California Public Utilities Commission

2016

Climate Adaptation in the Electric Sector:

Vulnerability Assessments & Resiliency Plans

This paper encourages Investor-Owned Utilities to conduct rigorous vulnerability assessments of their key assets, the system as a whole, and their customers. It also encourages the IOUs to construct resilience plans that cost out a range of options from full mitigation of a vulnerability, to partial mitigation options, to inaction noting the costs and consequences of each option.

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Executive Summary

Three of California's large investor-owned utilities are members of the Department of Energy's (DOE) Partnership for Energy Sector Climate Resilience (Partnership) and as part of their membership have agreed to conduct vulnerability assessments and produce resilience plans in 2016. The vulnerability assessments will determine which system assets are vulnerable and under what conditions. The resilience plan will create actionable plans for adaptation including costs and consequences. DOE envisions this as an iterative process that will be enhanced through the sharing of best practices among the member utilities.

This staff paper encourages the California IOUs to conduct robust assessments by identifying and prioritizing the magnitude and probability of climate impacts to their key assets and to expand their vulnerability assessments to also include assessments of:

- Current and future generation and distribution assets not owned by the utility
- The entire supply chain for fuel and critical parts
- Assets relied on in the telecommunications and water sectors
- California-wide and regional grid as an interconnected system
- Emergency management procedures
- Vulnerable communities
- Institutional barriers

This paper also encourages the IOUs to construct resilience plans that cost out a range of options from full mitigation of a vulnerability, to partial mitigation options, to inaction noting the costs and consequences of each option adopting both a cost/effectiveness and a risk management perspective. These plans are no doubt a first effort that will be improved upon over time, but a thorough first effort will go far in expediting the process.

Rigorous vulnerability assessments and resilience plans are the first steps towards ensuring that California's electric sector can withstand the challenges that climate change will bring. The exercise of examining all of the climate change-related vulnerabilities to the system followed by the process of envisioning all the potential remedies to those vulnerabilities is a solid first step the IOUs can take to address the future challenges head on.

Introduction

California is already experiencing impacts from climate change such as an increased number of wildfires, sea level rise and severe drought[1]. Utility efforts to deal with these impacts range from emergency and risk management protocols to new standards for infrastructure design and new resource management techniques. Utilities are just beginning to build additional resilience and redundancy into their

[1] Climate scientists have not determined whether the drought is caused by climate change, but all scientists working on the topic agree that climate change has made the drought worse.

infrastructure investments from a climate adaptation perspective, but have been doing so from an overall safety and reliability perspective for decades.

Significant efforts are also being made in those areas that overlap with climate change mitigation[2] such as diversification of resources, specifically the addition of more renewables to the portfolio mix, as well as implementation of demand response efforts to curb peak demand. Efforts are also under way to upgrade the distribution grid infrastructure, which should add significant resilience to the grid as well.

In April 2015, Governor Brown signed Executive Order B-30-15 that called for an adaptation implementation plan for each sector of the economy. As part of the energy sector efforts to create an implementation plan, the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC) held a joint workshop in July 2015[3] to better understand the adaptation efforts at the large investor-owned utilities. At that workshop, the four large investor-owned California utilities (IOUs) Pacific Gas & Electric (PG&E), Southern California Edison (SCE), San Diego Gas & Electric (SDG&E), Southern California Gas Company (SoCalGas), and one municipally-owned utility, Sacramento Municipal Utility District (SMUD), outlined their current and future efforts to adapt to climate change. Four[4] of the five utilities also confirmed their membership in the Department of Energy's (DOE) Partnership for Energy Sector Climate Resilience (Partnership), a voluntary effort run by DOE to enhance U.S. energy security by improving the resilience of energy infrastructure to extreme weather and climate change impacts. As part of the member agreement, each of the utilities will be required to produce a vulnerability report and a resilience plan within the next 18 months. These reports will help formalize the information and the internal processes that the utilities have been undertaking over the last several years. It will also facilitate a gap analysis for what additional efforts need to be undertaken and highlight coordination opportunities with the energy agencies and research community. Importantly, these plans will help stakeholders and regulatory agencies better understand estimated expenditures related to adaptation efforts.

Following the workshop, the energy agencies formed a working group on climate adaptation for the electricity sector. One of several near-term goals of the group is to support the utilities on the vulnerability assessments and resilience plans that they agreed to produce as part of their membership in the DOE Partnership. This collaborative effort will facilitate development of robust documents that can be the cornerstone of efforts to incorporate adaptation planning and measures into utility operations and relevant CPUC proceedings and CEC research. The working group recommended a work plan in the draft report, "Safeguarding California: Implementation Action Plans," which was issued in September 2015.

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[2] Mitigation is generally defined as actions that reduce carbon emissions, while adaptation is generally defined as actions that reduce the vulnerability to climate impacts.
[3] Presentations are available at: http://www.cpuc.ca.gov/PUC/energy/CPUC_and_Energy_Commission_to_Hold_Climate_Adaptation_Workshop.htm
[4] SoCalGas Company is a member through SDG&E

DOE Partnership for Energy Sector Climate Resilience

The DOE Partnership is “an initiative to improve the resilience of energy infrastructure to extreme weather and climate change impacts through the acceleration of investment in technologies, practices, and policies that will enable a resilient 21st century energy system.”[5] This effort is part of a larger federal government-wide look at climate resilience and builds upon the President’s Climate Action Plan and related federal policies and requirements. The latter includes Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance,[6] which requires each agency to evaluate their climate change risks and vulnerabilities to manage the effects of climate change on the agency's mission and operations in both the short and long-term as part of the formal Strategic Sustainability Performance Planning process.

Through this Partnership, the DOE and its partners will be able to develop resources to facilitate risk-based decision making and pursue cost-effective strategies for a more climate-resilient U.S. energy infrastructure.

The Partnership effort is currently focused on electric utilities and has 18 member utilities including SCE, PG&E, SDG&E, and SMUD. The first task for all partners is to identify priority climate and weather-related vulnerabilities. PG&E will also include their natural gas assets in their vulnerability assessment and SoCalGas will be participating through the SDG&E effort. Recently, DOE issued a draft guidance document to assist the partners in developing their vulnerability assessment reports. Next, they will issue a guidance document that expands upon the vulnerability assessments phase and includes plans for resilience solutions including cost/benefit analysis methodologies.

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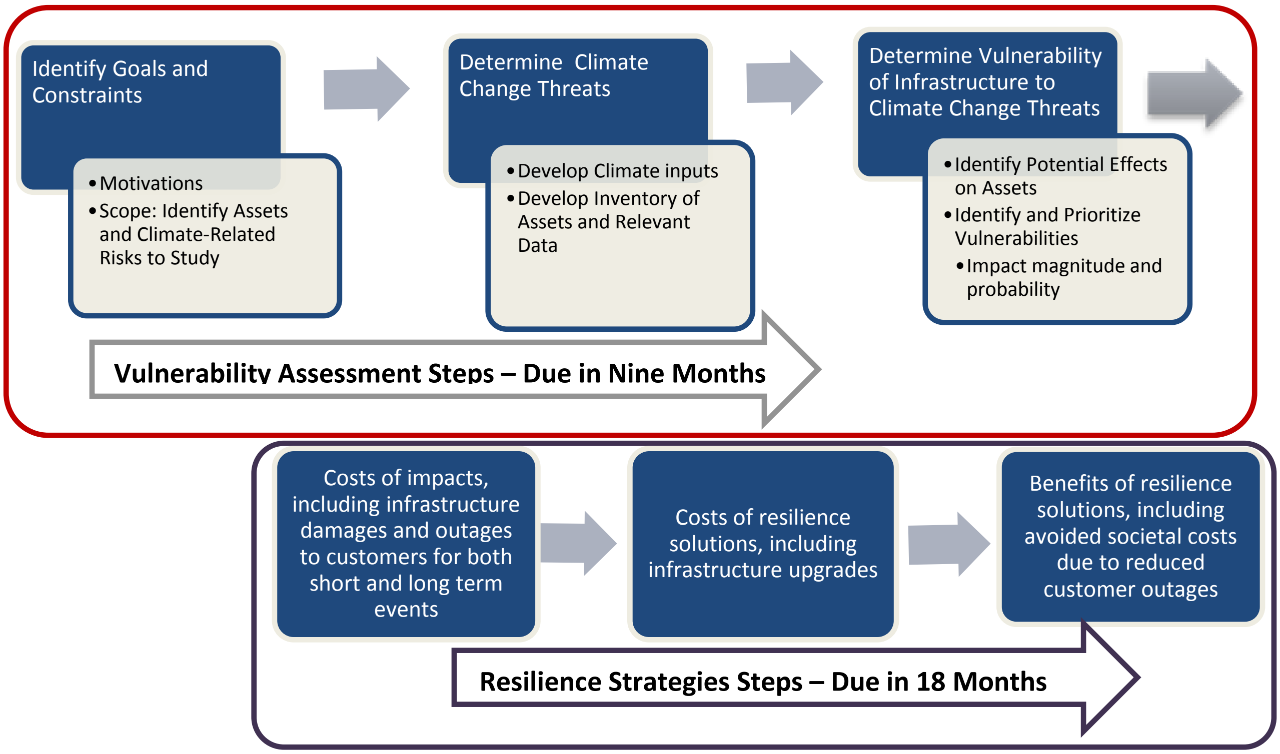
[5] http://energy.gov/epsa/partnership-energy-sector-climate-resilience

[6] https://www.fedcenter.gov/programs/eo13514/

Figure 1. DOE's Outline for Climate-Resilience Assessment Framework



Vulnerability Assessments

In calling for vulnerability assessments as the first step to climate resilience, the DOE Partnership guidance document states, "Climate change and extreme weather vulnerability in the energy context is a function of an asset's or system's exposure to climate-related risks and its sensitivity to them."[7]

The vulnerability assessment can vary greatly depending on who is conducting the assessment, why they are conducting it and against what future set of conditions they are evaluating their assets. For example, following Super Storm Sandy, Consolidated Edison (Con Edison) conducted an assessment to determine how to harden their assets against a future storm. The report was viewed as too narrow by several stakeholders who argued that the utility was not considering a wider breadth of climate change scenarios including impacts from sea level rise, extreme temperature changes, and more intense storms. The stakeholders formed the Storm Hardening and Resiliency Collaborative to develop innovative resiliency measures and to address how $1 billion in storm hardening funds proposed by the utility in their rate case should be invested. The resulting settlement with Con Edison was approved by the New York Public Service Commission (NYPSC) in February 2014 in a decision many hailed as "an historic decision that will serve as a nationwide model"[8] because it was the first commission to order a utility to protect its system against the effects of climate change. The NYPSC decision also called for the

[7] DOE Guidance, page 2
[8] https://www.edf.org/media/con-edison-take-new-measures-protect-against-effects-climate-change

continuation of the Collaborative and charged them with producing a vulnerability assessment that considered all potential impacts of climate change.

The UK's National Grid took a very different tack when they did their assessment in 2010. They created a matrix and evaluated each asset class against each climate variable to assess each of the following:

- Primary impact of climate change to the asset
- Threshold above which this will affect the organization
- Likelihood of the threshold being exceeded in the future and the confidence in the assessment
- Potential impacts on organization and stakeholders
- Timescale over which risks are expected to materialize

National Grid concluded: "This risk assessment has indicated that overall National Grid Electricity Transmission's assets and processes are resilient to climate change that is predicted to occur. Within this assessment there are some assets which require further assessment using more refined data. This is an ongoing process which is incorporated into National Grid's risk management process. It is important to note that even where an asset is at a potential risk in this worst case scenario model, the risk is localized to that asset and the process it supports and is unlikely to lead to a loss of supply. None of the risks considered are likely to result in a risk to the system as a whole."[9]

The real value of a vulnerability assessment lies not only in what is being evaluated, but also what is it being evaluated against. In the case of National Grid, they did their evaluation against a worst case end of the century high emissions scenario in each climate category. The scenarios they used included:

- Summer mean temperature rise of up to 8 degrees Celsius
- Increased heavy rainfall (by a factor of up to 3.5)
- Sea level rises of up to 43cm (17 inches)

Another value of conducting a vulnerability report is the understanding that it can provide on ***how*** climate change will impact system assets, not just ***if*** they will be impacted. In Lawrence Berkeley National Lab's (LBNL) 2012 report, "Estimating Risk to California Energy Infrastructure from Projected Climate Change,"[10] the authors went beyond the simple question of which assets will be impacted and delved into the more nuanced and detailed questions of how they will be impacted, under what conditions will they be impacted and what the consequences of those impacts would be. LBNL's model shows a summary of impacts that includes not only diminished capacity from all of the assets from generation to transmission and distribution, but also the cost consequences resulting from prevention, replacement, outage, and energy loss.

[9] National Grid, Climate Adaptation report, 2010, Executive Summary

[10] The report is available at: http://www.energy.ca.gov/2012publications/CEC-500-2012-057/CEC-500-2012-057.pdf

DOE Guidance on Conducting Vulnerability Assessments

Each utility member of the DOE Partnership signed a partnership agreement committing to identifying their priority climate vulnerabilities. The DOE guidance document identifies four key elements of the vulnerability assessment:

- Identify Key Climate Risks to Study
- Develop Inventory of Assets and the Potential Effects
- Identify and Prioritize Vulnerabilities
- Assess Magnitude and Probability of Impacts

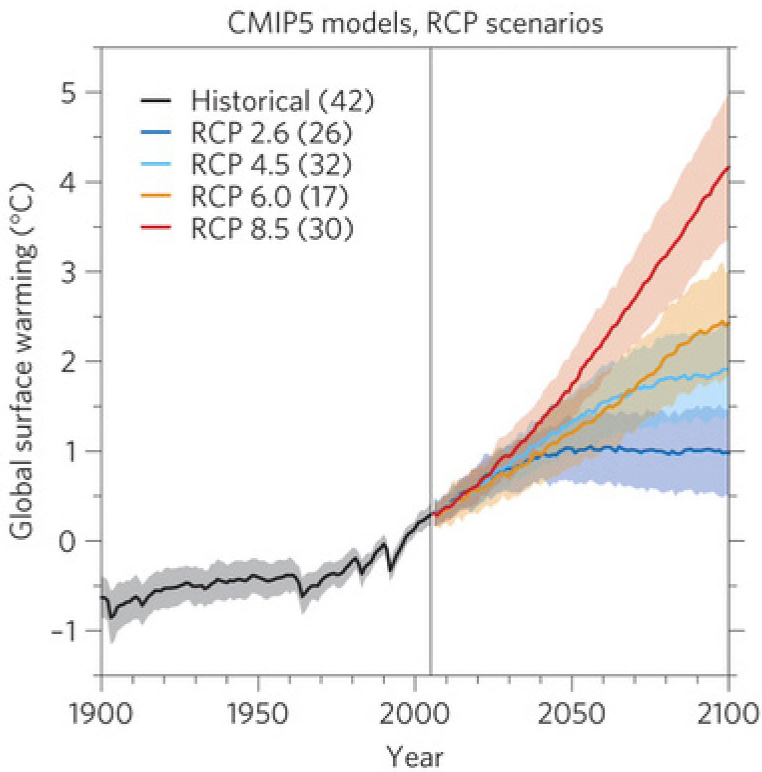
Identify Key Climate Risks to Study

Most vulnerability studies begin with an overview of future climate conditions. Since the past is no longer a predictor of the future, the industry must rely on scientific studies that have modeled future climate conditions. There are a number of scenarios that are available to be used as part of an assessment. Choosing which scenarios to use is a crucial decision in the vulnerability study because the magnitude of the impacts is a strong function of the magnitude of the climate changes and emission profiles in the scenarios being used. There are several issues to consider when choosing which scenario to plan for.

The first issue to consider is whether to adopt a high, moderate, or low emissions scenario. The difference between these represents the amount of success the international community will have in curbing emissions. The International Panel on Climate Change (IPCC) released a series of emission scenarios referred to as “representative concentration pathways” (RCP) to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. Most discussions that refer to a “high emissions scenario” are using the RCP 8.5 model, which represents the highest amount of emissions considered, the greatest concentration of GHGs in our atmosphere, and therefore the highest projected surface temperatures. Our historical trajectory roughly tracks RCP 8.5. References to the “low emissions” scenarios generally refer to RCP 4.5. However, RCP 4.5 is still beyond the limits of the Paris Agreement that came out of the COP21 in December 2015[11], where there was a renewed commitment to a goal of keeping warming to a maximum of 1.5 degrees Celsius. Looking at the graph in Figure 2 below, it is notable that uncertainty bands associated with the various IPCC pathways overlap for increased surface temperatures through about 2040-2050, but after that timeframe they diverge widely. That is because the impacts to the surface temperature are the result of cumulative carbon emissions. However, depending on the level of policy intervention to curb future carbon emissions, the outlook for temperature increases in each pathway post 2050 begins to look quite different. In conducting a vulnerability study, it is important to pick an appropriate set of emissions scenarios. In most cases, this choice would include both the high and the low RCPs given the wide difference in projected impacts.

[11] Parties to the United Nations Framework Convention on Climate Change (UNFCCC) meet annually at the Conference of the Parties (COP). The meeting in Paris in December 2015, was the 21st such meeting.

Figure 2. IPCC Representative Concentration Pathways[12]



The issue of which timeframe to look at is also an important factor when considering which scenarios to assess against. Most of the modeling work done to date has focused on changes projected in 2100. However, there are an increasing number of studies being conducted to understand the changes in a more near term timeframe. Even with more near term data available, it is not a straightforward choice. The Little Hoover Commission report, "Governing California through Climate Change,"[13] reported that there was no consensus among the people they interviewed in terms of which timeframe to prepare for. Some argued that 2030 is most appropriate because the impacts are more certain and investments are more likely to be made if they are not hampered by the unknown of a longer outlook. Others argued that it is better to pick a single target, stating that the threshold or magnitude of the impact was more important than the timeframe in which the impact would occur.

When picking scenarios for vulnerability assessments, another critical decision concerns which global climate model to use and what specific output numbers generated by that model's scenarios to use. For example, most of the models present scenarios with a wide range of impacts. The DOE report, "Effect of Sea Level Rise on Energy Infrastructure in Four Major Metropolitan Areas"[14] found that in 2050 Los

[12] www.CarbonBrief.org
[13] http://www.lhc.ca.gov/studies/221/report221.html
[14] September 2014, http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjh-_fB55XKAhVGzWMKHZD2DfAQFggcMAA&url=http%3A%2F%2Fenergy.gov%2Foe%2Fdownloads%2Feffect-sea-level-rise-

Angeles could experience anywhere between zero and two feet of sea level rise. This is a significant spread from a planning perspective. Another related question is whether to plan for "average" or "extreme" numbers. For illustration purposes, we looked at a single output model in the Cal-Adapt tool. While the number of extreme heat days in San Diego when the temperature exceeds 87 degrees Fahrenheit has historically been four days per year between 1950-1999, the model output showed that between 2050 and 2060, San Diego could average up to 38 extreme heat days per year. Looking closer at each year within that decade reveals that the number of extreme heat days could be as few as 17 days (in 2059) and as many as 59 (in 2060). The average number over the decade is 38, as is the median, as is the average of the high (59) and low (17) number of days. Planning for 38 days of extreme heat days therefore might seem appropriate, but it also means that the plan is too high half of the time and too low half of the time. It would only be correct in one of the 10 years. The models are not forecasts and these numbers are provided here only for illustration purposes to show the possible extreme variability of future weather patterns and the difficulty it presents for planning purposes.

Con Edison did not rely on models when seeking a planning target for future storm surge levels, but rather relied on experiential data. While various climate models suggest that the high range for sea level rise in 2050 could be as high as five feet, Super Storm Sandy storm surges reached levels as high as nine feet. Therefore, when Con Edison conducted their storm surge study, they used a "Sandy plus 3" scenario, which was based on the actual storm surge of nine feet plus a three-foot "buffer" to account for higher future sea levels.

Finally there are a number of methods to "downscale" or localize the climate impacts from global climate models. CEC is currently populating the Cal-Adapt tool to include updated downscaled data in approximately 3.5 square mile increments.[15] These data sets will have the added benefit of being the state-wide climate scenarios that can be utilized by all California state agencies, local governments, and utilities in their future assessments and resilience efforts. They offer another important consideration for planners: use a state-wide average for their assessments or much more localized data associated with assets?

In most cases, the execution of a vulnerability assessment should include the most up-to-date, localized information that includes the extremes in order to really understand the nature of the vulnerabilities and threshold at which individual assets are vulnerable.

California's Key Climate Risks

Over the last decade, California has experienced a number of significant climatic events including the warmest year on record in 2014, the record-breaking heat storm of July 2006, the record-breaking four-year ongoing drought, and a significant 2015 wildfire season.[16] These types of events all comport with the projections of climate modelers from the IPCC to the Scripps Institution of Oceanography.

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energy-infrastructure-four-major-metropolitan-areas-september&usg=AFQjCNGQrkxMhqoLdB5iPJZK_o9DdVi27w&bvm=bv.110151844,d.cGc

[15] www.cal-adapt.org

[16] Based on Calfire data

A growing body of evidence both empirical and modeled demonstrates some potentially dramatic changes and volatile events that will impact the infrastructure and operational environment of the electric and natural gas systems.

1. Temperatures

Temperatures in California are expected to rise, in some cases significantly over the next century. In SMUD's *Climate Readiness Strategy – Overview and Summary Findings*[17] report, they highlighted some of the extreme weather predictions that were reviewed as part of the climate action team efforts for the State of California Extreme Heat Adaptation Interim Guidance Document (August 31, 2012).

Table 1. SMUD *Climate Readiness Strategy* Report Extreme Temperature Predictions[18]

Model	Findings
Hayhoe et al. 2004	Increase of 3°-5° F in state-wide average temperature by 2030s and up to 9° F for summer average by 2050s under high emissions scenario
Drechsler et al. 2006	Summer daily maximum temperatures would increase by 2.2°–7.6° F by 2035–2065
Cayan et al. 2009	Increase in state-wide annual average temperature between 2.8°-10.8° F by end of century
Mastrandea et al. 2009	Extreme temperatures currently estimated to occur once every 100 years would occur annually under high emissions scenario
Ostro et al. 2011	Statewide changes in annual average temperature of 1.9° F in 2025 and 4.6° F in 2050 would translate to 2,100 to 4,300 excess deaths in 2025 and 6,700 to 11,300 excess deaths in 2050

As noted in Table 1 above, average temperatures and summer daytime temperatures will increase significantly. Many studies also point out that summer temperatures are expected to increase more than winter temperatures, but winter temperatures will also be noticeably warmer. Nighttime low temperatures are expected to increase more than daytime highs. Areas that are already hot will see the most temperature increase, and temperature increases in urban areas will be further exacerbated by urban heat islands. The number of extreme heat days will also increase significantly, as demonstrated in the table below from the report, *Preparing California for Extreme Heat*.[19] The historical average for extreme heat days per year for all California cities including Los Angeles is four days; the projection for

[17] http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwiBq4vp55XKAhUL5GMKHfbACmUQFgghMAE&url=http%3A%2F%2Fresources.ca.gov%2Fdocs%2Fclimate%2FStatewide_Adaptation_Strategy.pdf&usg=AFQjCNHqdedZb2LDYSieWbFZu5wEirg3Wg&bvm=bv.110151844,d.cGc

[18] ibid

[19] Link to Preparing California for Extreme Heat report

Los Angeles for 2050 in a high emissions scenario is 78 days and 110 in 2099. According to the same report San Francisco is projected to have 39 extreme heat days by 2050, and 126 by 2099.

Table 2. Model Estimated Number of Extreme Heat Days May 1 to Oct 1 in Selected California Cities*, 2050 and 2099[20]

City	2050	2099
Bakersfield	48	93
El Centro	60	101
Fresno	46	90
Los Angeles	78	110
Redding	35	75
Sacramento	44	85
San Diego	76	129
San Francisco	39	126
San Jose	71	111
Truckee	41	83

In July 2006, California, the Southwest and much of the country faced an extreme heat wave of triple digit temperatures that lasted over 20 days. Over that time, 765,000 Southern California Edison (SCE) customers lost power due to heat, wind or lightning strikes. SCE had to replace over 1,000 transformers and officials of the company were quoted as saying that “the hot weather has underscored the age and vulnerability of the region's electricity transmission system.”[21] They explained that the transformers failed either because their age compromised their performance or because they were “simply not built to carry the electricity demanded by customers during the heat wave” whose usage increased 18% over the same time the year before. High nighttime temperatures also kept the transformers from being able to cool down during the heat wave, which increased their failure rate.

A *Los Angeles Times* article reported that in a hearing at the state legislature on July 13, 2006 Cal-ISO spokesman Gregg Fishman said that “the corporations that provide the state’s energy have simply not prepared to cope with the current conditions for any length of time.” He said the infrastructure was built to withstand a one-in-10 year heat wave, but explained, “We’re not looking at a one-in-10 heat wave. I think we’re looking at one-in-50 heat wave.”[22] 147 people were reported to have died in California during that heat wave. A report released in March 2009 estimated actual loss of life at two to three times that number.[23]

In addition to daytime and nighttime temperatures and the number of heat waves all increasing, the SMUD resiliency report also notes that scientists predict an expansion of the summer heat season from

[20] “Preparing California for Extreme Heat,” October 2013. *High emission scenario A2 using average of four models. Number of days exceeding 98th percentile of baseline temperatures, based on a 1961-1990 baseline of four extreme heat days per year. Source: Analysis based on Cal-Adapt.
[21] *LA Times* article, Heat Stretches Power Network to the Limit, July 23, 2006
[22] *ibid*
[23] Estimating the Mortality Effect of the July 2006 California Heat Wave, March 2009, CEC-500-2009-036-D

the traditional two-month July-August timeframe to a four-month period from June to September, with extreme heat events likely throughout that period.

2. Hydrology

The hydrology in California will experience significant changes over the next few decades. Paradoxically, the state may very well experience both drought and increased rainfall simultaneously, with a greater share of precipitation coming from big storm events as was the case in San Diego this past July where, while in the midst of a drought, they received more rainfall in a single month than they had received in the previous 100 Julys combined.[24] A switch from winter precipitation falling as rain instead of snowpack will also change the state's hydrology.

CEC averaged data from a variety of models and downscaling techniques and found that the overall trend by 2060 is for a small amount of drying in the southern part of the state (< 10%), and negligible changes in precipitation in the North. The same study showed that patterns by season are more pronounced, with the northern part of the state experiencing wetter conditions in winter and drier conditions in the rest of the year. The southern part of the state shows moderate drying in fall, winter and spring but a strong increase in summer precipitation. This trend comports with the San Diego experience in July.

Overall, the state will likely experience:

- Potentially increased or decreased rain; and decreased snow pack
- Increased evaporation from higher temperatures
- Decreased number of storms, but increased intensity
- Increased humidity along the coast
- Less snowpack and earlier melting of snow pack, reduced spring and summer flows
- Increased frequency, intensity and duration of droughts

3. Sea Level Change

The Cal-Adapt website states: "Global models indicate that California will see substantial sea level rise during this century, with the exact magnitude depending on such factors as, global emissions, rate at which oceans absorb heat, melting rates and movement of land-based ice sheets, and local coastal land subsidence or uplift." In fact, there are several models predicting a wide range of sea level rise. Scripps Institution for Oceanography estimates that by the year 2050 sea levels will rise by between 5-24 inches and by 6-30 inches by the year 2100 relative to 2000.[25] DOE estimates that level could be as much as 66 inches by 2100, and the US Global Change Research Project (US GCRP) predicts a rise of 30-74 inches by 2100 relative to 1990. Sea level change coupled with an extreme storm event presents another level of threat to the California coast. At an event at the CPUC in July 2015, Dan Cayan of Scripps stated: "As mean sea level rises, the frequency and magnitude of extreme events would increase markedly. Under plausible rates of sea level rise, an event which in present day occurs less than once per year occurs scores of times per year by mid-21st Century and becomes commonplace by end of 21st Century.

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[24] SDG&E presentation to CPUC staff
[25] Presentation by Dan Cayan to CPUC on July 27th, 2015

Importantly the duration of extremes becomes longer, so exposure to waves is considerably greater."[26] Similarly, in a recent meeting, SDG&E meteorologists predicted that "the frequency and magnitude of extreme events increases from a once-in-a-year event to a multitude of events by 2050 and "commonplace" by 2100.[27]

A CEC-funded paper by the Pacific Institute, "The Impacts of Sea-Level Rise on The California Coast,"[28] found that 30 coastal power plants, with a combined capacity of more than 10,000 megawatts (MW), are at risk from a 100-year flood with a 1.4 meter (4.9 feet) sea-level rise. The majority of vulnerable plants are located in Southern California and along the San Francisco Bay. Scores of substations and transformers would also be exposed.

4. Impacts on the Electric Sector

The LBNL Study "Estimating Risk to California Energy Infrastructure from Projected Climate Change" found that higher temperatures will decrease capacity of the state's natural gas fired plants, decrease transformer and substation capacity, decrease transmission line capacity, and increase transmission and distribution line losses. At the same time the higher temperatures could increase peak demand by the end of the century by as much as 21% under a high emissions scenario. With the combination of the decreased system efficiency and higher demand, "it will be necessary to provide an additional 38.5% peak generation capacity."[29] During the July 2006 heat wave, CAISO officials reported that even though the grid hit a record peak of 50,203 GWh there was no danger of the grid experiencing brown outs or black outs. However, many customers still lost power due to the failure of other assets such as transformers. Over 765,000 SCE customers were without power for a period of time during the heat wave.

Wildfires are more likely to increase maintenance costs and decrease transmission line capacity than they are to cause electricity outages, according to the LBNL report. However, an increase in wildfire activity associated with climate change certainly increases the possibility of fire-related outages. In fact, the recent Butte Fire caused significant outages across a large territory.[30] In addition, SMUD's report points out that the increased fire activity is happening at higher elevations where large transmission lines are located and the outages could come either from equipment malfunction or temporary shutdown during an event. SMUD also notes there is an increasing risk of grass fires in urban, suburban and rural areas with significant transmission and distribution assets. The 2015 Valley Fire damaged or destroyed some of the cooling towers at the Geysers geothermal power plant, reducing its generation for months.

[26] Dan Cayan, presentation to CPUC, July 27th, 2015

[27] SDG&E Presentation
[28] http://pacinst.org/wp-content/uploads/sites/21/2014/04/sea-level-rise.pdf
[29] From "Estimating Risk to California Energy Infrastructure from Projected Climate Change." It is available at: http://www.energy.ca.gov/2012publications/CEC-500-2012-057/CEC-500-2012-057.pdf
[30] Cal Fire data: http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=1221

Sea level rise will not only potentially flood assets, but may accelerate corrosion of infrastructure. Flooding due to higher storm surge events will prevent repair operations and may prolong outages as well.

Changing precipitation patterns are likely to reduce hydroelectric power supply and water resources used to cool power plants.

Individually, these events are significant to grid assets. In conjunction, they are even more significant.

In SMUD's resiliency report, they provided a synopsis of the impacts of climate change to their electric system. It is outlined in Table 3 below.

Table 3. SMUD *Climate Readiness Strategy* Report Potential Effects to SMUD Infrastructure and Operations[31]

Impact Category	Potential Effects to SMUD Infrastructure and Operations
Ambient Temperatures	• More extreme summertime high temperature events, including daytime and nighttime heat waves • Increased warm season electrical load and peak demand • Reduced thermal and hydroelectric generation • Extreme temperature and variability impacts on system reliability • Increasingly severe "one-in-ten" heat storms effects on overall system reliability • Less efficient operation of transmission and distribution systems, including decreases in facility ratings and loss of operating life
Wildfires	• Projected increase in wildfire frequency and intensity • Potential wildfire impacts to transmission and out-of-district generation sources
Wind Patterns	• Increases or decreases in wind energy production and timing • Increases or decreases in delta breeze cooling capacity
Regional Hydrology	• Effects of changes in temperature and precipitation on snowpack in the Sierra Nevada mountains • Changes in timing and volumes of streamflow and impacts on hydroelectric capacity
Flooding	• Sacramento flood threats • Localized impacts on electricity infrastructure • Indirect impacts on gas transmission infrastructure in the San Francisco Bay Delta region

Develop Inventory of Assets and the Potential Effects

The second step after assessing the key climate risks is developing the inventory of assets. For most utilities, this exercise is very straightforward. What is less straightforward is assessing each asset's sensitivity to changes in the climate or extreme weather events. As noted in the LBNL study, "Estimating

[31] SMUD Climate Readiness Strategy Report, http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwiBq4vp55XKAhUL5GMKHfbACmUQFgghMAE&url=http%3A%2F%2Fresources.ca.gov%2Fdocs%2Fclimate%2FStatewide_Adaptation_Strategy.pdf&usg=AFQjCNHqdedZb2LDYSieWbFZu5wEirg3Wg&bvm=bv.110151844,d.cGc

Risk," this evaluation should not be based on a binary yes/no impact evaluation, but rather a more thorough analysis that addresses the number of ways in which an asset or asset class can be affected, and at what threshold that impact becomes a liability. Impacts can be direct, affecting energy infrastructure, and also indirect, impacting the supply chain or customers. DOE recommends looking at the following impacts:

- Reduction/disruption in generation capacity
- Increased demand for service
- Increased operational cost
- Increased capital cost
- Reduction in capital availability

There are many different ways to approach the analysis. Northern Power Grid in the U.K. evaluated the standard performance parameters of each asset type against the worst-case high emissions scenario of potential impacts including flooding, heavy rain storms, ice storms, wind gusts, drought, and lightning and created a matrix to rate the performance of each asset under each condition. Impact assessments included high, medium, low and no impact. They also included a category for no future predictions available. Importantly, Northern Power Grid also assessed not just *if* an asset would be impacted but specifically *how* an asset would be affected (*i.e.* would the lifespan be shortened or would it represent a performance issue) and during what timeframe the asset would be affected, current or 2080.

It is also useful in an evaluation to classify the type of problem the vulnerability causes based on the function of the asset. For example, is the failure of a peaking plant going to cause an outage or merely reduce reliability because it can no longer be called upon? The type of asset might also suggest a temporal or seasonal problem caused by winter rainstorms or summer droughts. All of this information can be combined to generate a comprehensive view of the specific vulnerabilities of the utility.

Identify and Prioritize Vulnerabilities

The third step in the process is to identify and prioritize the vulnerabilities. For example, the Northern Power Grid prioritized its vulnerabilities by analyzing the probability of an asset failure happening under a specific condition or combination of conditions. Part of the assessment of what vulnerabilities to prioritize is the evaluation of what actually happens if an asset fails. Would it be a catastrophic failure or a minor interruption of service, or one that would have no impact on the system due to built-in redundancies? How long would it take to repair or replace the asset, and how long would it take the system and the customers to recover? This analysis would be crucial to establishing priorities in the system. An asset which is highly likely to fail, but is non-critical to the grid would not be the highest priority. Conversely, an asset less likely to fail but more critical to the grid could be a priority. This type of prioritization is common in the electric sector when considering reliability and safety issues.

A thorough analysis should also reveal those assets that can be easily replaced with a higher-functioning equipment type versus those which currently have no alternative. Moreover, the analysis should also reveal equipment standards that do not meet future climate scenarios, as well as policy gaps that do not

require adherence to updated standards for placement of power plants and other assets. Costs and the risk of stranded assets should also be considered.

The evaluation should consider a confluence of climate events. For example, it is likely that a daytime heatwave event will be coupled with a nighttime heatwave event. In drought years the heat and lack of water can also exacerbate wildfires. The combination of these events would clearly stress the grid more than a single event would.

Finally, the utility, along with its regulators and stakeholders must establish priorities according to its goals and objectives as an electric provider. They must establish a set of guiding principles much like is done within the safety realm to help guide limited resources.

Assess Magnitude and Probability of Impacts

Part of the process to prioritize vulnerabilities includes an assessment of not only what the consequences of asset failure are, but also the probability of that failure. In general, there is much more certainty regarding the direction of change than there is regarding the magnitude of change, or the length of time it will take to reach a change. For this reason, a utility may want to consider impacts that are fairly certain to happen at some point this century, even if there is some uncertainty regarding when the impacts will occur. With information on consequence and likelihood, DOE recommends that agencies categorize assets into four groups regarding how likely an event is to happen and what the consequences would be if that event did happen:

- Assets that have a ***low likelihood*** of being impacted and a ***low consequence*** if impacted by a future climate condition
- Assets that have a ***low likelihood*** of being impacted and a ***high consequence*** if impacted by a future climate condition
- Assets that have a ***high likelihood*** of being impacted and a ***low consequence*** if impacted by a future climate condition
- Assets that have a ***high likelihood*** of being impacted and a ***high consequence*** if impacted by a future climate condition

These four categories form the basis of the vulnerability assessment.

Expanding the Vulnerability Assessments

Many of the vulnerability assessments done to date have provided an excellent start to the evaluation process. There are a few areas where those reports would benefit from an expansion of the evaluation:

- Broaden the Definition of Assets
- Assess the System as a Sum of its Assets
- Assess Future System Assets
- Assess Emergency Management Procedures
- Assess the Vulnerability of the Customers
- Assess Internal and Operational Vulnerabilities

- Create an Iterative Process for Updates and Improvements

Broaden the Definition of Assets

Many of the vulnerability studies in the electric sector to date have concentrated on the assets within the direct control of the utility. However, there are many other asset types that the IOU should consider in its vulnerability assessment.

For example, as a result of deregulation, the investor-owned utilities no longer own all the generation assets and rely on independent power producers and merchant generators for a significant amount of power. These assets should be considered part of any evaluation of vulnerabilities in the same way the IOUs assess their own assets. Most of the transmission lines are currently owned by the IOUs, but future lines may be privately owned. Those assets should also be considered.

Another critical group of assets outside the direct control of the utilities is distributed assets. There are several proceedings underway at the CPUC to expand the use of distributed energy resources (DER) on the grid. These include generation resources such as photovoltaic systems, storage systems from home and car batteries, and demand-response resources. These assets will be critical in an extreme weather event, and while there is an increasing body of knowledge regarding their ability to perform under extreme conditions, there are still areas in need of further investigation, including the ability of the owners of the systems to maintain the assets under stressed conditions. Utilities ought to conduct an assessment of the risks of the loss or impairment of these assets. Moreover, billions of dollars will be invested in the distribution grid over the next few years. This massive build out should be assessed in terms of its ability to withstand extreme climate events.

A thorough vulnerability assessment ought to include an assessment of the entire supply chain of the utilities. This kind of analysis is often done when assessing safety and reliability and even sustainability goals. The ability of the IOU to continue operations in an extreme weather event or changing climate will depend directly on its suppliers' ability to continue to supply fuel, replacement parts, and other crucial operating equipment.

The electric sector is also increasingly reliant on the telecommunications sector. If the internet or other communication systems are compromised, the electric sector will certainly be compromised from an operational standpoint, as well as an inability to communicate with customers, suppliers and repair crews. The utilities should be working with the telecommunication companies either as individuals or as industry groups to assess their vulnerabilities and the interdependencies of the two systems. Likewise, the water sector is crucial to the electric sector. Availability of water does not just impact hydroelectric output, it affects many levels of operations of the electric sector such as cooling in thermal power plants. In addition, availability of water for the electric sector is not just a function of how much precipitation falls, but also who has rights to the limited water resources that are available. An analysis of the water infrastructure's impacts on the electric sector would also be warranted.

Assess the System as a Sum of its Assets

The electric grid is a massive, interconnected system of assets. Therefore, while the assessment of the vulnerability of independent assets by each utility is critical, it is only the first step. The next step is to assess the vulnerability of the electric system and grid as a composite of its parts across the entire state. This would require that the investor-owned utilities as well as the publically owned utilities participate in a California grid-wide assessment. For example, such an assessment could consider what would happen if both Northern and Southern California were affected by a heat wave simultaneously. Would there be enough power, replacement parts and emergency personnel available for a state-wide event?

The next level question is what if that heat wave hit the entire southwest region? California is reliant on energy imports for approximately 25% of its power generally and up to 33% on peak summer afternoons, therefore, regional assets, especially generation and transmission, are also of critical importance. Arizona and other Southwest states from which California imports power may face even greater climate impacts than those predicted in California in terms of increasing temperatures and dry weather, which may curtail their ability to export power. In addition, a recent report from DOE states that precipitation and snowmelt patterns may change drastically in the Northwest, limiting the amount of hydropower that California can import in the summer months. Increasing temperatures during summer months in the Northwest would further limit power exports. California must consider its vulnerability from regional assets both from the standpoint of an asset’s ability to function in extreme weather conditions and the availability of excess energy to be exported to California when demand in their own states may very well be rising.

There has been a lot of discussion in California regarding the “duck curve” graph which demonstrates what happens on the grid on a typical spring day when demand is low, but production from renewable resources is high. What would that graph look like with an earlier springtime snowmelt that produces a greater amount of hydroelectric power in both California and the Northwest? Would the new timing of the availability of hydroelectric exacerbate the situation, or would it not affect it? The summer months might also prove difficult if Southern California and Arizona both experience a heat wave at the same time (as they did in July of 2006), where there is limited hydropower from the Northwest and reduced capacity of the thermoelectric and renewable resources as well as transmission lines. With the potential creation of regional markets, these states’ experiences will directly impact California. While more resources might be available, more demand will be relying on them.

Regionally, the potential lack of water due to droughts or changing precipitation patterns appears even more ominous than when viewed from the perspective of a single state. Therefore, when looking at regional issues, utilities should consider availability of water based on regional concerns and demand imbalances as well.

Assess Future System Assets

In many ways the future is here. The rapid and profound changes that are already occurring on the grid not only portend the future functionality, but will have profound impacts on its resilience. New assets, new asset types, new technologies, new providers, new delivery mechanisms and new markets are all rapidly evolving. They could be referred to as the “known unknowns” – meaning we know that the

system is changing, what we don't know is what the system of the future will be nor how it will perform under a changing climate.

In most cases these changes will reduce overall vulnerability of the grid by making it more adaptable and flexible, but the pace at which the grid is changing may introduce other vulnerabilities. For example, there is a heavy reliance on a faster pace of asset turnover to capture new technological capabilities, including increasing resiliency to changes in the climate. However, this rapid turnover could also mean that the assets are not built for a long life span and are therefore less sturdy.

Moreover, identifying the location of an outage in a more complex grid with more instruments is likely to be easier, but more instruments mean more potential failures. In addition, if the assets are distributed, how can the utility ensure that it can rely on the owners of the assets to maintain them and repair them quickly in the event of a failure? How do we ensure the grid of the future balances technological gains with resilience?

Assess Vulnerability Based on the Changing Load

Future demand curves could potentially be significantly higher than current loads and with a different load shape throughout the day and the year. In addition to population growth, there is a big push for transportation electrification of cars, buses and trains that would add a large load to both peak and off peak hours. The drought has amplified the importance of finding new water sources and has sparked the proposal of several desalination plants along the California coast. These plants are energy intensive despite recent efficiency gains. In addition to producing potable water, there is the energy intensive process of moving water from the desalination plants to the end users.

In addition, in our current climate conditions, only 59%[32] of the population in California owns air conditioners. With temperatures rising in all parts of California and humidity rising along the coasts, there could be an increase in market penetration of that technology in addition to increased usage. This load increase will occur at the same time that the stress on the system will limit output from all types of resources.

Assess Emergency Management Procedures

Following Super Storm Sandy, Con Edison issued a report entitled, "Post Sandy Enhancement Plan."[33] The report is not only a systematic review for hardening assets to protect them against future storm damage, it is also a thorough evaluation of their emergency management strategies. The end result is an exhaustive look at that one kind of event, and could be extrapolated to a broader set of events such as extended heat waves or winter storms. The report came with a $1 billion price tag for its hardening efforts.

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[32] *EIA's 2009 Residential Energy Consumption Survey,* www.eia.gov/consumption/residential/

[33] http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjX6bnl3ZXKAhVGzWMKHZD2DfAQFggcMAA&url=http%3A%2F%2Fwww.coned.com%2Fpublicissues%2FPDF%2Fpost_sandy_enhancement_plan.pdf&usg=AFQjCNFXWqNL4ZG0544mO-XdQPcUPIjapA&bvm=bv.110151844,d.cGc

To assess the emergency management aspects, Con Edison looked at two separate categories of actions. The first category reviewed was "improving estimated times of restoration and enhancing storm planning and restoration processes" in which they assessed issues such as internal staffing and assignments, contractor support, logistics, and emergency preparedness plans. Their plan also proposed conducting full-scale storm drills, increasing their restoration material and equipment inventory, and joining the statewide equipment sharing efforts initiated by the NYPSC following Super Storm Sandy.

The second category of actions they reviewed dealt directly with the customers. As their report states, "For many customers, knowing when their power will be restored is just as important as service restoration itself."[34] In the section, "Improving the flow of information to customers and other stakeholders," the utility reviewed their communication protocols for a variety of customer types from residential and commercial, to municipalities, government agencies, regulatory agencies, and emergency response agencies. The report revealed that the utility is still heavily reliant on telephone call outreaches, which is challenging when the telecommunications assets are damaged as well.

California utilities have a number of emergency outreach protocols already in place, but these should be evaluated against different types of scenarios especially in extreme weather events.

Assess the Vulnerability of the Customers

Just as Con Edison noted in their "Post Sandy Enhancement Plan," communications with customers is one of the most critical functions of the utility overall, especially in an emergency event. As climate events continue to occur and the range of emergency events from wildfires, to heatwaves, to storm surges increasingly affects customers, the utilities will need to determine the best way to engage and communicate with customers to manage their experience and expectations.

An increasing body of knowledge benefitted by an increasing amount of data makes it clear that customers are not homogenous. Different customer types will have different preferences for communication channels, as well as vulnerabilities in terms of needs and attention in an emergency or for a longer term change. The vulnerability evaluation should consider not only how to communicate with customers, but also how to help vulnerable populations and how to anticipate their actions and reactions to change. In the July 2006 heat storm, SCE customers increased their demand by 18% over the previous year. This comports with an LBNL study[35] which predicts an increase of 21% in peak customer demand is likely under extreme temperatures. This level of increased demand creates vulnerability when coupled with decreased system capacity.

[34] Post Sandy Enhancement Plan, page 77
[35] From "Estimating Risk to California Energy Infrastructure from Projected Climate Change." It is available at: http://www.energy.ca.gov/2012publications/CEC-500-2012-057/CEC-500-2012-057.pdf

The vulnerability of communities is also a key consideration. Most local governments are conducting adaptation plans according to their own assessed vulnerabilities and it is essential to partner with those organizations to understand where synergies lie.

Another vulnerability to consider is the vulnerability of the customer as a grid asset. Customers are increasingly becoming "prosumers" – customers who both consume and produce power – making them grid participants and even grid assets. As such, customers need to be assessed in terms of their overall contribution to the grid. Are they an asset that can be relied on, and what actions can be taken to expand the magnitude and availability of this asset in the future?

Assess Internal and Operational Vulnerabilities

In a March 2014 report on climate adaptation globally, the IPCC stated, "Most assessments of adaptation have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the processes of implementation or the effects of adaptation actions."[36]

Each utility should ask itself a key question: What are the institutional barriers in the utility that will prevent action on adaptation, and what incentives/policies are needed to overcome these barriers? Adaptation will affect all aspects of a utility's operations from short term to long term investment strategies, emergency operations, and data collection to name just a few. Communications between all business units will be essential to developing and executing a robust resilience plan.

Most importantly, utilities must assess their own adaptability and flexibility. As one consultant stated in the Little Hoover report, "static institutions and progressive climate change are on a collision course." As an enterprise-level problem, it will require an enterprise-level solution. The Little Hoover report lauded California for having taken first steps to address adaptation, but noted that a lack of leadership was hampering real forward momentum. It is worth examining how the utilities can chart a more aggressive course as well.

Create an Iterative Process for Updates and Improvements

Change is happening very quickly in the electricity sector and all of these changes need to be considered in the light of climate adaptation. In order to stay flexible and adaptable and make the right investment decisions based on the most up to date information, the utility should create an iterative process for the vulnerability study effort. An updated assessment ought to be conducted at least in advance of every general rate case to inform the investment process, but also to inform every aspect of the utility operations.

Each vulnerability study ought to chart out the priority issues that need to be addressed, a timeframe and methodology for addressing them, and a means and metric to measure success. California is required under AB1482 (2015, Gordon) to update its climate adaptation strategy every three years.

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36 https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjv0M2d4pXKAhUSz2MKHbx0AQEQFggcMAA&url=https%3A%2F%2Fipcc-wg2.gov%2FAR5%2Fimages%2Fuploads%2FIPCC_WG2AR5_SPM_Approved.pdf&usg=AFQjCNE4J9j3UuwH8bKOKuh-4k7lQ7Teng&bvm=bv.110151844,d.cGc

Executive Order S 3 05 also requires the state to conduct periodic climate vulnerability assessments. The state's Fourth Climate Change Assessment[37] is just commencing. These assessments provide the latest scientific information about climate change and its potential impacts that the utilities can use in their own vulnerability assessments and resilience plans. Moreover, it is an opportunity for the utilities to engage with state and local agencies to identify actionable research needed from the state assessments.

Resilience Plans

Adaptation planning begins with a two-part process. The first step is the vulnerability assessment to determine where the system is vulnerable and under what conditions. As discussed above, the assessment must include the threshold at which the vulnerability occurs as well as the probability and magnitude of an event occurring, and the type of consequences resulting from an event. That information is then used as the foundation for the second part of the process: the resilience plan. The resilience plan employs the information from the vulnerability assessment to create actionable plans for adapting to the vulnerabilities. Adaptation efforts include those actions taken to prevent a vulnerable asset from being compromised, such as raising a substation above anticipated sea level rise, or actions taken to mitigate the consequences of an event occurring, such as bracing the system with redundancies to cover for a substation compromised by storm surge or developing a plan to quickly replace damaged parts.

Importantly, resilience plans also outline the costs and consequences of each of these options. For example, the costs and consequences associated with raising a substation to protect it against sea level rise will be determined by what standards the new substation is built to and what conditions it is built to withstand (*i.e.* what amount of sea level rise). The option of not raising the substation will have a different set of costs including costs associated with storing replacement parts to repair the substation quickly and outage-related costs if the substation is compromised.

The cost of adaptation will not be inconsequential. Over the years, the grid has incorporated redundancies to address safety and reliability concerns and many of these investments will also benefit adaptation efforts. However, significant cost is likely to be incurred where climate changes tax the operational parameters of various assets on the system. The high cost of adaptation options will make the investment choices difficult, but competing priorities and the degree of uncertainty against which we are planning will make it even more complex. The resilience plans, therefore, need to act as a guide on how to spend the resources efficiently.

DOE Guidance on Resilience Plans

As part of the Partnership agreement, the utilities have agreed to produce resilience plans by the third quarter of 2016. DOE will be issuing its resilience planning guide in early 2016. In their initial guidance on the topic that came out with the guidance on the vulnerability assessments in 2015, DOE suggested that utilities consider three important areas in their resilience plans:

[37] http://www.climatechange.ca.gov/climate_action_team/reports/climate_assessments.html

1. Costs of climate change impacts, including infrastructure damages and outages to customers for both short and long term events
2. Costs of climate resilience solutions, including infrastructure upgrades
3. Benefits of climate resilience solutions, including avoided societal costs due to reduced customer outages

As part of the resilience planning guide, DOE will include examples of cost/benefit methodologies to facilitate the utilities' ability to conduct their assessments. In addition to the DOE cost/benefit analysis, the utilities are encouraged to conduct their own risk management analysis as part of their plan. While a cost/benefit analysis can help identify whether an action is cost effective, the rigor of the resilience plans will depend on a risk management analysis as well. Each vulnerability identified in the vulnerability assessment will need to be evaluated in terms of a broader discussion of the consequences of action versus inaction rather than simply a question of cost effectiveness. As noted above, the costs associated with raising a substation to avoid inundation from sea level rise are different from the costs associated with not raising it. The consequences too would be very different. But while a cost/benefit analysis may indicate that it is cost effective individually to raise all substations to avoid the damages of sea level rise, collectively that may not be an option. The level of uncertainty associated with the climate scenarios, adaptation costs, and consequences associated with action and inaction requires that the utilities address this exercise through a risk management approach as well.

Parameters for Resilience Planning

Much of the resilience planning efforts will revolve around estimating the costs of adaptation actions. However, it is first useful to address several parameters around which the adaptation costs and actions should be considered. Many of these issues are similar to the parameters discussed in the vulnerability assessments. Nevertheless, the resilience plans need to view these issues through a different lens because the question being addressed is different. A vulnerability assessment asks the question: at what point would we be affected? A resilience plan asks the question: at what point will we act? Some initial parameters are highlighted below:

1. What emissions profile should be used?

Although assessing vulnerability using the IPCC high emissions scenario seems prudent, hardening assets against the high emissions scenario may not. While infrastructure investments are built to withstand significant events, they are not usually built for the worst case scenario. As demonstrated by the graph on page 7, the differences in surface temperatures between the various scenarios are stark as are the impacts.

2. What timeframe should be used?

Downscaled models available on Cal-Adapt show potential climate scenarios from 2010 to 2100. These data sets show significant divergence in potential impacts beginning in the 2030[38] timeframe from those experienced in the 2010 timeframe. In fact after 2030, the temperature highs are demonstrably higher

[38] Updated data is currently being uploaded onto Cal-Adapt. These dates may change and should be used for reference only.

and the lows are higher as well. By 2100, the differences are even more significant. The graph on page 7 illustrates these dramatic increases, but also demonstrates that while average temperatures appear to be on a steady incline, actual temperatures experienced by cities in California will be significantly more volatile from year to year. Therefore, the high temperatures predicted to occur by 2100 could in fact be experienced in years well prior to 2100. This prompts another question:

3. What climate threshold should be planned for?

Even if planners decide that a new 30-year asset should not be built to accommodate the higher average temperatures predicted for the year 2100, they may need to consider that those higher temperatures might still be experienced as an event occurring prior to 2100. Many experts claimed that the July 2006 heat wave was a one-in-a 50 year event. Super Storm Sandy's storm surge was declared to be a one-in-a-thousand year event.[39] Given the level of uncertainty and volatility, several experts in the Little Hoover Commission report recommended planning for a specific climate change target such as a certain temperature or level of sea level rise rather than a certain timeframe such as 2030 or 2100.

4. What threshold should prompt action and investment?

The resilience plan should note the first level of impact that might affect an asset as well as a plan to repair or replace the asset. One of the key questions it should tackle is whether the action should be pre-emptive or reactive. For example, during the July 2006 heat wave, SCE replaced over 1,000 transformers. While the vulnerability assessment should help illuminate under what conditions the transformers are likely to fail, the resilience plan will need to address the more difficult question of whether the utility should undertake the expense of replacing/upgrading all (or a subset of) its transformers in preparation for a future heat wave, or whether it should wait until a transformer fails. Over 765,000 people were without power at some point during the heat wave, and loss of power can be very dangerous during a heat wave, especially for population vulnerable to heat. In some cases, such as relocating a coastal substation, the risk may be low enough to defer the investment until the next round of replacement would occur.

Risk and Resilience Planning

The vulnerability assessments establish what the risk levels of various climate change scenarios to the electric sector are. The resilience plan must then decide which risks to address and when. The risk can be mitigated either by preventing the damage from taking place or by mitigating the consequences after the event has happened. The decision tool used by many planners is a cost/benefit analysis which provides a binary choice: if the benefits of prevention outweigh the cost, then the preventive action is worth taking.

However, in reality, the choice is generally not a binary one. In a recent paper, entitled, "Vulnerability of the U.S. Electric Grid System: Predicting Wildfires and Power Outages in California,"[40] the author

[39] http://www.livescience.com/24496-hurricane-sandy-new-york-future-superstorms.html
[40]http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwiM4va6tNLJAhUIzGMKHUHMDP4QFggcMAA&url=http%3A%2F%2Fethanvasquez.com%2Fprofessionalexperience%2FJunior%2520Independent%2520Research.pdf&usg=AFQjCNH87cDXqewC7_vwXMUQX0bTHJOY_g

estimated the costs of hardening infrastructure against wildfire in the "tens of billions" of dollars and the cost of the power outages that might result from the wildfires at $832 million over the next 100 years. The choice, if based purely on economics (and assuming these numbers are correct) is $8.32 million per year in damages versus $100 million per year in mitigation measures. Results of this cost/benefit analysis would suggest it may be more cost effective not to harden the infrastructure. Of course, this example also illustrates the difficulty in solving a problem of this magnitude with asymmetric information. The estimate of "tens of billions" in hardening costs is an unsubstantiated number, while the $832 million in damages is based on significant, although uncorroborated research. Having asymmetrical information will invariably lead to a skewed cost/benefit analysis.

The choice regarding efforts for storm hardening is equally difficult. *Safeguarding California* states that "State of the art modeling shows that a single extreme winter storm in California could cost on the order of $725 billion – with total direct property losses of nearly $400 billion and devastating impacts to California's people, economy and natural resources."[41] Several proposals have been considered to harden the coast line including one that would construct hundreds of miles of coastal "armor" such as levees, dikes and seawalls along the shoreline, and another that would build a $75 billion dam (barrage) across the Golden Gate.[42] The cost/benefit choice (again assuming the numbers are correct), is a $75 billion dam to prevent the losses of $290 billion per storm event (assuming the Bay Area would suffer 40% of the total $725 million in damages).

After experiencing Super Storm Sandy, the NYPSC approved a $1 billion storm hardening effort by Con Edison. Sandy caused an estimated $65 billion in damages along the east coast and caused more than 8 million customers to lose power according to a National Hurricane Center report.[43] Sandy was reported to be a one-in-a-thousand year hybrid winter storm hurricane. According to a LiveScience.org article,[44] by the end of the century, surge flooding at the 100-year level of 5.3 feet could occur every 3-20 years, while flooding caused by a 500-year surge of 10.2 feet could happen every 25-240 years. Sandy reached levels of almost nine feet, and planning around New York is for "Sandy plus 3" despite the fact that modeling suggests it is not likely that a storm of that size would hit New York again any time soon.

These examples demonstrate the limits of a cost/benefit analysis in addressing risk. Decisions this complex cannot be made on the basis of a one-dimensional tool. Rather, the decisions must consider the degree to which a utility will need to indemnify themselves against future events in order to continue to provide their customers uninterrupted service and what costs they are willing to incur on behalf of their customers to achieve that level of service.

But what level of risk is appropriate for the utility to take and what level of cost is appropriate? Many safety programs state a goal of "zero accidents" because to state that any number of accidents is

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[41] Safeguarding California, Page 4.
[42] San Francisco Bay Conservation and Development Commission. November 20, 2007." Analysis of a Tidal Barrage at the Golden Gate." http://www.bcdc.ca.gov/pdf/planning/Golden_Gate_Dam_Report.pdfA. Also, San Francisco Bay Conservation and Development Commission. 2009. "Rising Tides Competition." http://www.risingtidescompetition.com/risingtides/Home.html.
[43] www.nhc.noaa.gov/data/tcr/AL182012_Sandy/pdf
[44] http://www.livescience.com/24496-hurricane-sandy-new-york-future-superstorms.html

acceptable is not socially or politically palatable. The cost of prevention might be very high, but the perception that "failure is not an option" usually supports the expenditure in safety programs.

However, under future climate conditions, to have a stated policy driving at "zero damage or outages" from wildfires, sea level rise, or other climate-related events would seem at the very least an ambitious reach goal. But if "zero" is not achievable, what level of damage is an appropriate level to plan for? How many outages are acceptable? And how much are ratepayers willing to invest to harden the system? Is it appropriate to spend significantly more to harden a system to prevent infrastructure and economic damage than it would cost to fix the infrastructure damage after it has happened? Conversely, is it appropriate to value only the physical damage in the calculation, or does the calculation need to try to monetize and include all of the devastating impacts that will be experienced?

Utilities and policy makers will need to develop a robust decision-making framework that can assist in making difficult decisions across the complex electricity system. Cost/benefit analysis can be a useful tool, but as seen above, it has its limitations in this context.

The resilience plans will need to articulate clearly the utility's core objectives and an overall vision of resilience to facilitate the adaptation investment prioritization process. They will also need to present their finding in terms of risk management. In addition, a stakeholder process will be needed in order to agree upon the level of climate risk being faced, the adaptation priorities outlined in the resiliency plan, and the mechanism by which the right investments will be chosen.

Recommendations

The following recommendations are for the investor-owned utilities, but could be equally applied to publically-owned utilities.

1. The large California investor-owned utilities are encouraged to conduct a rigorous vulnerability assessment as per the guidance provided by the DOE Partnership for Energy Sector Climate Resilience that calls for the following items to be assessed by January, 2016:
    - Identify Key Climate Risks to Study
    - Develop Inventory of Assets and the Potential Effects
    - Identify and Prioritize Vulnerabilities
    - Assess Magnitude and Probability of Impacts

2. The IOUs are also encouraged to complete the expanded vulnerability assessment issues identified in this paper by June, 2016:
    - Broaden the Definition of Assets
    - Assess the System as a Sum of its Assets
    - Assess Future System Assets
    - Assess Emergency Management Procedures
    - Assess the Vulnerability of the Customers
    - Assess Internal and Operational Vulnerabilities

- Create an Iterative Process for Updates and Improvements

3. When DOE releases its guidance for the Resilience Plans that are due in the Fall of 2016, the IOUs are encouraged to follow that guidance, which DOE has initially outlined as covering:
   - Costs of climate change impacts, including infrastructure damages and outages to customers for both short and long term events
   - Costs of climate resilience solutions, including infrastructure upgrades
   - Benefits of climate resilience solutions, including avoided societal costs due to reduced customer outages

4. The IOUs are also encouraged to construct resilience plans that cost out a range of options from full mitigation of a problem, to partial mitigation options, to inaction noting the costs and consequences of each option adopting both a cost/effectiveness and a risk management perspective.

Conclusion

Rigorous vulnerability assessments and resilience plans are the first steps towards ensuring that California's electric sector can withstand the challenges that climate change will bring. The exercise of examining all of the climate change-related vulnerabilities to the system followed by the process of envisioning all the potential remedies to those vulnerabilities is a solid step the IOUs can take to address the future challenges head on. This process will be iterative; there are too many aspects that must be considered to hope that they can all be addressed in one report. Some of the issues are entirely new, while others are an existing challenge that must be investigated under a new light. Stakeholders, policy makers, and regulators will need to build off the foundation of these reports for robust implementation and begin the difficult process of deciding which actions to take in the face of significant uncertainty.