The Electricity Journal 32 (2019) 106642

Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/tej

Resilience management practices for electric utilities and extreme weather

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ARTICLE INFO

Keywords:
Electric utilities
Resilience
Extreme weather
Climate change
Management practices
Vulnerabilities
Resilience maturity model, self-assessments

ABSTRACT

This paper describes management practices of a model resilient electric utility that can serve as a framework for advancing planning and preparation for extreme weather and climate hazards. The framework focuses on practices grouped into eight domains progressing through five levels of maturity. For each domain, a discussion of resilience management practices is provided along with examples. By assessing its maturity level and taking steps to increase it, a utility can realize increased resilience benefits.

1. Introduction

A range of extreme weather events can impact electricity infrastructure, and power generation, including extreme storm events, heat waves, extreme cold events, sea level rise, floods, droughts and wildfire. All regions of the nation can be impacted, and all components of electricity supply and demand are potentially vulnerable (DOE, 2013, 2015a; DOE, 2015b, a; Zamuda et al., 2018). These extreme weather hazards are projected to increase in frequency, intensity and duration in the future due to climate change (USGCRP, 2017; 2018). Correspondingly, the costs of power interruptions and damages to electricity infrastructure are increasing, including costs related to repairs, disruption, and lost productivity (NOAA, 2019; LaCommare et al., 2018; Larsen et al., 2017; DOE, 2017a, a; EOP, 2013a; Campbell, 2012).

This paper identifies key management practices for advancing a model extreme weather-resilient electric utility. These management practices are based on best practices of utilities and insights from the electricity industry. The scope includes both near-term acute risks, such as more frequent and extreme storms and wildfires, and longer-term chronic risks, such as rising temperatures and sea levels associated with a changing climate. For the purpose of this paper, "*resilience*" is defined as: *the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions*" (EOP, 2013b).

Many utilities are already engaged in activities to enhance their resilience to extreme weather (DOE, 2015a, a, Zamuda et. al., 2018). However, the practice of planning for and implementing resilience strategies is not yet universal among the Nation's utilities. In many cases, utilities are just beginning to consider or project how changes in extreme weather and climate will affect their operations, infrastructure, and business future. Nonetheless, many utilities are well-positioned to pursue greater resilience by enhancing or adapting their current management practices to address their changing extreme weather vulnerabilities and implement effective resilience planning processes and solutions (DOE, 2013, 2015a; DOE, 2015b, a; DOE, 2016b, and DOE, 2016c).

2. Model resilience management practices

This paper presents effective management practices as a framework for use by utilities to enhance their resilience in eight key domains: *Governance and Accountability, Stakeholder Engagement, Communication, Risk Management, Investments, Supply Chains, Services, and Employees*. These domains are adapted from related work on maturity models (DOE, 2014; Caralli et al., 2011; Carnegie Mellon, 2011, and Ceres, 2010). For each domain, a set of management practices with a brief discussion is provided, as well as illustrative examples. The management practices are structured in a framework of progressing maturity levels (i.e., Initiating, Progressing, Optimizing, Leading, and Pioneering) representing defined stages of an organization's progress toward achieving its resilience vision. The maturity levels for a given

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https://doi.org/10.1016/j.tej.2019.106642

Initiating	Progressing	Optimizing	Leading	Pioneering
Corporate policy includes a commitment to comply with applicable resilience requirements.	*Support is visible and routinely demonstrated; Roles are clearly documented and understood; Corporate policy commits to resilience beyond industry standards. The organization publicly promotes the benefits of its resilience vision and strategy.*	*Leadership tracks resilience performance, risks and vulnerabilities, and establishes goals and objectives for continuous improvement; Corporate vision and policy addresses resilience, including response and recovery as well as preparation to reduce and avoid short- and long-term negative effect.*	*Leadership annually reviews resilience performance and establishes goals and objectives; Performance evaluation and compensation is related to resilience success; Corporate policy addresses life cycle corporate assets and operations, supply chains, and communities in their service area.*	*Leadership sponsors innovative and transformative change in resiliency policy and practices for the electricity sector; Corporate policy commits to transform resilience performance and establishes a leadership role for ensuring resilience in the electricity sector.*

Fig. 1. General criteria of each maturity level of *Governance and Accountability*.

domain are cumulative. To progress to a higher level for a given domain, an organization should address the management practices in all lower levels for that domain. The maturity indicator levels for each of the eight domains are independent of each other; an organization may be operating at different levels of maturity across the eight key domains.

2.1. Governance and accountability

A model resilient electric utility's management is responsible and accountable for resilience strategy and performance, and provides oversight and accountability for achieving resilience goals. *Governance and Accountability* management practices should include: (1) *Ensuring that management's roles, responsibilities, and accountability for resilience are clearly defined, communicated and understood;* (2) *Embedding resilience considerations into utility policies and risk management systems to guide day-to-day decision-making; and* (3) *Approaching management decisions with full consideration of the impacts of disruptions throughout the decision's life cycle.* Fig. 1 illustrates the progressing maturity of model *Governance and Accountability* management practices.

Within a model resilient electric utility, a functional connection is institutionalized between the roles and responsibilities of leadership and the resilience performance of the utility. Leadership understands and embraces their individual and collective impact on the utility's resilience. To support resilient governance and accountability, institutional policies and risk management systems that guide day-to-day decision-making are designed to provide actionable insight into the effects of resilience decisions.

Leadership encourages utility resilience by: (1) Engaging with local governments and agencies to determine and implement policies and regulations that can stimulate resilience investments; (2) Engaging with local government offices and critical customers to ensure planning and preparedness for future extreme weather events; (3) Engaging and leading preparation, response, recovery and mitigation activities; (4) Engaging in long-term resilience planning that balances mitigation of risk to acute shocks and long-term stresses posed by changes in extreme weather; (5) Developing capabilities at multiple levels to track and evaluate resilience performance; and (6) Routinely reviewing resilience performance, significant vulnerabilities and incidents, and action plans for improvement.

An example of best practices for *Governance and Accountability* includes the Exelon Board of Director's Corporate Governance Committee, which is responsible for overseeing the management of environmental matters, and annual reviews of the company's performance associated with extreme weather adaptation and resiliency. Exelon established its Climate Change Policy to formalize the corporation's position on changes in extreme weather, orient its business to take meaningful action to reduce greenhouse gas emissions, and build system resilience (Exelon, 2017). Exelon's Enterprise Risk Management (ERM) and Continuous Improvement processes address enterprise risks related to climate and extreme weather in the nearer term (i.e., up to 10 years through their Strategic Plan) and longer term (i.e., more than 10 years out through emerging risk reporting and Environmental Aspect and Impacts assessments).

2.2. Stakeholder engagement

The model resilient electric utility systematically identifies a diverse group of internal and external stakeholders, and regularly engages with them on resilience risks and opportunities. Model management practices include: (1) *Identifying and regularly engaging a diverse and comprehensive group of stakeholders focused on resilience risks and opportunities, with thorough, ongoing, in-depth, and timely dialogues;* (2) *Working with representatives from regulators, science, industry, and community to define objectives, goals, lines of responsibility, and areas for collaboration;* (3) *Embedding extreme weather resilience into internal stakeholder engagement and everyday practices; and* (4) *Engaging investors and senior executives to reinforce resilience priorities and address risks and*

Initiating	Progressing	Optimizing	Leading	Pioneering
Stakeholder engagement is internally focused on electric utility employees; External engagement is typically in response to specific extreme weather events.	*Both internal and external stakeholder are identified and periodically engaged in dialogues. Vulnerabilities, resilience actions, improvements and benefits are routinely tracked and shared with stakeholders.*	*A diverse and comprehensive group of stakeholders are systematically identified and engaged regularly, focused on resilience risks and opportunities; engagement is thorough, ongoing, in-depth, and timely.*	*External and internal stakeholders and senior executives are routinely engaged to inform strategy, risk management, and enterprise-wide resilience decision-making.*	*Stakeholder engagement employs innovative practices that transform industry resilience expectations.*

Fig. 2. General criteria of each maturity level of *Stakeholder Engagement*.

opportunities, and to inform strategy, risk management, and enterprise-wide decision-making. Fig. 2 illustrates the progressing maturity of model *Stakeholder Engagement* management practices.

Stakeholder Engagement is critical to accurately characterizing a company's resilience postures, recognizing roles and responsibilities of the community, identifying opportunities for improvement, developing effective resilience strategies, and implementing solutions that align with the values and needs of a broad stakeholder base. The group of stakeholders should be diverse, covering all aspects of operations and service and ensuring representation of varied perspectives. Engagement with the regulatory community, which plays a key role in the resilience decision-making process, is also critical.

Engagement should include individual employees through senior management teams in substantive and ongoing dialogue. This internal stakeholder set should include asset management and operations groups to look at potential long-range effects of changes in extreme weather to reliability. Engagement with other utilities is essential to develop synergies between risk management, commercial growth and innovation, as well as best practices across the utility industry. Utilities should consider incorporating resilience into existing stakeholder groups and processes. Coordination and engagement with stakeholders can be useful in prioritizing efforts to further address resilience gaps or emerging risks that shift priorities or courses of action.

Stakeholder Engagement examples include San Diego Gas & Electric's (SDG&E's) coordination with about 40 stakeholders representing local schools, water districts, and fire departments to develop a joint fire-prevention plan aimed at preventing major wildfires in the San Diego region (SDG&E, 2018a). Through this collaboration, SDG&E identified and implemented solutions to reduce the potential of a powerline-related fire, including undergrounding lines where feasible and hardening its overhead electric system. SDG&E also partners with local fire agencies, Fire-Safe councils, Community Emergency Response Teams (CERTs) and the San Diego County Fire Chiefs' Association to promote coordinated safety and fire prevention and preparedness. SDG&E has also partnered with the U.S. Forest Service, UCLA, CalFire, the Desert Research Institute, and the National Weather Service to create a web-based product that assesses and shares daily fire potential information with first responders, government agencies, and the general public to enhance public safety (NERC, 2014).

2.3. Communication

The model resilient electric utility ensures effective communication of its resilience goals and performance both within the industry and to the public to enhance industry accountability and sharing of best practices. This can be accomplished through: (1) *Communicating significant resilience goals, and planned or current actions taken to achieve those goals, relating to their direct operations, partnerships (e.g., subsidiaries, joint ventures), products and supply chains to enhance accountability and awareness of best practices; and,* (2) *Using of a broad range of communications channels or mechanisms to share resilience information with the broader internal and external community*. Fig. 3 illustrates the progressing maturity of model *Communication* management practices.

Although effective communication is an essential component of stakeholder engagement, communication is also a key attribute of utility resilience for broader industry accountability and transparency. It helps to foster transparency in resilience gaps, raise awareness of activities to close those gaps, and encourage sharing of best practices within the industry to increase the collective resilience of the Nation's electrical power system.

Electric utilities are undertaking external and intra-industry communications of performance targets and goals to achieve regulatory compliance in annual reliability performance and GHG emissions (PG&E, 2017a, 2017b, 2017c,EPA, 2017). In the absence of formal communication requirements focused on resilience, existing communication activities can serve as an initial basis for resilience communication that can be expanded as stakeholder engagement and other activities grow.

Communication examples include Seattle City Light's development of a public Climate Change Vulnerability Assessment and Adaptation Plan and related website with additional information about efforts the utility's efforts to understand impacts and increase extreme weather resilience (SCL, 2019). This information was also incorporated into the electricity sector chapter of the City of Seattle Climate Preparedness Plan, which went through a stakeholder review process.

Another example is the U.S. Department of Energy's (DOE) establishment of a public-private partnership (*Partnership for Energy Sector Climate Resilience*) with electric utilities to serve as a mechanism to develop, implement and communicate vulnerabilities and resilience solutions for extreme weather risks, and to identify resilience challenges and opportunities locally, regionally and nationally. (DOE, 2019).

2.4. Risk management

The model resilient electric utility uses leading risk management approaches for system planning and operations. Resilient utilities capably measure and forecast the climate-related impacts to performance of their infrastructure and employees. Furthermore, resilient electric utilities deliver value to the communities they serve by designing and implementing solutions to cost-effectively decrease their risk profile. Model *Risk Management* practices include: (1) *Expanding or adapting risk management activities to encompass historic extreme weather risks as well as longer-term, systemic and emerging risks such as changes in extreme weather due to climate;* (2) *Conducting vulnerability assessments and develop resilience planning strategies that proactively address emerging extreme weather threats;* (3) *Integrating extreme weather resilience considerations into long-term investment strategies and preparedness planning;* (4) *Engaging with external stakeholders, suppliers, regulators, and other relevant parties to characterize and plan for risks among these external parties that could affect the utility; and* (5) *Integrating quantifiable attribute-based and performance-based resilience metrics into planning and operation (*Petit et al., 2013; Watson et al., 2014; Vugrin et al., 2017*)*. Fig. 4 illustrates the progressing maturity of model *Risk Management* practices.

Risk Management practices should be integrated into utility planning and operations at multiple levels. A resilient utility expands or adapts these practices to address emerging or uncertain threats through focused assessments of vulnerability, and crafts resilience plans using the best available science and information. The resilient utility conducts vulnerably assessments that evaluate the exposure, sensitivity, and adaptive capacity of current practices and systems to existing or emerging extreme weather threats to inform longer-term planning activities (DOE, 2016a, b; DOE, 2016c).

Risk assessments should extend beyond physical infrastructure to examine impacts on operations, electricity supply and demand, workforce and organizational risk management practices. Information about operations and electricity demand can be collected and cataloged from practices that are influenced by changes in extreme weather and environmental conditions over longer time horizons and serve to inform the development of long-term plans or strategies that address these risks. Given the evolving nature of extreme weather impacts, it is essential that the resilient utility periodically monitors extreme weather observations and projections, and accounts for changing conditions by updating long-term risk management, investment, and resilience plans to account for new information.

The reliance of utilities on suppliers effectively exposes utilities to upstream risks that could cascade on to the utilities themselves. Resilient utilities engage with these external or dependent parties to conduct joint exercises and to share information on emerging risks, resilience best practices, technologies, policies and priorities. This enables utilities and their partners to collaboratively address shared risks and resilience priorities. The grid is essential to the operation of many

Initiating	Progressing	Optimizing	Leading	Pioneering
Communication of resilience challenges, plans and actions, and lessons learned/best practices are limited and focused on selected individuals and/or electric utility organizations using limited communication channels and tools.	*Mechanisms established to periodically share resilience information with a broader internal and external community based on their relevance to ensuring reliability and resilience of utility assets and operations. Communications and understanding will evolve over time and the resilience message should be relevant and understandable.*	*Routine and regular communication occurs with a diverse set of mechanisms (websites, interviews, publications, videos, social media) established to communicate utility resilience goals, planned and current actions taken to achieve those goals, and trends in resilience performance.*	*Establish and maintain communication channels and relationships with internal and external organizations to collect and provide resilience information, including threats and vulnerabilities, to reduce risks and to increase operational resilience.*	*Resilience communication occurs trough a range of innovative communication mechanisms and practices between executive management, employees, suppliers, and stakeholders (i.e., customers, regulators, etc.) to drive resilience performance. Resilience is integrated into a broader communication strategy for the utility.*

Fig. 3. General criteria of each maturity level of *Communications*.

other critical infrastructures (e.g., transportation, communication, health services). Resilient utilities coordinate with the downstream operators of these interdependent systems to ensure that potential disruptions do not cascade to other infrastructure sectors.

Risk Management examples include AVANGRID's vulnerability assessment, in which resilience strategies were identified that could reduce the risk to its electric and gas transmission and distribution system (DOE, 2016a). These strategies were categorized as system hardening, system automation & control, system inspection & maintenance, system emergency preparedness & management, and alternative system applications. The strategies identified in the vulnerability assessment were prioritized using a likelihood-consequence matrix, and then further evaluated using cost-benefit analysis to ultimately inform a resilience action plan.

2.5. Investments

The model resilient electric utility invests resources to achieve cost-effective resilience and reliability solutions, minimizing negative impacts of extreme weather to their customers. *Investments* by these utilities focus on system-level solutions that may be coordinated with other utility or government infrastructure investments, as well as individual energy assets and buildings. The design process for these investments considers updated standards for at-risk assets. These investments coordinate with other utility or government infrastructure investments to maximize broader regional resilience. Model Investment management practices include: (1) *Ensuring that the benefits of resilience investments are well-understood and quantified;* (2) *Targeting investment at system-level resilience across scales, from generation to transmission to distribution; and* (3) *Targeting investment at asset-level resilience, including facilities and equipment.* Fig. 5 illustrates the progressing maturity of model *Investments* management practices.

Investments that improve the resilience of electric utilities include those focused on broad system-level resilience as well as utility-owned individual asset resilience. Resilient utilities incorporate performance-based and attribute-based resilience metrics into this process. In this way, some investments will be made primarily with extreme weather resilience in mind, but other investments not targeted primarily at resilience (e.g., incorporating customer-installed distributed resources) are also analyzed and evaluated for resilience co-benefits. Capital spending by local investors such as city governments and infrastructure owners is incorporated to leverage funding, maximize benefits, and minimize unintended outcomes. As utilities develop their resilience strategies, a key step in the analytical process involves costs and benefits evaluations of potential resilience improvements, and understanding tradeoffs between resilience benefits and traditional blue-sky benefits, to prioritize resilience investment decisions and demonstrate that identified resilience projects yield net benefits for their customers, and are considered prudent investments by regulators.

Resilience investment will also be necessary at the individual asset level, including assessing the adherence of current facilities and new construction to resilience standards, updating design standards, and

Initiating	Progressing	Optimizing	Leading	Pioneering
A documented resilience management strategy exists including approaches for risk prioritizing. Adequate resources (people, funding, and tools) are provided to support risk management activities, including extreme weather events.	*Risk criteria for evaluating, categorizing and prioritizing asset and operational risks based on impact, tolerance of risk and risk response approaches are defined and available to employees. Standards or guidelines have been identified to inform risk management activities and address risks and risk uncertainty that may be increasing over time. Personnel performing risk management activities have the skills and knowledge needed to perform assigned resilience responsibilities.*	*Risk assessments are routinely conducted on the electric utility's assets and operations to identify new or evolving risks, and cost-effective resilience solutions are identified, deployed, and tracked for performance improvement. Risk management activities use both historic event data as well as projected threat information over the life cycle of assets to address longer term systemic and emerging risks.*	*Engagement with external stakeholders, partners, regulators, and other relevant parties to characterize and plan for risks among these external parties that could affect the utility. Integrate quantifiable attribute-based and performance-based resilience standards and metrics into planning, design, and operations.*	*Executive management sponsors innovative and transformative change in risk assessment (tools, data and methodologies) and risk management policy and practices for the electricity sector, serving as a leader for change and ensuring resilience of the electricity sector.*

Fig. 4. General criteria of each maturity level of *Risk Management*.

Initiating	Progressing	Optimizing	Leading	Pioneering
The organization has a defined strategy for meeting resilience goals and driving resilience decisions and investments. The organization identifies the electricity supply, distribution and demand requirements for its services, and vulnerabilities, needs and investments necessary to enhance resilience in the short-term.	*Resilience investment decision-making is planned and proactive to achieve both short- and long-term resilience goals over the lifecycle of critical utility assets. The utility quantifies resilience benefits for some investments.*	*Resilience is enhanced not only for electric utility assets and operations at the local level, but also extends to suppliers and the regional/national level. Mechanisms are in place to track the effectiveness of resilience investments. The organization makes information that includes resilience costs and benefits available to stakeholders.*	*The organization seeks to optimize the use of a diverse resilience strategy (e.g., hardening, relocating, energy efficiency, distributed energy resources, energy storage, etc.) to optimize the effectiveness and benefits of electric utility resilience investments. In addition, the utility has programs to encourage customers to identify and adopt resilience solutions (backup distributed generation, smart grid, energy efficiency, etc.).*	*Innovative resilience technologies, assets, and business processes are integrated into the organization to enhance reliability and resilience at the local, regional and national levels to optimize utility, customer and societal value and economic benefits.*

Fig. 5. General criteria of each maturity level of *Investments*.

Initiating	Progressing	Optimizing	Leading	Pioneering
Utility understands critical supply requirements and critical suppliers for all critical assets and operations.	*Engagement with critical suppliers to understand resilience capabilities and relevant risks and vulnerabilities.*	*Utility supply chain policies align with utility resilience goals, to drive supply chain decisions and investments.*	*Utility uses performance- and attribute-based resilience metrics of suppliers to make procurement decisions. An integrated resilience plan is in place that ensures available resources and new sourcing capacity.*	*Utility has a flexible, redundant, responsive, agile supply chain as demonstrated through performance- and attribute-based metrics of suppliers and provides leadership for regional and national resilience capabilities.*

Fig. 6. General criteria of each maturity level of *Supply Chains*.

investing in extreme weather-resilient technologies. This may require that utilities incorporate extreme weather considerations when selecting sites for new facilities or deciding whether to continue to invest in assets and buildings that are in areas projected to be increasingly vulnerable. Similarly, the design of new facilities, or changes to existing facilities, may require that design standards that are influenced by extreme weather (e.g., operating temperatures, water availability) better account for changing environmental conditions. The selection of different building or asset materials, water availability or consumption efficiency, new technologies, and performance expectations may be essential considerations for enhancing the extreme weather resilience of assets and buildings.

Utilities should focus on total costs of potential resilience measures, which include up-front capital costs as well as operating and maintenance costs, and legal liability costs over the lifetime of the resilience measure. This could include job losses, sales and revenue losses, and penalties and litigation costs. Resilient utilities should evaluate a variety of benefits, including direct benefits from avoided damages and costs (based on potential costs of impacts), avoided revenue losses due to interrupted service, as well as co-benefits (e.g., system reliability, energy efficiency, reduced emissions, public safety).

Model *Investment* examples include Public Service Electric and Gas's (PSE&G's) Energy Strong Program and Break-Even Analysis (PSE&G, 2013). In response to damages from Super Storm Sandy, PSE&G initiated their Energy Strong program to support their resilience investment request to the New Jersey Board of Public Utilities. A breakeven analysis was applied to the Energy Strong program evaluate resilience investments in which the value of the investment is compared with customer interruptions that could be avoided over the lifetime of the investment. Through this analysis, it was determined that the proposed Energy Strong program would result in reductions in the number and duration of outages caused by severe weather events, providing value to customers.

2.6. Supply chain

The resilient electric utility should ensure that assets and operations are resilient to extreme weather events, and that critical supply chains achieve resilience objectives comparable to those the electric utility has established for itself. Leading utilities in this area establish resilience procurement criteria, catalyze improved supplier performance, and facilitate disclosure of suppliers' resilience information. Model *Supply Chain* management practices include: (1) *Setting supply chain policies and codes aligned with overall resilience standards;* (2) *Addressing resilience performance in procurement criteria and contracting;* (3) *Ensuring that critical suppliers meet the electric utility's standards for resilience performance; and* (4) *Disclosing a list of their key suppliers and measures and discloses supply chain resilience performance.* Fig. 6 illustrates the progressing maturity of model *Supply Chain* management practices.

In-depth knowledge of key supplier's vulnerabilities will enable an electric utility to ensure the reliability of its supplier base and anticipate potential problems in delivery of critical supplies. Several aspects of supply chain structure can be used to start characterizing the supply chain, including:

- Prevalence of single source suppliers
- Redundancies (additional facilities, additional buffer inventories and stocks, additional capacity).
- Flexibility (of sourcing, transport systems, etc.).
- Responsiveness (how quickly can the supplier respond, what business continuity plans do they have in place, etc.).
- Proximity of distribution (in the event of physical disruptions such as storm damage limiting transportation infrastructure).

Just-in-time inventory control increases vulnerabilities in complex supply chains during disruptions (Tang, 2006). The traditional metrics of supplier performance for procurement decisions could be supplemented with metrics of supplier ability to adapt and respond during

disruptions. Since it may not be possible to assess supplier performance during past disruptions, supplementing procurement decisions with suppliers' attribute-based metrics will improve understanding of resilience potential.

Some key grid components pose difficulties for supply chain management because of long manufacturing lead time and high vulnerability (DOE, 2017c). For example, to address known vulnerabilities in large power transformer supply chains, utilities have instituted a variety of mechanisms to ensure that spare transformers are available (DOE, 2017a).

Fuel supply chains and fuel assurance are also a growing consideration for electricity system reliability and resilience (DOE, 2017c; EIA, 2018). Supply constraints can create increased price risk and, in extreme cases, could impact reliability and resilience. A resilient utility should assess their system level supply chain risks and understand what is needed to maintain power system reliability and resilience under a variety of conditions as the mix of generation technologies evolve and the environment for which they must operate changes.

An example of a *Supply Chain* management practice is Exelon's work as a founding member of the Electric Utility Sustainable Supply Chain Alliance. Exelon has worked with 19 other utilities to develop sustainable standards for a variety of commodities and improve supplier disclosure of relevant environmental performance metrics (EUI, 2019). Exelon has begun engagement with key suppliers around their business risks (including extreme weather) and their business continuity planning efforts to manage these risks.

2.7. Services

A resilient electric utility designs and delivers services to enhance the resiliency of its customers by cost-effectively using appropriate and innovative business models and technologies. Innovations can be enhanced through a better understanding of customer service requirements, appropriate R&D expenditures, new business approaches, and strategic collaborations. Model *Services* management practices include: (1) *Making appropriate R&D investments in new technologies that can cost-effectively deliver new resiliency services;* (2) *Innovating business approaches that align with customer resiliency needs and create lasting value;* (3) *Aligning marketing practices with resilience goals and marketing their designed-for-resilience services; and* (4) *Collaborating within and across sectors to innovate and scale resilience services and contribute to the development of cost-effective resilience solutions.* Fig. 7 illustrates the progressing maturity of model *Services* management practices.

Electric utilities that deliver electricity to retail customers are increasingly considering alternative business models that include a resilience services-driven approach. As utilities consider sector-wide developments and potential vulnerabilities to extreme weather, resilience can be considered as a driver of value to customers.

Utilities can focus on delivering resilience services that customers may find valuable, such as home automation, energy efficiency, and demand response programs, or broader customer resilience services such as on-site backup generation, microgrid programs, and purchasing or leasing distributed energy technologies. A holistic approach could include addressing all energy needs for the customer, where the utility coordinates heating, cooling, transportation, and other services that enhance resilience in the most cost-efficient manner.

Resilience services-driven utilities may also focus more broadly on extracting an optimal value from the system of deployed technologies. For example, behind-the-meter customer devices could be utilized for grid services so that the benefits of one customer's device can be shared with other customers to maximize benefits and system-level resilience. A performance-based approach could incentivize a resilience-driven utility through which system-wide performance-based resilience metrics can be utilized as a performance category for which utilities can assess customer value.

Utilities could consider various options to integrate and market services that vary in intensity, including: making resiliency improvements that will broadly affect rates and services; and, developing and pricing resiliency services that consumers can choose to purchase. Some businesses may rely on consistent supply of power and face greater losses in the event of disruption than they have in the past, such as those providing other critical services during disasters (e.g., food, health, and shelter) that increasingly rely on consistent power to effectively function. These potential changes provide increased opportunities for partnerships between electric utilities and businesses, such as various product offerings by the utility for more reliable and resilient electricity service, including incorporation of distributed energy sources, microgrids, energy storage, and paid purchase agreements for reliable energy sources.

A *Services* example includes Consolidated Edison's Distributed System Implementation Plan (DSIP) in 2016, which was a five-year self-assessment and strategic roadmap that strives to take a larger look at the efforts the company is undertaking to give customers more choice, control, and convenience and to remake the day-to-day planning and operation of the electric system (ConEd, 2016). The DSIP outlines Con Edison's plan to efficiently integrate distributed energy resources (DER) and promote the company's goals of customer engagement, reliability, and operational excellence.

2.8. Employees

A resilient electric utility considers resilience as a component of recruitment, compensation and training, and encourages resilient lifestyle choices; it recognizes that a resilient workforce will require open communication and teamwork; it assesses the impact of extreme weather for its impact on worker health and safety. Model *Employee* management practices include: (1) *Recruiting and retaining high quality employees is critical to a resilient workforce;* (2) *Empowering professional development through training and educational courses on resilience, leadership, teamwork, and new skill development;* (3) *Fostering dynamic and*

Initiating	Progressing	Optimizing	Leading	Pioneering
Utility explores ways to adapt existing business practices to offer resilience services. Conduct detailed customer analysis of resilience requirements and research/explore ways to provide resilience services to customers upon request.	*Significant pilot programs and investments in resilience technologies and practices to identify future services and energy products. Targeted marketing promotes pilot programs to a subset of customers.*	*Market designed-for-resilience services that match resilience goals. Pilot projects to provide resilience services to customers upon request.*	*Work with regulators and stakeholders to develop new business models and revenue streams for resilience services. Collaborate within the electricity industry to identify additional resilience solutions. Roll out new services to stakeholders.*	*Collaborate within and across sectors to innovate and scale resilience services and contribute to the development of open source cost-effective resilience solutions.*

Fig. 7. General criteria of each maturity level of *Services*.

Initiating	Progressing	Optimizing	Leading	Pioneering
Employee roles and responsibilities with regard to utility resilience are defined, communicated and understood.	*Open communication on resilience threats, plans, actions and opportunities is established between employees and management and among employees.*	*Programs are adopted to recruit and retain high quality employees skilled and knowledgeable about resilience.*	*Employees are empowered and develop professionally through training and educational courses on electricity sector resilience and new skill development necessary to manage and protect electric utility assets.*	*The utility sponsors innovative and transformative change in workforce management and organizational risk management, serving as a leader for change and ensuring resilience and reliability of the electricity sector.*

Fig. 8. General criteria of each maturity level of *Employees*.

flexible workforces that are better able to adjust to continually changing operational and work environment; (4) *Ensuring open communication between employees and management and among employees; and* (5) *Ensuring employee safety, especially with increasing severity and frequency of extreme weather events impacts requiring their attention.* Fig. 8 illustrates the progressing maturity of model *Employees* management practices.

A resilient workforce will enable utilities to safely and successfully adapt to new challenges, identify and take advantage of new opportunities, and foster a culture of innovation. Communication, teamwork, and the empowerment to continue to learn about the impact of extreme weather on utility operations and the service community is fundamental to a resilient workforce. New employees should be recruited through effective protocols, offering competitive compensation packages, and prioritizing resilience. Utilities should highlight their efforts on resilience when recruiting new employees.

Maintaining and growing a stable and resilient workforce requires effective employee retention, resilience training and education, and empowerment by fostering a creative work environment. A resilient utility should ensure that resilience tools, technology and methodologies are available and continuously improved with employee input. In addition, employees at all levels of the organization should be able to contribute to enhanced utility resilience through mechanisms such as resilience councils or teams. A resilient utility should also encourage employees to consider resilience in their personal lives, such as the developing personal emergency preparedness plans.

A model resilient utility embeds resilience into its fundamental culture by developing policies that foster a self-sustaining culture of resilience. Empowering employees through educational growth and training opportunities, should focus on individual resilience, healthy lifestyles, and safety, as well as professional development combined with the acquisition of new skills. In addition, utilities should assess safety implications of extreme weather on employees (e.g., increased heat stress, danger due to more frequent extreme events, wildfires and floods).

Employee examples include Exelon's partnership with the Association of Climate Change Officers to pilot climate change training with infrastructure engineers and elicit feedback on how best to tailor extreme weather training to job needs.

3. Conclusions

This paper provides a framework describing key management practices of a model extreme weather-resilient electric utility. This framework can be used to assist utilities in tracking their progress in enhancing resilience to extreme weather. By assessing its current maturity level for each domain and taking steps to increase its levels as appropriate, an organization will move closer to obtaining the desired benefits of an effective resilience strategy. There are multiple benefits to consider in conducting a resilience self-assessment, including: (1) Establishing a baseline assessment of the utility's current level of resilience management practices related to extreme weather resilience and providing a method for tracking progress over time; (2) Increasing awareness and understanding of any key gaps in existing resilience management practices and efforts; (3) Enabling dialogue between the utility and key stakeholders who may otherwise not collaborate regularly; (4) Enabling discussion of priorities for investment and action based on a shared understanding of the current level of resilience management practices; and (5) Ultimately leading to resilience management practices, measures and implementable projects that will deliver increased resilience for the utility over time. Establishing a target level for each domain may be an effective strategy to guide resilience program improvements. Organizations should assess the costs and benefits of achieving specific maturity levels in defining their resilience program improvement goals.

Disclaimer

Acknowledgements

This paper was produced by Craig Zamuda, U.S. Department of Energy's Office of Policy, Thomas Wall, Leah Guzowski, Joshua Bergerson, Janet Ford, and Lawrence Paul Lewis of Argonne National Laboratory, and Robert Jeffers and Sean DeRosa of Sandia National Laboratories. A number of people provided constructive comments on a predecessor of this manuscript including: John Lushetsky, Lawrence Mansueti, David Meyer, Rakesh Batra, DOE; Ashley Lawson, C2ES;

Kristin Ralff Douglas, California Public Utility Commission; and representatives from DOE's Partnership for Energy Sector Climate Resilience, including Matthew Russel, Austin Energy; Arthur Kruppenbacher, Elissa Levin and Carl Ast, AVANGRID; Michelle DeMascio, Charles Viemeister, and Neil Weisenfeld, Consolidated Edison of New York; Steve Tullos, Entergy; Melanie Dickersbach, Exelon Corporation; Michael Brytowski and Gordon Pietsch, Great River Energy; Michael McPeck and John Gavin, National Grid; William Stanton and Roseanne Crockett, New York Power Authority; Kit Batten, Pacific Gas and Electric; Raymond Alvarez, Public Service Electric and Gas; Kathleen Ave, Sacramento Municipal Utility District; Kathryn Giannecchini and Brian D'Agostino, San Diego Gas and Electric; Crystal Raymond, Seattle City Light; Hiro Kuchida, Jennifer Pearce, Amber Topoleski Richards, and Donald Daigler, Southern California Edison; Karen Utt, Tennessee Valley Authority; and Daniel Brown, Xcel Energy.

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