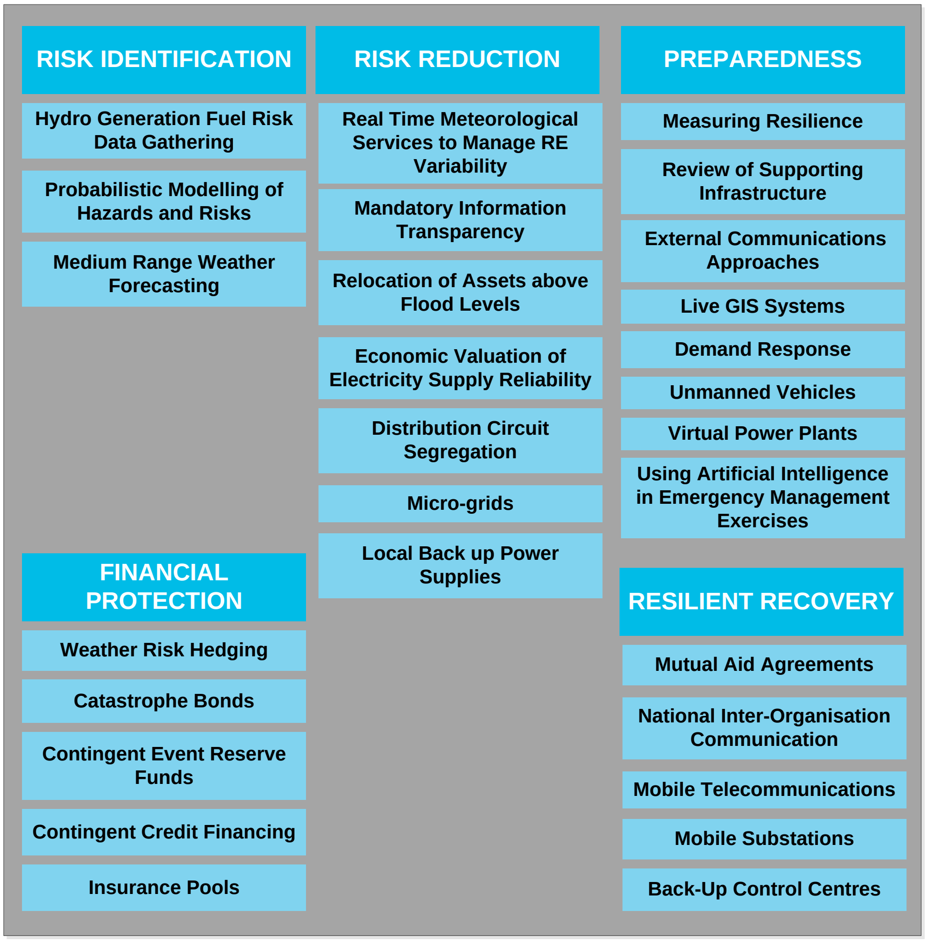
There is a clear desire among developing countries to build capacity in standard risk management practices. By using an integrated (holistic) approach, risks can be analyzed, and opportunities to reduce risks and make power-supply systems more resilient can be evaluated in order to prioritize and sequence actions. Through poor management or lack of knowledge or finance, standards are often unknown, not enforced, or not followed. Power utilities that lack the guidance of a national standards institution may follow incorrect standards, resulting in services that are not resilient to significant natural hazards. **Closing the gap to meet current standards and implement good industry practices should be the priority before embarking on resilience measures to address the incremental effects of climate change**.

Enhancing Resilience: Emerging Practices

Based on the results of the literature review and industry survey, along with a comparative analysis of their application in developed and developed countries, the study identified a set of emerging and potential practices (figure ES.1). When utilities have adopted a risk management approach, these measures can be added incrementally to enhance resilience across the power-sector value chain—from fuel supply and generation, transmission, and distribution to system operations and regulations. This section highlights key emerging and potential practices under each pillar.

Some of these engineering, organizational, and financial-resilience measures originated in developed countries. A number of those measures identified in the literature review have low response rates, even among developed countries, and have been limited to pilots. If implemented, these practices could potentially improve the technical, financial, and organizational resilience of the power utilities. Thus, they warrant further discussion and research, including in-depth case studies, in order to develop lessons with broader applications.

Figure ES.1 Emerging Practices in the Power Sector, by Risk Management Pillar



Risk Identification. Building capacity for risk assessment and analysis can lead to improved understanding and identification of disaster risk. Improved data collection, data sharing, and modeling allow governments, communities, and the private sector to better identify, quantify, and anticipate potential impacts of natural hazards, enabling better informed decision-making for risk management. For example, prior to the February 2011 earthquake in Christchurch, New Zealand, the distribution network owner, Orion, had identified earthquakes as the most significant potential hazard that could affect its network and had mitigation plans in place to respond to this event.

This study identified several emerging practices in risk identification: **hydro generation fuel-risk data gathering**, **probabilistic modeling of hazards and risks**, and **medium-range weather forecasting**. Analysis of historical information on hydrology and rainfall during the development of hydro generation facilities enables engineers and designers to ensure facilities are built to withstand extreme conditions or incorporate flexibility into structures so they can be upgraded for climate resilience at a later date. Probabilistic modeling can be used for stress analysis purposes, to assess the potential failure of supply to a part of a power system, and to make probabilistic fuel and market price projections. Medium-range weather forecasting models allow generators and retailers to respond to forecast changes in supply and demand by modifying supply arrangements, such as purchasing additional hedges or fuel stock, or conserving hydro reserves.

Risk Reduction. Greater consideration of disaster risks in policy making, investment, asset design, and management and operating procedures can reduce risks in society and avoid creating new risks. Appropriate maintenance of infrastructure investment is a critical, but often compromised, area of risk reduction. The potential consequences of failing to develop a good maintenance culture are underscored by tropical cyclone Ian, a category-five cyclone that hit the Ha'apai Islands of Tonga in January 2014, destroying or severely damaging 95 percent of power lines. When AECOM consultants interviewed Tonga Power Limited (TPL) following the event, senior management emphasized the need for good maintenance as a lesson learned. Although not an emerging practice per se, good maintenance has the highest opportunity to improve power-sector resilience, particularly in developing countries.

This study identified seven emerging and potential practices in risk reduction**: real-time meteorological services to manage renewable-energy variability**, **mandatory information transparency**, **relocation of assets above flood levels**, **economic valuation of electricity supply reliability**, **distribution circuit segregation, micro-grids**, and **local backup power supplies**. Among these, valuing lost load from power outages caused by natural hazards is a prerequisite for prioritizing and selecting the order of risk management options to be implemented. If power supply reliability is not given an accurate monetary value, it becomes difficult to quantify how much should be invested in risk-reduction measures in order to maintain reliable services. It is suggested that case studies on countries where this measure has been applied in regulations be developed and reported on for potential use by other utilities and regulators. In addition to estimating the economic value of lost load, cost-benefit analysis is required to make the business case for investing in resilience measures. Utilities need to understand their risk profile and its relation to potential consequences. Enhanced understanding and knowledge of the utilities and regulators, along with the use of standardized methodology and tools, will help in enabling the adoption of cost-benefit analysis.

Preparedness*.* Developing an institution's disaster-management and forecasting capacity can improve its ability to manage crises. Emerging practices in preparedness include **measuring system resilience**, **reviewing supporting infrastructure**, and **utilizing external communications approaches and live GIS systems**, as well as **demand response** and use of **unmanned vehicles**, **virtual power plants**, and **artificial intelligence in emergency management exercises**.

Frameworks developed to measure the resilience of cities and urban systems, which include power assets and services as a subcomponent of overall resilience measurements, could be easily adjusted for application in the power sector. One potential practice worthy of further exploration is a scorecard similar to the UNISDR Disaster Resilience Scorecard for Cities. Also, there is an opportunity to learn from the successes and challenges that industries in non-power sectors have experienced regarding the role of supporting infrastructure and identifying best-practice approaches that can be applied to the power sector. In addition, case studies could be developed to identify best practices in external communications and transparent GIS systems.

Financial Protection*.* The financial sector is increasingly involved in energy-sector resilience, providing large levels of finance and varied ways to reduce the financial impacts of major disruptive weather and geological events affecting the power sector. Using financial protection strategies can increase the financial resilience of governments, utilities, the private sector, and households. The emerging practices identified in this study are **insurance pools, weather risk hedging**, **catastrophe bonds**, **contingent credit financing,** and **contingent event reserve funds**. The foundation for countries to achieve sophistication in using these innovative risk-transfer instruments is a formal layering strategy used to provide financial resilience, facilitating post-event recovery and reconstruction.

The past five years have seen a significant expansion in the range of innovative financial instruments and products that can be used to model complex underlying risks in less than optimal data environments, as well as the willingness of financial markets to use these instruments as the basis for designing various types of risk-transfer contracts. In the context of general education on layering practices and products in financial risk management, there is an opportunity to raise the power sector's awareness of the availability of these innovative instruments, along with traditional insurance products.[2]

Resilient Recovery. The emerging practices identified in this study can enhance the quality and timeliness of recovery and reconstruction efforts. For example, when the wind storms of December 1999 caused major damage to France's power infrastructure, 17 countries contributed to speeding up the restoration via **mutual aid agreements**. Another emerging practice, **national inter-organization communication**, focuses on strengthening relationships between utilities and institutions within a nation so that post-event coordination is efficient and helpful rather than burdensome; deficiency in such two-way information-sharing slowed the coordination of immediate response actions and power restoration following the March 2011 Japan tsunami. **Mobile telecommunications**, including satellite phones and mobile multi-use communication units, can facilitate faster response and information exchange, particularly in remote areas (e.g., Brazil and Tonga). Given the long time required to replace large substation transformers, some utilities are turning to the use of **mobile substations**, including mobile transformers (e.g., Texas). In the case of seismic events, which may damage or destroy control centers, an emerging practice is to redirect all substation communications to a **backup control center**.

Utilities cannot implement these resilient measures in isolation. Strong government support is also needed (e.g., appropriate policy and regulatory frameworks), along with institutional coordination and information sharing.[3] In many developing countries, however, the organizational factors that provide resilience are often unknown or not considered. For example, structured cooperation between hydro-meteorological services and power utilities is often lacking, making it necessary to modernize national hydro-meteorological services, assess the socioeconomic value of accurate and timely data, and tailor it to meet specific sector needs.

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[2] The World Bank Group (WBG) offers a wide menu of innovative disaster risk financing instruments, along with unique knowledge and advisory services, which can be customized to clients' needs. Risk-financing instruments include insurance-linked securities (e.g., catastrophe bonds, multi-catastrophe bonds, and catastrophe/weather derivatives); regional insurance pools; and contingent loans, including investment and catastrophe deferred drawdown options (DDOs). In Uruguay, which generates 80 percent of its electricity from hydropower stations, UTE, the country's government-owned utility, spent 50 percent more than budgeted on fossil-fuel costs in 2012 due to a hydro shortage. The WBG insured UTE for 18 months against drought and high oil prices. UTE will receive a payout (depending on market oil prices at that time) from the WBG if the rainfall index is below a pre-determined level.

[3] It would be interesting to document emerging practices in such countries as Brazil, where severe drought has badly affected hydro-dominated power generation. The state has interacted with the utilities as the nation has endured one of the driest periods in history. Recently, ONS, Brazil's national grid operator, cut power to several major Brazilian cities, including São Paulo and Rio de Janeiro.

Key Lessons

Several key lessons can be drawn from the findings and insights of this study's global industry survey, literature review, and emerging practices:

- The most cost-effective tool for power-sector resilience is to follow current standards, including design and process standards and guides, and good industry and risk management practices. International equipment standards are well developed and are continuously being improved on in order to cater to varying levels of weather and geological hazards. But they are often not used, particularly in developing countries.

- Many power-sector organizations are unaware of standard (holistic) risk-management practices that create the foundation for identifying the best risk-treatment options. The research findings showed that many organizations in developing countries have weak or no risk-management frameworks. While this study does not advocate for the literal adoption of ISO 31000, it does provide a well-proven, internationally accepted methodology that can be used as a guideline for best practice in risk management. Coupled with standard practices in cost-benefit analysis that account for the economic valuation of lost load, an organization can rank risk-treatment options and adopt the most valuable resilience measures.

- Broadening resilience responses from a primarily technical engineering focus to those encompassing an organizational and financial focus is needed. The return on resilience from investing in good organizational culture and frameworks in order to quicken restoration of services can often be many times greater than that from physical and technical improvements. In the wake of major disasters, equipment design is not enough to prevent supply disruption. In many cases, the ability to respond quickly and appropriately is the more important factor. Good organizational resilience and institutional preparedness—including effective leadership and inspiration—provide the best support framework for recovery and rebuilding.

Addressing Implementation Challenges

Implementing emerging practices are not without challenges.[4] In poor developing countries of Sub-Saharan Africa, for example, poor governance, low capacity, obsolete networks, and low levels of electricity access are common barriers. Countries that have just begun to shift from old and inefficient systems to modern ones are especially vulnerable to disaster shocks and stress.

Given the variant risk nature of natural hazards and specific treatments required in various country/sector situations, a one-system-fits-all solution does not apply. Specific studies can be launched to provide a best practice–based matrix for use and implementation in a given situation or develop a matrix of adaptive resilience measures for exposure to particular risks.

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[4] Due to survey constraints, this study was unable to elaborate on the conditions under which the emerging practices were developed, which would increase our understanding of how weather and geological risks were managed among the electric utilities. It is recommended that in-depth case studies be conducted to fill this knowledge gap.

Establishing a separate disaster risk management (DRM) plan for the power sector is useful for increasing the focus on the power sector and attracting additional financial resources; however, it should be closely coordinated with a nationwide plan since the impact of natural disasters is not limited to electricity infrastructure. Other critical infrastructure is affected, including water; roads, rail, and ports; telecommunications; and agriculture. Thus, each country needs to establish its own criteria for prioritization.

The Way Forward

This study provides power utilities a menu of options for considering emerging practices that will be of most value to their organizations' particular situations. Some measures will provide immense value to certain power-sector participants and none to others. However, by following standard risk-management procedures, combined with cost-benefit analysis, the value propositions for individual organizations become clear: Power utilities need to develop an integrated, cost-effective DRM strategy, taking into account emerging practices and their own situations and risk tolerance.

This study can serve as a useful reference to raise the profile of power-sector resilience. It is our hope that it initiates discussion and debate, leading to interventions that improve the capacity of power utilities to cope with near-term weather and geological shocks, as well as the longer-term effects of climate change, ensuring the reliability of electricity services along the way.