Resilient power: How utilities can identify and effectively prepare for increasing climate risks

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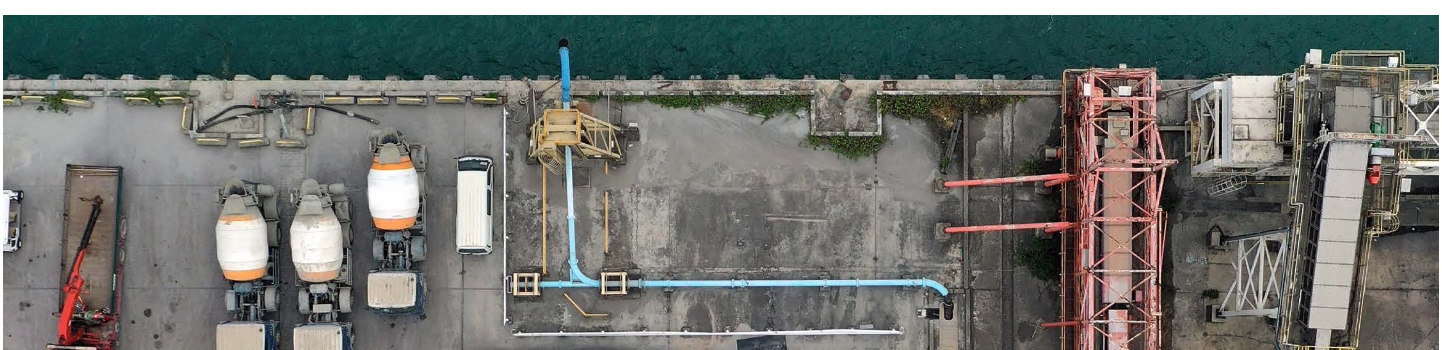
Executive summary

Prominent threats to utilities, especially extreme weather events, are common and increasing. For utilities and their stakeholders, understanding likely impacts from these events is key to protecting our energy infrastructure, ensuring critical systems are able to function during and after an event, and supporting community resilience. Currently, many utilities are only beginning to respond to these vulnerabilities and close the over $500 billion resilience investment gap plaguing energy providers across the United States. Yet, they are under pressure from regulators and consumers to take action.

For utilities to take meaningful steps toward implementing resilience, they must meet several challenges including: understanding the vulnerabilities of their infrastructure and processes (ranging from worker safety to asset failure), prioritization of available options to address resilience gaps, and effective communication with regulators and other stakeholders on the benefits of resilience investment—including for their disadvantaged or vulnerable customers.



This report identifies the potentially critical hazards for utilities, breaks down why many utilities today are largely behind in responding, and provides guidance and insight on how utilities can effectively develop resilience plans.

Assessing utility vulnerability to hazards and extreme weather

Energy system vulnerability is a combination of exposure to a climate stressor and an asset's sensitivity to said stressor. A utility's vulnerability to climate hazards depends on the region in which it is located and the types of assets it operates. Power plants in coastal areas have potential exposure to sea level rise, while transmission lines in high fire-threat areas may experience wildfires. Underground network systems in cities may become increasingly vulnerable to heatwaves.

The main climate trends impacting utilities in regions across the U.S. are listed below, accompanied by potential damages or hazards to utility infrastructure. These summaries are meant to raise awareness for utilities, and whether or not a particular utility is truly at risk from these hazards will depend on several factors, including the proximity of assets to hazard areas, the sensitivity of the specific asset to the hazard, and the existing risk mitigations or adaptive capacity.

Sea level rise and flooding

Many coastal regions in the U.S. will experience increased flooding potential and actual flood events due to either sea level rise, more precipitation, or both. In low-lying and coastal areas, flooding, storm surge, and tidal inundation can severely damage power plants, electric substations, power lines, and other key utility assets, leaving customers without power for hours, days, or even weeks—depending on whether or not crews can access equipment.

A 2014 study by the Department of Energy on the effect of sea level rise on energy infrastructure in four major metropolitan areas found that as many as 160 individual energy assets, including power plants, substations, and petroleum facilities, would be threatened by the end of the century.[1]

Main hazards and impacts to utilities

Sea level rise and flooding

Rising temperatures

Extreme storms

Wildfires

[1] https://www.energy.gov/sites/prod/files/2014/10/f18/DOE-OE_SLR%20Public%20Report_Final%20_2014-10-10.pdf

Regional impact: Sea level rise and flooding

In California, for example, San Diego Gas and Electric (SDG&E) partnered with ICF to identify potentially impacted systems and develop effective mitigation plans. ICF's climate analysis found that substations in Mission Bay and San Diego Bay are the most vulnerable—four substations could be exposed to 100-year coastal flooding by mid-century. Further, 16 additional substations could be exposed by the end of the century. If flooded, essential service to customers may be interrupted for an extended period of time. The region has already seen instances of extreme flooding in 2016 and 2017.[2]

In Seattle, higher winter soil saturation will increase the chance of landslides, which could damage ground equipment.[3] Furthermore, the city could also see flooding along the Puget Sound coastline due to sea level rise.

Throughout the Midwest, states are projected to see an increase in flooding, primarily due to a climb in humidity and extreme or heavy precipitation events, as well as long-term drought conditions in the summer months.[4] In the spring, rainfall amounts have increased over the last 30 years from April to June. Precipitation, especially during the post-winter thaw, results in the perfect conditions for flood events during these months.

Meanwhile, high tide flooding has increased by a factor of 10 across the U.S. Northeast over the last 50 years. At this rate, the region will experience flood-related inundation in excess of 30 days per year by 2050. Further, more intense precipitation events could lead to more inland flooding.[5]

For example, the City of Philadelphia partnered with ICF to address and mitigate these potential impacts.[6] An analysis of the region found that sea level rise will result in increased water levels in both Schuylkill and Delaware rivers, essentially inundating parts of Philadelphia for extended periods of time—requiring local authorities and utilities to plan for such a future.

Rising temperatures

Climate projections indicate an increase in the frequency, severity, and length of heat waves for many regions. For utilities, higher temperatures impact efficiency and could result in reductions in generation, transmission, and distribution capacity. The additional capacity needed to overcome this reduction would cost approximately $180 billion by the end of the century, according to Proceedings of the National Academy of Science of the United States of America (PNAS).[7] The same projections also show a 2.8% increase in average hourly load across regional transmission organizations (RTO), including the Electric Reliability Council of Texas (ERCOT), PJM Interconnection, and New York Independent System Operator. These higher peak demands will require even more investment in generation, transmission, and distribution infrastructure along with increased storage as the grid is modernized.

Regional impact: Rising temperatures

Overall, the U.S. is experiencing warmer and sustained temperatures across all regions, including long-term heatwaves. Con Edison's (Con Ed) Climate Change Vulnerability Study, produced in partnership with ICF, took into account the utility assets' sensitivities to rising temperatures due to climate change.[8] Through this analysis, Con Ed found that the grid would have a higher likelihood of experiencing equipment failures during prolonged heat waves.

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2 https://www.latimes.com/local/lanow/la-me-new-storm-california-floods-muslides-snow-20170121-story.html
3 https://www.seattle.gov/light/enviro/docs/Seattle_City_Light_Climate_Change_Vulnerability_Assessment_and_Adaptation_Plan.pdf
4 https://science2017.globalchange.gov/chapter/7/, https://nca2018.globalchange.gov/chapter/21/
5 https://nca2018.globalchange.gov/chapter/2/#key-message-6
6 https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf
7 https://www.pnas.org/content/114/8/1886
8 https://www.coned.com/-/media/files/coned/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-vulnerability-study.pdf?la=en

The report notes that applying the Representative Concentration Pathway (RCP) 8.5 climate scenario for 2050 to its 2018 infrastructure and absent any interim adaptation efforts, a significant number of networks would be targeted for remediation based on the company's standard of reliability.

According to climate projections in the Fourth National Climate Assessment, the Northeast region of the U.S. will primarily encounter increased temperatures (along with rising sea levels).[9] By as early as 2035, the Northeast is projected to be over 3.6 degrees Fahrenheit warmer on average. In turn, the region will see declining snow and ice overall.

The Midwest is becoming significantly hotter overall when compared to any other region in the U.S. In Chicago, daily temperatures reaching over 100 degrees Fahrenheit are projected to increase in regularity—becoming common as early as 2070.

Meanwhile, between 1901 and 2016, the Southwest region has warmed significantly overall. In fact, the average annual temperature today is 1.6 degrees Fahrenheit higher than at the beginning of the 1900s. And this warming will only continue.

In fact, current climate models of the Southwest region project an 8.6 degrees Fahrenheit increase by 2100—resulting in wildfires that are expected to burn over 77% more acres statewide at the turn of the next century.

Extreme storms

In the 2010s, the U.S. experienced more billion-dollar disasters than in the past two decades combined—119 compared to 59 in the 2000s and 52 in the 1990s.[10] These intense weather events bring flooding and high winds that can cause significant damage to energy systems and infrastructure.[11]

The vast majority of transmission and distribution infrastructure in the U.S. is overhead and, in turn, exposed to storms. Vulnerability of overhead electric infrastructure is a function of the operating environment as well as the system design. For example, older radial distribution in sparsely tree-covered areas may actually be less vulnerable to storms because of the lower threat that vegetation presents, than newer, more advanced, looped systems that serve a heavily forested region.

Regional impact: Extreme storms

Most regions are projected to experience rapid change over the next few decades, resulting in a continued increase in major weather events that can impact infrastructure and interrupt service to large numbers of customers.

For instance, in February 2021, Texas experienced extreme winter storms, which left over 4 million residents without power during its peak. Hurricanes are also a major threat: ERCOT reported widespread outages after Hurricane Harvey—with more than 293,000 customers out of service only one day after Harvey made landfall. After Hurricane Irma, 4.2 million customers lost power, including 3.6 million Florida Power and Light customers alone. In some coastal areas, 97% were out of power.

In regions experiencing these events more frequently, like the Southeast, crucial infrastructure could be severely—and repeatedly—damaged again and again, causing service outages and the need for costly equipment repairs or replacement.

[9] https://nca2018.globalchange.gov/chapter/18/
[10] https://www.climate.gov/news-features/blogs/beyond-data/2010-2019-landmark-decade-us-billion-dollar-weather-and-climate
[11] https://www.socalgas.com/1443742022576/SoCalGas-Case-Studies.pdf

Wildfires

Climate change will cause rising temperatures and drier conditions that will increase the risk of wildfires when utility infrastructure comes into contact with foliage, particularly during high-wind conditions. Utilities continue to advance their ability to assess this risk via real-time weather forecasting, cameras, asset inspections, and grid intelligence. Utilities are hardening infrastructure to reduce the risk of failure, and, in turn, reducing the risk of wildfire. During high-wind conditions, utilities shut off power to customers in some areas to reduce the risk of wildfire until the extreme weather has subsided. Given that these "public safety power shut-offs" are extremely disruptive to society, utilities are investing in solutions to lessen their impact including microgrids, or installing sectionalizing switches on circuits and advanced technologies to reduce fire risk, allowing circuits to continue to stay energized.

Regional impact: Wildfires

Many communities living in the Northwest and Southwest regions of the U.S. are exposed to risk from wildfires. In California, the state wildfire commission noted that existing models of capital to fund utility wildfire risk prevention in the state are insufficient with the changing climate.[12] Currently in the state, while credit rating deteriorates, utility borrowing costs increase, making funds to flow into essential improvements for safety difficult to obtain.

Promising start to addressing vulnerabilities, but much more needed

As the U.S. experiences more extreme climate events, cracks are showing in our energy systems and infrastructure. In response, key stakeholders, including utilities, investors, state and local governments, and federal agencies, are taking stock of these vulnerabilities and attempting to address them.

At the federal level, one example includes how the the Department of Energy formed the National American Energy Resilience Model (NAERM) to address the growing threats to energy systems, including climate change.[13] At the state level, California Public Utilities Commission (CPUC) created a process to compel utilities to note and address the impacts of climate change, Oregon implemented guidelines for local energy resilience, and various states have created resilience offices.[14]

As promising as these initial responses are, much more is needed to improve the resilience of power systems, especially given the significant differences in potential regional hazards and sensitivity of particular assets. Individual utilities need to develop specific plans to address potential threats and environmental hazards to their own unique infrastructure, systems, and customers to prevent future outages, safeguard communities, and build resilience to prevent weather-related damage.

Understanding the $500 billion investment gap

Utilities have largely been slow to respond to the threats climate change poses to energy systems—and the communities they serve. This is due to a variety of factors, including an overall lack of insight into the degree of infrastructure exposure; the complexity around how to measure vulnerabilities, hazards, and stressors; and uncertainty about appropriate timing and level of investment for adaptation measures. On top of this, utilities face immense difficulty in securing funding for proactive resilience investments.

[12] http://opr.ca.gov/meetings/wildfire-commission/2019-06-07/docs/20190607-Item_7_Appendix_II_Fund_Workgroup_Report_Draft.pdf
[13] https://www.energy.gov/oe/articles/developing-resilience-model-north-america-s-energy-sector-infrastructure
[14] https://www.icf.com/insights/energy/climate-adaptation-utilities-consequences-increased-state-regulations, https://www.oregon.gov/energy/safety-resiliency/Documents/Oregon-Resilience-Guidebook-COUs.pdf

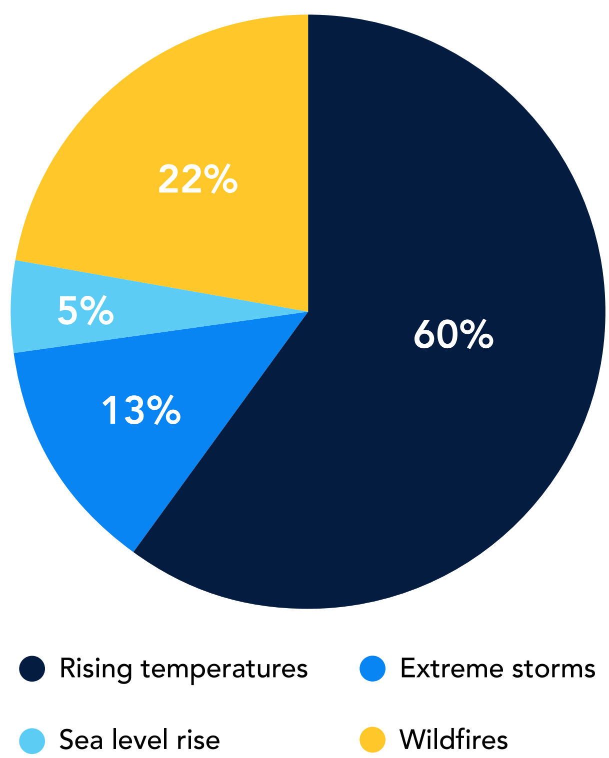
Resilience investment gap

According to an ICF analysis, there is an additional capital investment gap of more than $500 billion needed to provide the level of resilience required for U.S. investor-owned energy utilities to effectively address risks from climate change and prepare energy systems for a changing environment. This gap is driven by multiple sources of investment costs, outside of general operations and maintenance costs, across utilities aimed at protecting infrastructure and assets against rising temperatures, extreme storms, sea level rise, wildfires, and other climate-related hazards. Crucial adaptations needed to thwart various threats represent more of this gap, including (the below percentages are based on an ICF analysis):

- Rising temperatures: As a result of warming regions, increasing temperature impacts generation, transmission, and distribution systems in several ways. Particularly, higher ambient air temperatures increase customer demand while reducing the efficiency of equipment (i.e. transformers and transmission lines). This combination requires greater delivery capacity while making it harder for systems to remove heat. More frequent, severe, and longer heat waves also stress grids and increase the risk of blackouts, requiring additional investments to strengthen system reliability. The impact of increasing temperatures accounts for around 60% of the total climate resilience investment gap.
- Extreme storms: Extreme storms damage crucial infrastructure. High winds cause physical damage to overhead systems, ocean flooding impacts coastal facilities, and rain causes flooding of inland facilities. Adaptations needed to harden infrastructure for extreme storms represent around 13% of the investment gap.
- Sea level rise: Sea level rise impacts electric systems, primarily coastal generating plants and substations, by threatening to inundate facilities and exacerbating storm surge. Adaptations needed account for about 5% of the investment gap.
- Wildfires: As some areas become drier, electric transmission and distribution systems are becoming both an increasing cause of wildfires—and more directly threatened by them. To reduce the likelihood of causing fires and increase flexible responses, adaptations like hardening systems and reconfiguring the grid represent about 22% of the climate resilience investment gap.

Asset owners and utility stakeholders have started to address some resilience gaps and make significant investments in storm hardening. For example, Florida Power and Light has invested over $5 billion since 2006 to harden its electric system.[15] However, for most utilities, it can be difficult to navigate with competing priorities or effectively communicate resilience efforts as an immediate priority.

Rising temperatures account for nearly 60% of the $500B climate resilience investment gap



[15] https://www.fpl.com/reliability/system-improvements.html

How utilities can effectively prepare for increasing, but uncertain, hazards

Utilities can begin addressing the resilience investment gap by analyzing the risks from changing hazards, prioritizing options in a flexible resilience plan, and working with stakeholders to align on resilience goals and proactive investment levels.

Importantly, relatively few utilities have conducted or released comprehensive, forward-looking analyses, similar to Con Edison's Climate Change Vulnerability Study and Climate Change Implementation Plan.[16] A great deal of work remains to be done in assessment, planning, and investment to prepare for an uncertain future marked increasingly with extreme climate events.

Get started: Begin with a high-level screening exercise

To develop resilience plans, utilities must first evaluate the vulnerability of assets (including critical infrastructure), operations, and processes. But how can utilities efficiently determine which threats are the most pressing and which assets are most vulnerable in order to embark on a full-scale study?

A high-level screening of infrastructure and operations can help utilities prioritize where to focus on investigating and performing more detailed analysis. For example, Seattle City Light developed a climate vulnerability assessment to help determine whether potential impacts are likely and consequential enough to warrant adaptation actions.[17] Such screening exercises can consider asset exposure—where major assets (i.e. transmission lines and substations) are coincident with hazard areas (i.e. future flood zones, future high temps, etc.) based on readily available regional or national climate information.

An effective way to inform this exercise, and quickly identify priority vulnerabilities, is by compiling relevant hazard information, including information about future climate changes, and engaging with key subject matter experts through a workshop, survey, or other means of gathering direct feedback.

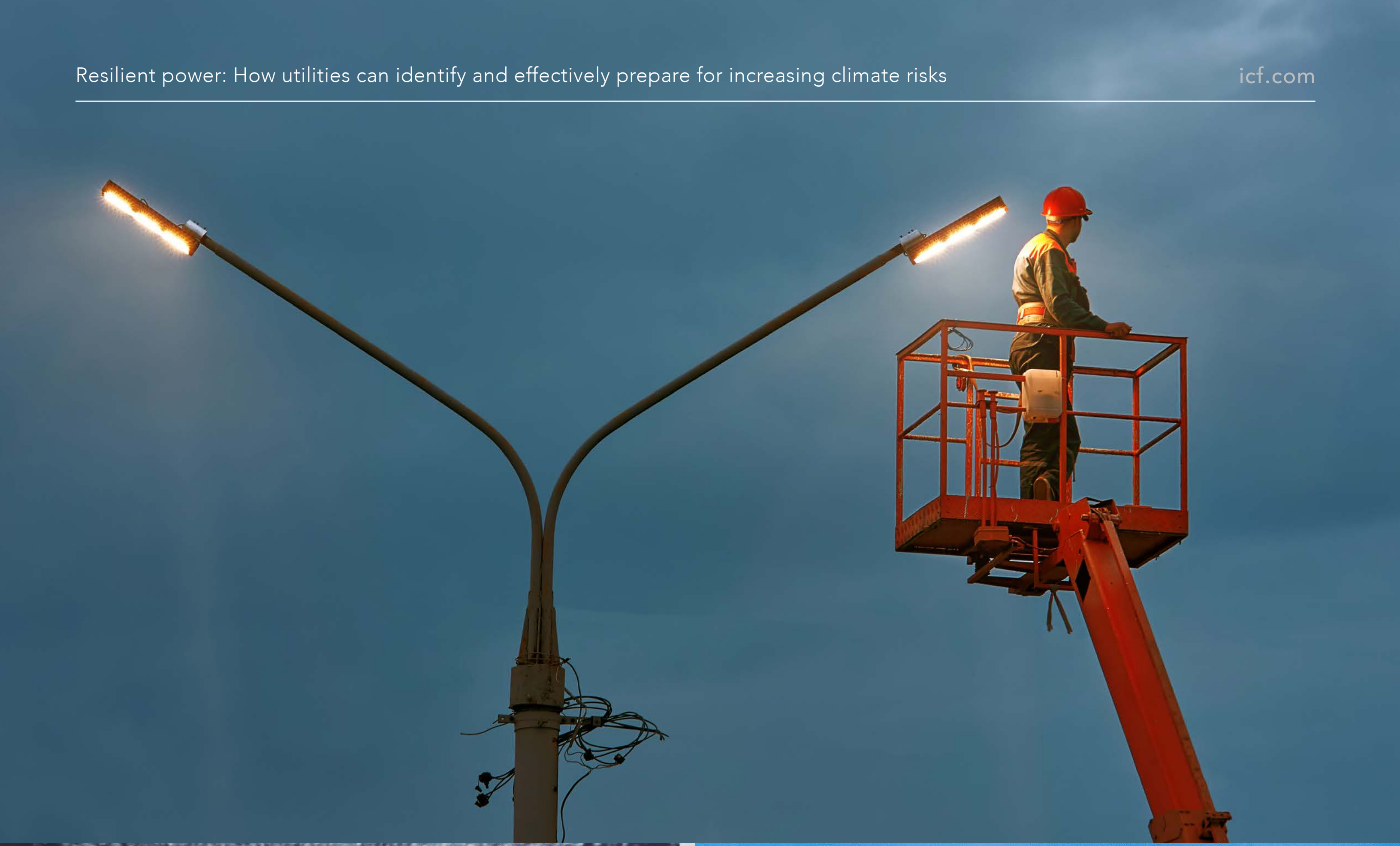
Conduct in-depth risk assessments on priority locations and assets

Through digging into the priorities identified during a utility's initial screen, a detailed analysis can quantify risk and support design of resilience investments. These studies will help utilities determine the current state of energy systems and processes, tailor the climate projections most suited for a specific region and area, and quantify the costs associated with inaction versus gradual system hardening to move resilience efforts forward in a focused and cost-effective way.

Vulnerability studies can inform meaningful resilience plans and investments if they include specific information on current asset condition and asset damage functions or modes of impact, rooted in system performance data or available proxies. For example, an analysis of grid vulnerabilities in Los Angeles County drew on current substation load factors in the region to determine impacts on the ability to meet load under future temperatures.[18]

In addition, findings will be more actionable for the utility if the analysis includes climate hazard data tailored to a utility's specific assets and service areas, as well as details for each asset class to match the sensitivities and potential impact modes. For example, ICF's detailed analysis of potential local sea level rise and storm conditions supported San Diego Gas & Electric's analysis of risks to their coastal assets to inform investment planning.[19]

[16] https://www.coned.com/en/our-energy-future/our-energy-vision/storm-hardening-enhancement-plan
[17] https://www.seattle.gov/light/enviro/docs/Seattle_City_Light_Climate_Change_Vulnerability_Assessment_and_Adaptation_Plan.pdf
[18] https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-013_ADA.pdf
[19] https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M320/K713/320713398.PDF



Utilities should use climate analytics to effectively see if and how assets could be impacted. With over 30 climate models available to utilities that can each drastically change hazard projections, the model selection process can be confusing and feeds into overall uncertainty. Climate analytics[20] generate future climate conditions using a large ensemble of models that can be directly tailored to the utility, making it more actionable. Climate analytics makes it easier for utilities to visualize and understand impacts in relation to their specific systems and operations.

For example, experts working with these projections can provide utilities with specialized temperature ranges, allowing them to more accurately forecast loads and evaluate system responses to various temperatures over time. Additionally, utilities can see how low-probability and high-impact climate events, such as coastal storms, may damage individual assets in the future.

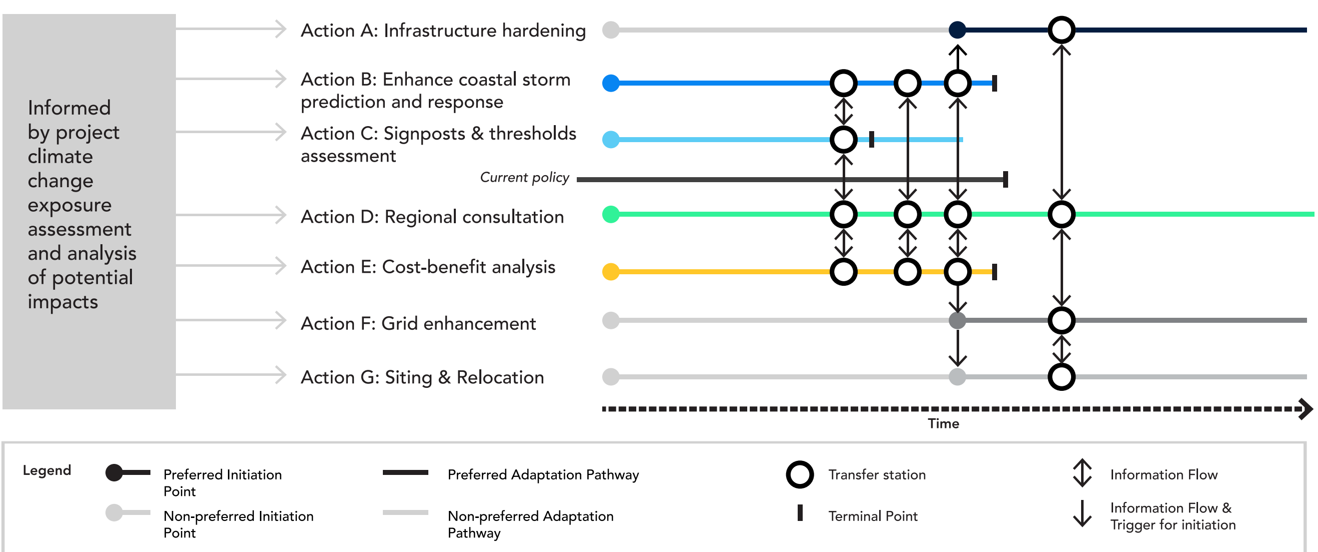
Utilities should also explore the risks posed by their asset vulnerabilities, especially those that could affect their most critical and vulnerable customers. Understanding the number and types of customers that would be impacted from an outage event will provide insights that can be used in prioritizing resilience investments and communicating investment benefits. These analyses may be augmented with community engagement and inputs on local vulnerabilities.

Develop a robust, flexible resilience strategy that integrates stakeholder perspectives

An effective resilience strategy, based on insights from in-depth risk analysis, can prove challenging to develop, design, and execute within an ever-changing, uncertain environment complicated by a range of stakeholder perceptions and priorities. One approach, flexible adaptation pathways—advanced by ICF—helps build robust plans that acknowledge the unknown and help manage complexity.[21]

Flexible adaptation pathways include identification of timely and necessary adaptations to manage risk over time and improve resilience. This pathway approach encompasses various decisions that may need to be made in the future, yet the timing and selection of these actions are inherently flexible and dependent on environmental, technological, or even regulatory change. See Figure 1.[22]

Figure 1



[20] https://www.icf.com/insights/energy/climate-analytics-help-utilities-prepare
[21] https://www.icf.com/insights/energy/building-utility-resilience-changing-climate
[22] https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-004_ADA.pdf

Included on these pathways above in the white circles are triggers, or specific points where information gathered by consistent monitoring action dictates another adaptation response. Having appropriate signposts and thresholds that raise alarm when approaches need to be adjusted or revamped helps manage uncertainty and allows utilities to adapt. Proactive steps can help utilities avoid derailing entire plans or requiring massive amounts of additional investment.

In addition to flexible adaptation pathways, utility resilience strategies can draw on new climate-informed guidelines that inform changes in asset management, planning, and operational processes. Such guidelines establish one or more pathways using tailored climate information that define climate variables to be used in engineering or other decisions. Guidelines may consider the criticality of the asset in the system or other factors when setting the design values.

To create a strategy that will effectively guide implementation and investment, utilities must also work with relevant stakeholders to determine core resilience goals, given the importance of customers and the community. Utilities must clearly define and convey the value that the proposed resilience investment provides to stakeholders.

Although the energy industry is still grappling with how to fully value investments in resilience, utilities can identify tangible benefits for their resilience projects. Those benefits include direct resilience or adaptation benefits, as well as co-benefits. Adaptation benefits include the flexibility, reversibility, and robustness of solutions that support the flexible resilience strategy. Co-benefits include safety, customer financial benefits, and reputational benefits that come from the investments and should reflect the benefit of addressing customer impacts identified in the risk assessment. Capturing the full range of these benefits when presenting to stakeholders can help build mutual support for a resilience strategy.

In addition, the utility and stakeholders will need to align, either through a rate case proceeding or other venues—on the amount of proactive resilience investment. This investment level will reflect a balance of perceived risks, effectiveness of resilience investments in reducing risks, and willingness to accept unmitigated risks. ICF's total cost framework and customer-restoration metrics provide an important initial step forward to help utilities quantitatively analyze the appropriate levels of investment in resilience.[23]

Resilience projects offer tangible benefits

Adaptation benefits:

- flexible solutions
- reversible solutions
- robust solutions

Co-benefits:

- safety
- customer financial benefits
- reputational benefits

[23] https://www.fortnightly.com/fortnightly/2013/10/what-price-resiliency

Build integrated solutions to address the resilience gap

After performing an analysis and developing a flexible resilience strategy, utilities still face competing, immediate priorities that also need funding. The fact that most hardening activities don't see direct results makes it even more difficult to address the resilience investment gap.

To confront immediate priorities while still implementing resilience, utilities can stack and integrate resilience projects with investments aimed at meeting complementary objectives—utilities are the primary players in the race to meet decarbonization, electrification, grid modernization, and other goals. ICF has advanced a framework that helps to maximize the respective impact of investments in resilience and other "competing" objectives by identifying commonalities that can be leveraged to amplify benefit. By viewing the individual objectives through an integrated lens, the overlapping and complementary areas of a somewhat complex venn diagram can be seen. Building a stacked and integrated solution—such as utility battery storage and undergrounding—within a single project allows for each invested dollar to support multiple strategic goals.

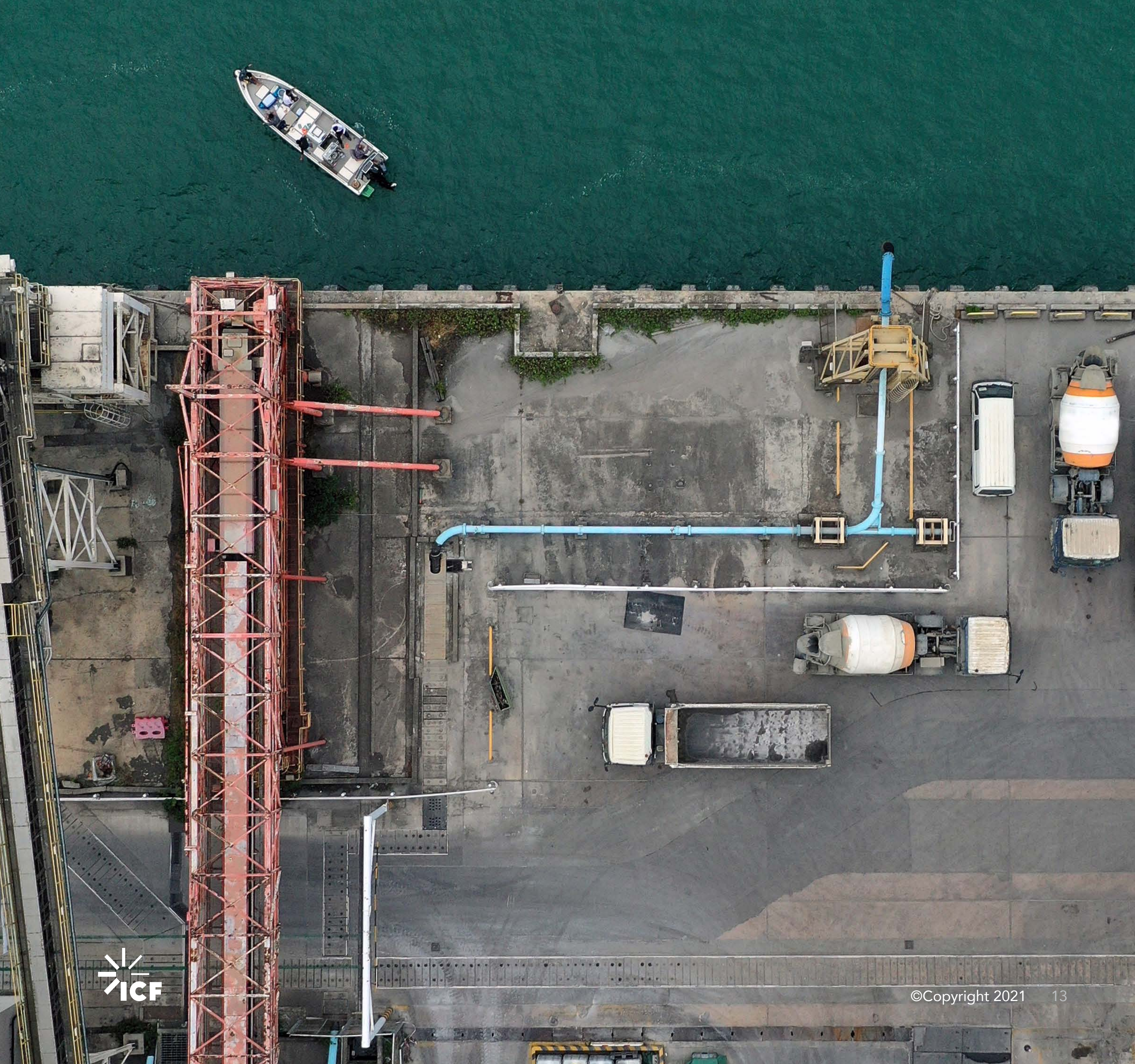
Additionally, by using techniques like flexible adaptation pathways, utilities can make investments at the right time, even under uncertainty around future conditions, helping to avoid over-building, stranding investments, and spreading costs over time. As highlighted before, the specific selection and timing of investments is designed to be flexible over time, based on the inflow of new decision-relevant information.

Finally, utilities can collaborate with local agencies to augment the value of resilience investments. Since so much infrastructure is interdependent, it's important to collaborate with local entities to ensure that investments in grid resiliency are coordinated with investment plans for both upstream and downstream infrastructure. Coordinating grid investments with a local government's plans for critical loads, such as water treatment facilities, will support optimizing the nature, amount, and timing of grid resilience projects. Federal resilience programs such as the FEMA BRIC program can be a potential funding source for meeting the resilience needs of utilities and the communities they serve.[24]

[24] https://www.icf.com/insights/disaster-management/isaias-need-fema-bric, https://www.icf.com/work/disaster-management/fema-bric-hazard-mitigation-funding

Conclusion

Even with prevailing uncertainties and increasing extreme events, it is possible for utilities to develop resilience plans that utilize tailored climate projections translated into information that helps them address vulnerabilities to close the resilience investment gap. The key to preventing long-term and major damage to utilities and assets, as well as cost to stakeholders, is to begin building resilient energy systems based on data-backed efforts that illuminate risks as the climate continues to change. Although this may seem overwhelming, utility leaders can employ straightforward, adaptable, and strategic steps when creating a path towards resilience—from conducting vulnerability analyses to prioritizing projects that support the resilience of their vulnerable customers.



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Judsen Bruzgul has been analyzing potential impacts from climate change and connecting insights to management and policy decisions since 2002. As a senior director at ICF, he helps clients assess vulnerabilities and manage risks from a changing climate and extreme weather to infrastructure and natural resources in the U.S. and abroad. Judsen's expertise includes translating climate science into practical information for decision making, conducting risk assessments for assets and operations, analyzing costs and benefits of resilience actions, and supporting long-term planning for climate adaptation and resilience.

Judsen currently leads a portfolio of work assessing risks and building resilience to extreme weather and climate change with energy utilities across the U.S. Prior to joining ICF, he was a visiting fellow with the American Meteorological Society Policy Program, working on projects to improve how communities access and utilize information to help build resilience. He also worked at the White House Council on Environmental Quality, developing and implementing resilience policy recommendations for the U.S. Judsen earned his doctorate from Stanford University in biological sciences and has a bachelor's degree from Middlebury College.

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Neil's industry experience includes corporate strategy and long-range planning, energy resilience, grid modernization, asset management, and regulatory and policy engagements. He holds a Master of Science in Electrical Engineering from Manhattan College, a Bachelor of Engineering in Electrical Engineering from the City College of New York, and is a licensed Professional Engineer in the State of New York.

In his current role as a senior energy resilience expert, he focuses on assessing vulnerabilities and managing risks from a changing climate and extreme weather to energy infrastructure in the U.S. and abroad. He works with clients to incorporate climate projections, future scenarios, risk assessments, and their objectives into actionable adaptation plans to build long-term resilience.

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