

# STAFF PAPER

California Energy Commission

**DOCKETED**

**13-IEP-10**

TN 72412

DEC 18 2013

## Climate Change and the California Energy Sector

David Stoms<sup>a</sup>, Guido Franco<sup>a</sup>, Heather Raitt<sup>b</sup>, Susan Wilhelm<sup>a</sup>,  
Sekita Grant<sup>c</sup>

*a-Energy Generation Research Office, b-Executive Office, and c-Commissioners Office*

*California Energy Commission*

### DISCLAIMER

This paper was prepared by members of the staff of the California Energy Commission. As such, it does not necessarily represent the views of the Energy Commission or the State of California. The Energy Commission, the State of California, its employees, contractors, and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this paper; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This paper has not been approved or disapproved by the California Energy Commission nor has the Commission passed upon the accuracy or adequacy of the information in this paper. This paper has not been approved or disapproved by the full Commission.

DECEMBER 2013

CEC-100-2013-002



## ACKNOWLEDGEMENTS

The authors would like to thank the *Integrated Energy Policy Report (IEPR)* staff for their help organizing the June 4, 2013, IEPR Lead Commissioner workshop. Dave Michel, Simone Brant, and Joe O'Hagan of the California Energy Commission contacted some of the prospective presenters. Many other Energy Commission staff assisted with comments on previous versions of some of the material in the staff paper that was initially written for other climate change documents.

The authors would also like to thank the presenters (listed below) at the workshop that helped support this staff paper. The presenters, representing academia, agencies, utilities, and the private sector, graciously contributed their time and effort to contribute to the workshop.

- David Pierce, Scripps Institution of Oceanography
- Dan Cayan, Scripps Institution of Oceanography
- Joshua Willis, NASA Jet Propulsion Laboratory
- Garth Hopkins, Caltrans
- Craig Bolger, Pacific Gas and Electric Company
- John Radke and Gregory Biging, University of California, Berkeley
- Todd Esque and Ken Nussear, U.S. Geological Survey
- John Maulbetsch, Consultant
- Gretchen Hardison, Los Angeles Department of Water and Power
- Kathleen Ave and Obadiah Bartholomy, Sacramento Municipal Utility District
- Andrew Petrow, ICF International



## ABSTRACT

Recent studies have described the potential vulnerability of California's energy supply and demand infrastructure to the effects of climate change, including higher temperatures, reduced snowpack, sea-level rise, and extreme events like heat waves, flooding, and wildfires. This staff paper for the *2013 Integrated Energy Policy Report (IEPR)* summarizes this research about the projected changes in California's climate and the impacts of those changes that create potential vulnerabilities in the energy system. The paper identifies future research needs to help the energy sector prepare for climate change and then concludes with key policy issues. The goals of this staff paper are to set the stage for California's Fourth Climate Change Assessment and to help align the *IEPR* with the forthcoming *Safeguarding California Plan*, an update to the *2009 Climate Adaptation Strategy*.

**Keywords:** Vulnerability, adaptation, preparedness, readiness, extreme events, energy supply, climate change

Please use the following citation for this report:

Stoms, David, Guido Franco, Heather Raitt, Susan Wilhelm, Sekita Grant. 2013. *Climate Change and the California Energy Sector*. California Energy Commission. Publication Number CEC-100-2013-002.

# TABLE OF CONTENTS

	Page
<b>Acknowledgements</b> .....	<b>i</b>
<b>Abstract</b> .....	<b>iii</b>
<b>Executive Summary</b> .....	<b>1</b>
Climate Changes and Projections Relevant to California’s Energy Sector.....	1
Impacts of Climate Change on Energy Supply .....	1
Research Needs.....	2
Priority Issues and Recommendations .....	2
<b>CHAPTER 1: Introduction</b> .....	<b>5</b>
<b>CHAPTER 2: Climate Changes and Projections Relevant to California’s Energy Sector</b> .....	<b>7</b>
Summary of Past Research.....	7
Evidence of Changes.....	8
Projections of Future Change.....	9
Extreme Events .....	10
<b>CHAPTER 3: Impacts of Climate Change on Energy Supply</b> .....	<b>14</b>
What We’ve Learned to Date.....	14
What Is Being Done—Safeguarding Our Energy System.....	15
Diversify Energy Supply to Reduce Vulnerability to Extreme Weather-Related Events and Climate Change.....	15
Protect Existing Energy Facilities and End Users From Impacts of Climate Change.....	17
Assess Environmental Impacts From Climate Change in Siting and Licensing of New Energy Facilities.....	17
Develop Hydropower Decision-Support Tools to Better Assess and Manage Climate Change Variability.....	18
Energy Sector Responses to Climate Change: Case Studies.....	18
<b>CHAPTER 4: Research Needs</b> .....	<b>22</b>
Improve and Update Climate Change Indicators.....	24
<b>CHAPTER 5: Priority Issues and Recommendations</b> .....	<b>26</b>

Climate Change Research and Policy Coordination With Other State Agencies.....	26
Actions That Both Safeguard the Energy System And Reduce GHG Emissions .....	27
Informing Local Planning Efforts About Energy Sector Vulnerabilities and Capacity to Prepare for Climate Risk.....	27
Summary of Recommendations .....	29
<b>References .....</b>	<b>31</b>

## LIST OF FIGURES

	Page
Figure 1: California Statewide Maximum and Minimum Temperatures.....	10
Figure 2: Heat Waves in California Since 1950.....	11
Figure 3: Projections of Heat Waves in California .....	12
Figure 4: Potential Extreme Water Levels in the San Francisco Region .....	13
Figure 5: Significant Weather-Related California Electric Grid Disturbances.....	25
Figure 6: Cal-Adapt Website.....	28
Figure 7: CaLEAP Website to Help Communities Plan for Energy Assurance in the Face of Emergencies, Including Extreme Weather Events.....	29

## EXECUTIVE SUMMARY

State-sponsored research has played a major role in recent advances in understanding the potential impacts of climate change on California, including those impacts on many facets of the energy sector. The *2013 Integrated Energy Policy Report (IEPR)* Scoping Order called for “consideration of the potential vulnerability of California’s energy supply and demand infrastructure to the effects of climate change, including higher temperatures, reduced snowpack, sea-level rise, and extreme events like heat waves, flooding, and wildfires.” This staff paper summarizes what has been learned about energy sector vulnerability, what research needs remain to better understand potential impacts and preparedness options, and key policy issues. It also helps to align the *IEPR* with forthcoming California climate change policy documents.

### Climate Changes and Projections Relevant to California’s Energy Sector

Several recent sources of information discuss how climate has been changing in California and how it may evolve in the rest of this century. This chapter mostly focuses on what information has become available recently and what is being produced by the research community for California. The State has sponsored research on climate change, particularly on improved methods for modeling regional climate scenarios and sea-level rise that support vulnerability assessments for the energy sector.

Analysis of historical data provides evidence of increasing temperatures in California and changes in the spring snowpack in the Sierra Nevada that are likely caused primarily by increased concentrations of greenhouse gases in the atmosphere. Nighttime minimum temperatures in particular have been increasing in recent decades.

Climate projections suggest that heat waves will increase in frequency, last longer, start earlier in the year and end later, and will become hotter than in the historical record. Precipitation in California is highly variable, and this high variability will continue to be a feature of California’s climate in the future. Projections imply a potential for more frequent inland flooding in the future. As mean sea level rises, the frequency and magnitude of extremes would increase markedly. High sea-level surges that used to occur very infrequently in the historical period would become very common by the end of this century and would last for extended periods.

### Impacts of Climate Change on Energy Supply

Climate change is likely to compromise energy supplies, particularly during temperature peaks when demand will be exacerbated. Principal impacts on energy supply could be reduced electricity output from thermal power plants, lower capacity of the transmission and distribution infrastructure to deliver electricity, damage to infrastructure from extreme weather events, and changes in the availability and timing of renewable energy resources.



The energy sector is taking many steps to increase preparedness for these potential impacts. The sources of energy generation are being diversified to reduce negative climate impacts on any particular source. The vulnerability of the energy system has been assessed to identify the components at greatest risk that need to be protected. In addition, research and development have been performed to find technology solutions to overcome potential impacts. The environmental impacts of climate change are considered in siting new energy facilities. Decision-support tools are being developed to manage energy systems more effectively in a changing climate. Preparedness activities by a few utilities are presented, as well as new methods of forecasting weather-related electricity demand.

## Research Needs

California has developed an unmatched legacy of state-level research on climate change and its impacts, and the Energy Commission has been instrumental to this progress. Nevertheless, the growth of new data, knowledge, and analytical capabilities dictates the need for continuing research to help the State achieve its existing and future policy goals. This chapter highlights a few key topics. Foremost among these is the forthcoming fourth California Climate Change Assessment. Details of the assessment are being worked out at this time, but this staff paper outlines some of the energy-related topics the assessment is likely to address. First, because most planning activities at the local, regional, and state levels have time horizons of 20 to 30 years, future research will illuminate impacts and options to prepare for climate risks over the next few decades without losing sight of what may happen in the second half of this century. Second, this staff paper will identify research needs for assessing vulnerability of the energy sector to extreme events over the next few decades and strategies to reduce risk. Third, the effects of climate change on renewable energy generation are not well understood but could be critical for California to achieve its aggressive renewable and GHG emissions goals. Fourth, this staff paper presents research needed to determine how to design California's energy system in order to reduce greenhouse gas emissions and increase the level of renewables in the electricity mix while making the system more resilient. The final topic highlighted is to support development and measurement of climate change indicators for the energy portion of a cross-sector state effort.

## Priority Issues and Recommendations

- **Sponsor research on regional climate projections, energy sector vulnerability, and strategies to reduce climate risk.** Continue to sponsor climate change research on regional climate projections, the vulnerability of the energy sector, strategies to prepare for climate risks, and barriers that can hamper implementation of promising measures.
- **Fund research, development, and demonstration for technologies that reduce greenhouse gas emissions.** Continue funding research, development, and demonstration on technologies that reduce greenhouse gas emissions and that need public support in California.

- **Support actions that provide both reductions in GHG emissions and preparation for climate risks.** California should emphasize climate mitigation actions to reduce greenhouse gas emissions that also make the energy system more resilient, reliable, and efficient in the face of climate change.
- **Expand support for Cal-Adapt and CaLEAP, tools that assist local planning efforts.** Sustain and expand Cal-Adapt (a Web-based interactive visualization tool developed to convey the risks of climate change to local decision makers and Californians who live in affected communities) and CaLEAP (a program that local governments use in preparing plans to ensure that key assets are resilient to disaster events that impact energy). These tools have proven to be valuable aids to local communities in planning for climate change.
- **Assess the vulnerability of transportation fuel infrastructure to climate change.** The Energy Commission will assess the vulnerability of the transportation fuel infrastructure, such as refineries, pipelines, marine terminals, underground storage tanks, and fueling stations, to extreme weather events and other climate impacts.
- **Continue to coordinate climate change research by California agencies.** The Energy Commission will continue to provide coordination support to climate change research sponsored by state agencies in California via the Climate Action Team Research Working Group. The Climate Action Team consists of state agency secretaries and the heads of agencies, boards, and departments. It is led by the Secretary of the California Environmental Protection Agency. The Climate Action Team created a Research Working Group to guide research on the impacts of climate change on California; improve research coordination among state departments; identify research gaps and opportunities for collaboration; and provide a forum for discussing future state climate change research priorities.



# CHAPTER 1:

## Introduction

Observed changes over the last several decades across the western United States reveal clear signals of climate change. Statewide average temperatures increased by about 1.7°F from 1895 to 2011<sup>1</sup>. Temperatures in California are projected to rise significantly during this century as a result of the heat-trapping gases humans release into the atmosphere. This broad conclusion holds regardless of the climate model used to project future warming. In addition to increased average temperatures, climate scientists project that summer temperatures will rise more than winter temperatures, and the increases will be greater in inland California, compared to the coast. Heat waves will be more frequent, hotter, and longer. By late-century, projections show a tendency toward drying in the south part of the state due to a potential reduction of precipitation. Even in projections with relatively small or no declines in precipitation, central and southern parts of the state can be expected to be drier from the warming effects alone as the spring snowpack will melt sooner, and the moisture contained in soils will evaporate during long, dry summer months. A warming planet will also result in sea-level rise to unprecedented levels compared to observations in the historical period. Secondary effects of these projected changes include, among different impacts, changes in vegetation patterns and increased risk of wildfire.

State-sponsored research has played a major role in recent advances in understanding the potential impacts of climate change on California, including those on many facets of the energy sector. In particular, the State sponsored a series of climate change assessments, as directed by Executive Order #S-3-05. The first assessment, published in 2006, made clear that the level of impacts is a function of global emissions of greenhouse gases and that lower emissions can significantly reduce those impacts. The second study, released in 2009, made the case that preparing for the risks from climate change is a necessary and urgent complement to reducing emissions. The state's third major assessment on climate change in 2012, in contrast to the previous two assessments, explored local and statewide vulnerabilities to climate change, highlighting opportunities for taking concrete actions to reduce climate-change impacts. A fourth assessment is being planned.

In part because of the findings from this series of assessments, the *2013 Integrated Energy Policy Report (IEPR)* Scoping Order<sup>2</sup> called for “consideration of the potential vulnerability of California’s energy supply and demand infrastructure to the effects of climate change, including higher temperatures, reduced snowpack, sea level rise, and extreme events like heat waves, flooding, and wildfires.” This staff paper summarizes what has been learned

---

1 Estimated from data available from the California Climate Tracker ([http://www.wrcc.dri.edu/monitor/cal-mon/frames\\_version.html](http://www.wrcc.dri.edu/monitor/cal-mon/frames_version.html)). Accessed on 7/12/2013.

2 [http://www.energy.ca.gov/2013\\_energy\\_policy/documents/2013-03-07\\_scoping\\_order\\_2013\\_IEPR.pdf](http://www.energy.ca.gov/2013_energy_policy/documents/2013-03-07_scoping_order_2013_IEPR.pdf).

about this vulnerability, what research needs remain to better understand potential impacts and options to reduce climate risks, and key policy issues. The document is a synthesis of the three climate change assessments, Energy Commission's sponsored reports, IEPR workshops on April 30, 2012,<sup>3</sup> and June 4, 2013<sup>4</sup>, and the California Climate Extremes Workshop held December 13, 2011, at Scripps Institution of Oceanography in La Jolla, California (Pierce 2012).

The State of California strives for a comprehensive, integrated climate change policy through legislation, regulation, Executive Orders, and the policy documents that they prescribe. Foremost of these are the *AB 32 Scoping Plan* (ARB 2008) and the *Climate Adaptation Strategy* (CNRA 2009). Updates of both documents are underway, as is the *Environmental Goals and Policy Report* and the interagency, statewide *Climate Change Research Plan*. The goals of this staff paper are to help align the *IEPR* with this evolving suite of policy documents and to set the stage for the fourth Climate Change Assessment.

---

3 [http://www.energy.ca.gov/2012\\_energy\\_policy/documents/#04302012](http://www.energy.ca.gov/2012_energy_policy/documents/#04302012).

4 [http://www.energy.ca.gov/2013\\_energy\\_policy/documents/#06042013](http://www.energy.ca.gov/2013_energy_policy/documents/#06042013).

## **CHAPTER 2:**

# **Climate Changes and Projections Relevant to California's Energy Sector**

There are several sources of information discussing how climate has been changing in California and how it may evolve in the rest of this century (for example, Franco et al. 2011; Cayan et al. 2012). For this reason, this chapter focuses mostly on what has become available recently and what is being produced by the research community for California. This chapter very briefly summarizes state-sponsored research on climate, presents some of the available evidence about detectable climate changes in California, and ends with a discussion about climate projections for the rest of this century.

### **Summary of Past Research**

In 2003, the State, via the California Energy Commission's Public Interest Energy Research (PIER) Program, adopted a long-term strategy to track how climate is changing in California, to assess the reasons for these changes, and to produce "probabilistic" climate projections for California that would be suitable for both research and long-term planning (Franco et al. 2003). Since then, all the steps included in that strategy have been implemented but, as shown in the *California Climate Change Research Plan* (in preparation), much more needs to be done. The completed steps included:

1. Developing and testing of a new statistical downscaling technique (Bias Corrected Constructed Analogue [BCCA]) designed to simulate daily events (Hidalgo et al. 2008; Maurer and Hidalgo 2008; Maurer et al. 2010).
2. Developing a technique to translate multiple climate projections into "probabilistic" distributions (Dettinger 2005).
3. Developing a protocol to compare results of dynamic and statistical techniques for downscaling global climate models to a scale suitable for California (Duffy et al. 2005).
4. Enhancing three dynamic regional climate models and using them for simulations of historical conditions (Miller et al. 2009).
5. Comparing dynamic and statistical regional climate models for California (Miller et al. 2009).
6. Examining how well global climate models are able to simulate conditions over the North American West Coast (Cayan et al. 2008b; Cayan et al. 2009).
7. Developing multiple daily climate projections for California using statistical and dynamic regional climate models at about a 12 kilometer (km) resolution (Pierce et al. 2012; Pierce et al. 2013).
8. Developing "probabilistic" climate projections for California for the middle of this century (Pierce et al. 2012).

In addition, at the request of researchers performing ecological impacts studies for the Third California Climate Assessment, the State supported further downscaling of the scenarios created with the BCCA method to generate climate scenarios with geographical resolution of less than 1 km (0.625 miles) with monthly temporal resolutions (Thorne et al. 2012).

The State has also supported work on annual sea-level rise projections, creating scenarios fully compatible with the climate scenarios described in the above paragraph (Cayan et al. 2008a; Cayan et al. 2009). Researchers led by Scripps Institution of Oceanography have also produced hourly sea-level rise scenarios for both the second and third California climate assessments to investigate the possibility of extreme sea-level events. More recently they have considered the effect of ocean waves in the open ocean driven mainly by winds far from California that travel to the coast (Graham et al. 2012) and contribute to the dynamics affecting how far water can penetrate inland (that is, wave run-up) (Bromirski et al. 2012). This information is also essential to realistically estimate the effects of erosion on dunes and cliffs. Finally, a report from the National Academy of Sciences (NAS) further investigated how the annual averaged sea-level rise would change in the future considering, among other things, the vertical movement of coastal lands (for example, subsidence) (National Research Council 2012). Prior assessments of sea-level rise used in the California climate assessments are contained within the range estimated by NAS.

In climate monitoring, the California Energy Commission and the California Department of Water Resources (DWR) have supported the creation of the California Climate Tracker at the Western Regional Climate Center<sup>5</sup>. This website uses data from hundreds of meteorological stations in California and a standard method (Abatzoglou et al. 2009) to report continuously how temperature and precipitation levels are changing in climatologically homogeneous regions in California.

The State has also provided modest but important support for the installation and maintenance of meteorological stations in remote areas and the deployment of a dense network of temperature and other sensors<sup>6</sup> to estimate how conditions change in areas where high weather gradients are expected, such as mountainous and coastal areas.

## **Evidence of Changes**

There are already detectable changes in California's climate, and some of them have been shown to be likely due to the increased concentration of greenhouse gases (GHG) in the atmosphere. Studies fully or partially supported by California agencies have shown, among other things, that the already-observed overall increased temperatures and changes in the spring snowpack in California are, to a high degree of statistical confidence, not entirely the result of natural variation and are likely caused primarily by increased concentrations of GHG in the atmosphere (Bonfils et al. 2007; Pierce et al. 2008; Hidalgo et al. 2009). Research

---

5 <http://www.wrcc.dri.edu/monitor/cal-mon/>.

6 [http://meteora.ucsd.edu/weather/observations/sio\\_other/crd\\_obs.html](http://meteora.ucsd.edu/weather/observations/sio_other/crd_obs.html).

also indicates that the unexpected negative trends in maximum daily temperatures in some agricultural areas are due to increased irrigation in the 20th century (Snyder et al. 2006; Kueppers et al. 2008; Bonfils and Lobell 2007; Lobell and Bonfils 2008) and that several hydrological parameters (for example, early melting of snow) are showing emerging climate change signals (Pierce and Cayan 2013b).

Researchers with Pacific Gas and Electric (PG&E), analyzing their own hydro-meteorological measurements, have reported that most of the observed changes have occurred on the relatively lower elevation northern Sierra. They report multiple trends in the areas where PG&E has important hydroelectric facilities. For example, they report that average minimum January temperatures have risen by about 5 to 6 °F around Lake Almanor in northwestern Plumas County when comparing two more recent successive 35-year periods. April-through-June runoff on the east branch of the north Feather River has declined by 40 percent since 1964. March runoff has increased for all the watersheds that they have analyzed, and water-year runoff has increased in the recent 35 years for watersheds south of the Yuba River and decreased north of the Yuba River (Bolger 2013).

## **Projections of Future Change**

Some decision makers have expressed their desire to obtain probabilistic climate projections to use them in a risk-assessment framework in their long-term planning. In California, state-sponsored research has started to develop these quasiprobabilistic climate projections using 16 general circulation models and regional climate models that downscale the coarse geographical resolution of the global models to squares of about 7 miles per side. The regional climate models include both statistical and dynamic models. The statistical models are based on mathematical relationships between the outputs of the global climate models and observations at the local scale. The dynamic models are numerical models similar to the ones used for weather predictions that simulate the dynamics of the atmosphere.

Quasiprobabilistic projections are not real probabilities in the statistical sense because they are developed using only 25 climate projections that may not capture the full universe of uncertainties associated with climate projections. The probabilities were calculated for a period by the middle of this century because expected changes in climate are a strong function of the greenhouse gas emissions already in the atmosphere, and future emissions in the next 30 years do not have a strong effect on climate by the middle of this century. These emissions, however, do start affecting climate projections after 2050.

Regional climate models, in general, do not take into account the effect that small particles in the air (aerosols) may have on regional climate. The Energy Commission, in cooperation with the California Department of Water Resources, funded a field study to investigate how aerosols may be affecting precipitation patterns and amounts in the Sierra Nevada. Prior Energy Commission-supported studies suggested that aerosols may be reducing precipitation in the Sierra Nevada (Rosenfeld et al. 2008), negatively affecting water supply



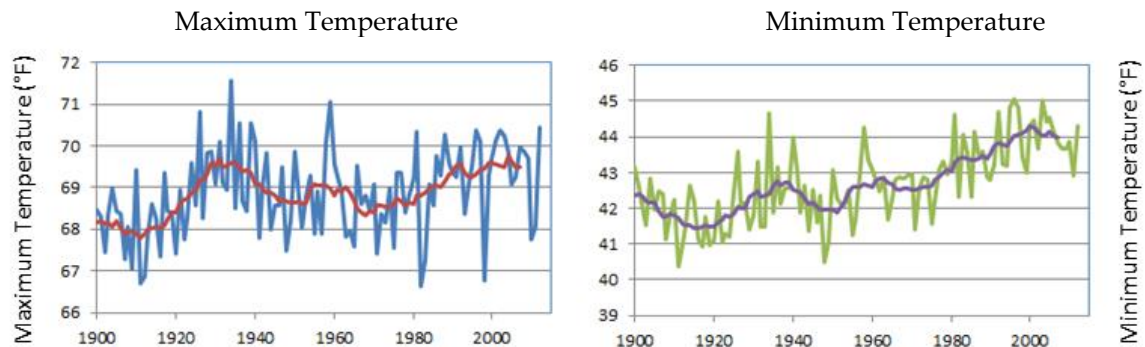
and hydropower generation. The field study known as CalWater<sup>7</sup> has resulted in several publications in scientific journals, including a paper in the prestigious weekly journal *Science* (Creamean et al. 2013). One of the findings from CalWater is that locally emitted or formed aerosols from gaseous emissions, such as oxides of nitrogen, can indeed reduce precipitation efficiency. However, the main finding is that transport of dust and biological material from Asia and Africa high in the atmosphere (aloft) can substantially increase precipitation falling as snow. This finding is due to the fact that these particles act as excellent seeds for the formation of ice (ice nuclei), and precipitation involving ice is more efficient. During CalWater two almost identical storms, but only one affected by transport of aerosols aloft, generated about 40 percent more precipitation (Ault et al. 2011). Regional climate models do not model precipitation very well. The proper treatment of aerosols in regional climate models has the potential to substantially improve regional climate projections.

## Extreme Events

This section discusses three types of extreme events of direct importance to the energy sector: heat waves, extreme precipitation, and surges in sea levels.

The magnitude of annual daytime maximum temperatures has a weak increasing trend for the last 110 years, as shown in the left graph in Figure 1. This is not the case for annual mean minimum daily temperatures, as shown in the right graph in the same Figure 1 where a clear trend toward higher temperatures in recent decades is evident.

**Figure 1: California Statewide Maximum and Minimum Temperatures**



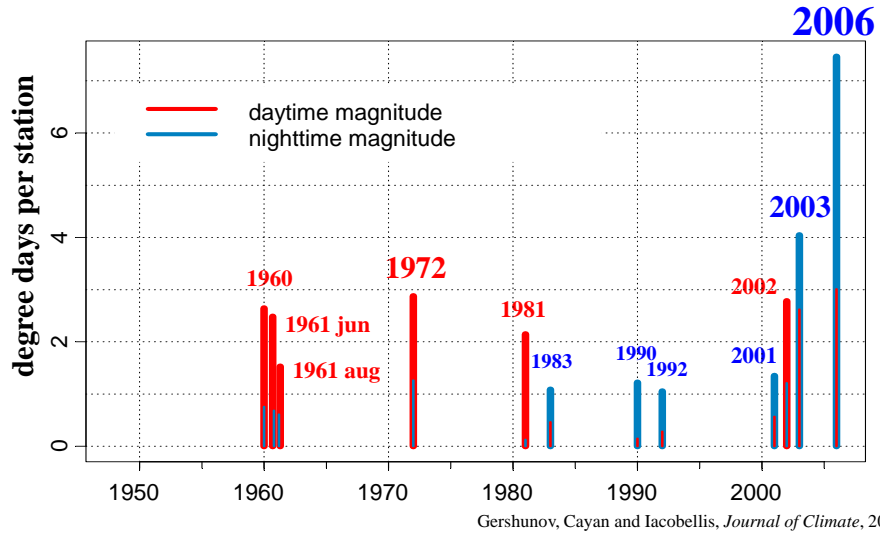
Data source: California Climate Tracker (<http://www.wrcc.dri.edu/monitor/cal-mon/>)

Similar trends have been observed for extreme temperatures. Cayan (2013) reports about the largest heat waves on record since 1948 in California (Figure 2), showing that recent daytime parts of the heat waves are not unusual from an historical perspective, but that heat waves

<sup>7</sup> <http://atofms.ucsd.edu/content/calwater-2011>.

characterized by the nighttime characteristics clearly show a positive (increasing) trend. It is possible that the nature of the California heat waves might be changing.

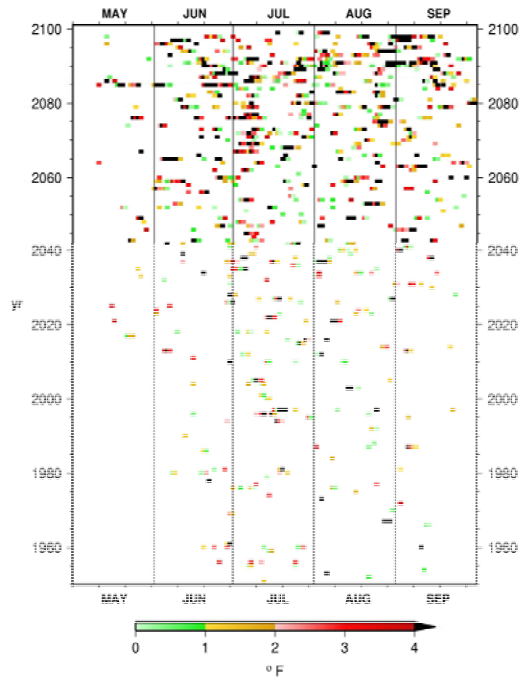
**Figure 2: Heat Waves in California Since 1950**



Source: Cayan, 2013

Climate projections suggest that heat waves will become more frequent, will experience higher temperatures than in the historical record, and will last for longer periods. They would start early in the year, and the heat wave season would end later in the year. Figure 3 shows how heat waves would evolve in the Sacramento region if they are defined as days with maximum daily temperatures equal or exceeding 106 °F from May to September.

**Figure 3: Projections of Heat Waves in California**

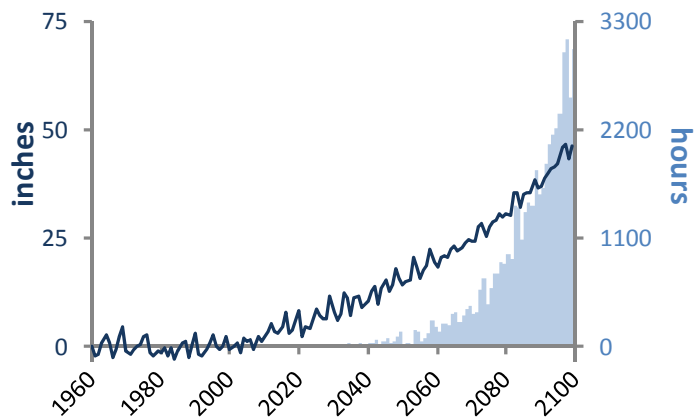


Source: Cayan, 2013

Precipitation in California is highly variable, and this high variability will continue to be a feature of the state's climate in the future (Cayan 2013). Analysis of historical records show that inland floods are associated with elevated three-day average streamflows (Florsheim and Dettinger 2007). Analyses of projections for this parameter imply a potential for more frequent inland floods in the future (Das et al. 2011).

Sea-level rise projections have been reported in Energy Commission research. The main conclusion is that as mean sea level rises, the frequency and magnitude of extremes would increase markedly, as shown for one of these projections in Figure 4. This figure shows that as mean sea level increases (left y-axis), high sea-level surges that used to occur very infrequently in the historical period (99.99 percentile) would become very common by the end of this century and would last for extended periods.

**Figure 4: Potential Extreme Water Levels in the San Francisco Region**



Source: Modified from Cayan, 2013

An interesting observation is that storminess associated with the power of the ocean waves hitting the California coast seems to be decreasing (Gemrich 2011), but this finding is not universally accepted. Models that simulate the effect that winds in the open ocean have on wave conditions on the California coast project that storminess would continue to decrease over the rest of this century (Bromirski et al. 2012). Sea-level rise, however, will dominate the risk of coastal flooding in the second half of this century.

Other indirect extreme events, such as wildfires and drought that affect the energy sector, have been reported in other Energy Commission research (for example, Krawchuk and Moritz 2012).

# CHAPTER 3:

## Impacts of Climate Change on Energy Supply

### What We've Learned to Date

Climate change is likely to compromise energy supplies, particularly during temperature peaks when demand is exacerbated. Principal impacts on energy supply include the efficiency of thermal power plants to generate electricity, the capacity of the transmission and distribution infrastructure to deliver electricity, damage from extreme weather events, and changes in the availability and timing of renewable energy resources. These impacts were assessed in a comprehensive study conducted by the Lawrence Berkeley National Laboratory for the 2012 California Climate Change Vulnerability and Adaptation Study. The study suggests that the current electricity infrastructure is more vulnerable to climate change than previously believed (Sathaye et al. 2013), although a rapidly evolving electricity system offers the opportunity to reduce vulnerability.

The Lawrence Berkeley National Laboratory study found that higher temperatures would decrease the capacity of thermal power plants (for example, natural gas, solar thermal, nuclear, and geothermal) to generate electricity during particularly hot periods. The estimated decrease varies by region, emission scenario, and climate model. California's gas-fired generating plants have a nameplate capacity of 44,000 megawatts (MW). By the end of the century, this capacity could be reduced by as much as 10,000 MW on hot days, compared to a maximum of 7,600 MW in the 1961-1990 period. Similarly, the study suggested that higher temperatures would result in a 2 to 4 percent reduction in transformer and substation capability, a 1 to 3 percent increase in transmission and distribution losses, and a 7 to 8 percent decrease in the capacity of a fully loaded transmission line. Assuming no change in technology advancements or population, the study suggests energy supplies need to increase by about 39 percent by the end of the century simply to meet increased demand resulting from climate change and to offset diminished capacity of thermal generating plants and substations.

The energy system will also become more vulnerable to extreme weather events, such as wildfires and coastal flooding (Sathaye et al. 2012). Under some climate scenarios, the likelihood of wildfires occurring near large transmission lines is expected to increase dramatically in parts of California by the end of the century. The study found a 40 percent increased probability of wildfire exposure for certain transmission lines, including the line that brings hydropower generation from the Pacific Northwest to California during peak demand periods. In addition, about 20 coastal power plants and about 80 substations are at risk of flooding (or partial flooding) due to sea-level rise.

Most research has explored potential impacts on electricity infrastructure and, to a lesser degree, that of natural gas. No state agency, however, has yet assessed the vulnerability of the infrastructure providing the fuels used in the transportation sector (for example,

refineries, pipelines, marine terminals, underground storage tanks, and fueling stations) to both extreme weather events (for example, flooding, fire, storms) and other climate impacts (sea-level rise, coastal erosion, rising temperatures).

## **What Is Being Done—Safeguarding Our Energy System**

### **Diversify Energy Supply to Reduce Vulnerability to Extreme Weather-Related Events and Climate Change**

A more diversified energy system will reduce the negative impacts of climate-related events. For example, hydropower generation is a key source of electricity during peak demand periods in the hot months of the year. However, because climate change is expected to reduce electricity generation from hydropower units during the summer, this shortfall could impact electricity supply reliability. A diversified portfolio of electricity generating units, including photovoltaic (PV), thermal solar power plants, geothermal units, and conventional power plants will be able to cover the expected shortfall. Here are some examples of actions taken so far:

- California is on track to meet its interim requirements of 20 percent renewables by 2013 and of 25 percent renewables by 2016, and is well-positioned to meet 33 percent by 2020. Since 2003, 5,288 MW of renewable capacity achieved commercial operation under the Renewables Portfolio Standard (RPS) program. More than 790 MW of renewable capacity came on-line in the first and second quarters of 2013, and another 2,385 MW of capacity is forecast to reach commercial operation by the end of the year. The 3,175 MW of renewable generation capacity forecast to come on-line in 2013 would represent the largest year-to-year increase in capacity since the beginning of the program.
- The CPUC and Energy Commission managed programs that offered rebates to lower the upfront costs of emerging renewable technologies for customers to generate their own electricity. Rebate programs are in place for PV systems for new homes, small fuel cells, and small wind turbines. These programs have led to the installation of nearly 4,000 MW of renewable generation in California that began operation between 2010 and 2012. Another 2,200 MW of new renewable generation is under construction in California and will begin coming on-line in 2013.
- California is developing the first Desert Renewable Energy Conservation Plan (DRECP). The DRECP working group—consisting of the Energy Commission, California Department of Fish and Wildlife, U.S. Bureau of Land Management, and U.S. Fish and Wildlife Service—is developing guidelines to identify areas suitable for renewable energy projects and transmission corridors, while developing long-term natural resource conservation areas that protect fragile desert ecosystems.
- California implemented several programs and plans that support policies and incentives that will help spur distributed, on-site renewable energy generation systems.

- The Renewables Program in the Energy Commission’s Energy Research and Development Division successfully implemented the Renewable Energy Secure Communities (RESOCO) program, which supports community-scale renewable energy projects at three stages of development: exploratory, pilot, and implementation.
- Advanced generation initiatives under the Energy Commission’s RD&D Program supports renewable-based decentralized advanced power generation and combined heat and power, clean fossil fuel (primarily natural gas), and distributed generation.
- The Energy Commission’s Renewable Energy RD&D Program also implemented a follow-up program to the earlier RESOCO efforts through the community-scale renewable energy development, deployment, and integration (REDDI) supporting projects that demonstrated optimized community-specific renewable energy systems, developed tools and models to quantify impacts and benefits of increasing local renewable energy penetrations in California, and developed breakthrough renewable energy technologies.
- The Energy Commission provided Web-based tools on planning and permitting resources for renewable energy systems that will help streamline permitting of renewable energy projects. Also, the Energy Commission worked with other state agencies, stakeholders, and local governments to develop a model ordinance to help streamline permitting for distributed generation solar PV systems in California, which was adopted by the California County Planning Directors Association in 2012.
- The Energy Commission published a staff report in April 2011 (*Developing Renewable Generation on State Property: Installing Renewable Energy on State Buildings and Other State-Owned Property*) to encourage expansion of such development. The report recommended a goal of 2,500 MW of renewable energy on state properties.
- The Energy Commission published the *Renewable Power in California: Status and Issues* report in 2011 that, along with the recent *IEPR*, recommended overarching strategies for achieving the RPS requirement of 33 percent renewable energy by 2020, achieving the Governor’s goal for 12,000 MW of localized renewable energy resources, and increasing investment in renewable energy in California.
- The Energy Commission has funded research designed to develop the tools for improved environmental (ecological) evaluations and for identification of sites that would minimize environmental impacts to streamline permitting. Some of the research data and siting tools are already in use, and additional research is ongoing or will start in the near future.
- The Energy Commission demonstrated the ability of microgrids to increase the penetration of renewables, improve energy efficiency, and accelerate the integration of electric vehicles onto the grid. These features were demonstrated on actual microgrids located on the campus of the University of California, San Diego, on the facilities of the Santa Rita Jail in Alameda County and on the grid networks of San Diego Gas & Electric and the Sacramento Municipal Utility District. Microgrids

allow for continuous operation where implemented (for example, Santa Rita Jail), even when power outages affect portions of the State.

## Protect Existing Energy Facilities and End Users From Impacts of Climate Change

Most studies to date have involved vulnerability and risk assessments of existing energy facilities or studies to improve performance. The energy sector has not generally begun to invest capital to protect facilities. The rate of change will be slow enough in the near future to allow a gradual response as part of the normal cycle of maintenance and renovation. Some studies by utilities have found relatively low vulnerability of their facilities to sea-level rise (Hardison 2013; Pacific Gas and Electric Company 2013).

Studies to date fall in to two categories: vulnerability assessments of energy infrastructure and studies of technological alternatives to reduce risk from extreme weather conditions. The former include a study in the Third Climate Change Assessment that examined vulnerability to increased temperatures, sea-level rise, and increased risk of wildfire (Sathaye et al. 2012). A new PIER-funded project is beginning to examine the potential risk to energy infrastructure from flooding and sea-level rise in the Sacramento-San Joaquin Delta, where fragile, decaying levees are vulnerable to breaching (Radke and Biging 2013). Such studies, and those mentioned above by utilities, will help guide energy planners to which facilities are most at risk and how soon so that strategies to reduce risk can be implemented right away.

On the technology side, thermal power plant cooling is an issue in hot weather. At higher temperatures, cooling is less efficient, which in turn reduces the generation of electricity. The frequency and magnitude of hot days are projected to increase in the future, magnifying this existing problem. Moreover, hot days are often windy, compounding the problem further. A series of Energy Commission-funded studies has tested various technological solutions, such as spraying jets of water in the inlet and installing wind screens to shield the condenser (Maulbetsch 2013).

## Assess Environmental Impacts From Climate Change in Siting and Licensing of New Energy Facilities

There are two primary aspects of incorporating climate change impacts into siting and licensing of energy facilities: consideration of future risks of proposed sites to extreme events such as sea-level rise and flooding, and the cumulative impacts of development and climate change on species of concern and other environmental factors. The Energy Commission's Siting, Transmission, and Environmental Protection Division examines proposed power plant sites for risks from sea-level rise and increased flooding as part of the reliability analysis required under the Energy Commission's power plant certification process.

Renewable energy facilities, like any other project, must comply with state and federal environmental laws, such as the Endangered Species Act. Species listed under this act or its



California counterpart typically have declined from a complex mix of habitat loss and other threats. Climate change is another potential threat in that the habitat conditions each species prefers is expected to move across the landscape. Sites that are currently unsuitable or marginal habitat for an endangered species may become more suitable in the future. Moreover, as species need to migrate in response to climate change, they must do so across a highly disturbed and fragmented landscape. Renewable energy developments could potentially block the few remaining dispersal routes that will become critical to species' survival. Energy Commission-funded research has begun to explore how climate assessments can be done with an example of the threatened Mohave ground squirrel (Esque and Nussear 2013). The DRECP is applying the project findings to identify climate change extension areas within or outside the Mohave ground squirrel's historic range but considered suitable for occupancy in the event of range and distribution shifts in response to climate change. More research is needed, however, to identify climate change extension areas for other species and the interactions of climate change with energy development and other stressors on native biodiversity.

### **Develop Hydropower Decision-Support Tools to Better Assess and Manage Climate Change Variability**

In some cases, the energy sector may be able to prepare for climate change impacts by modifying how energy facilities are managed instead of, or in addition to, engineering solutions. Hydropower is an excellent example of this.

A demonstration project supported by the Energy Commission and the National Oceanic Atmospheric Administration has shown that using probabilistic hydrological forecasts in a modern decision support system can substantially outperform current management rules for five of the major water reservoirs (for example, Shasta Lake, Folsom Lake) in Northern California (Georgakakos et al. 2005). The same system has been shown to potentially reduce the negative effects of climate change by increasing water supply and hydropower generation in critical times when compared with how current operating rules would perform under future climate scenarios (Georgakakos et al. 2011a; Georgakakos et al. 2011b). At the same time, this study highlights the issue that technical solutions sometimes are not enough. In this case, modernizing the operating rules would require substantial interagency coordination efforts and, potentially, may require an act of the U.S. Congress for the federally managed reservoirs.

### **Energy Sector Responses to Climate Change: Case Studies**

Many utilities are assessing their vulnerability and planning to prepare for climate change. Some of these efforts were presented at the June 4, 2013, IEPR workshop and are summarized here.

*Los Angeles Department of Water and Power (LADWP)*—The largest municipal utility in the nation has benefitted from city-sponsored local vulnerability assessments in partnership with local universities and has begun implementing actions to reduce risks from climate

change (Hardison 2013). Researchers from UCLA produced downscaled data from global climate models for the Los Angeles area to give LADWP very detailed projections of mid-century climate conditions. The city of Los Angeles also sponsored a sea-level-rise vulnerability study for Pacific Palisades, Venice/Playa del Rey/Los Angeles Airport (LAX), and San Pedro/Wilmington/Port of Los Angeles. Preliminary findings suggest that energy facilities in these areas have relatively low vulnerability to sea-level rise and associated flooding.

*Sacramento Municipal Utility District (SMUD)*—SMUD has been examining climate impacts on its electricity service since 2008 to manage changes and to prepare for those beyond its control. SMUD contracted studies on effects on peak demand, hydropower, flood risk, and efficiency of thermal power plants (Bartholomy and Ave 2013). Of particular concern are potential increases in nighttime temperatures that allow less cooling of transformers and substations and, therefore, lower efficiency; changes in snowmelt and hydropower generation; and changes in wind patterns both for electricity generation and cooling effects. The “Delta Breeze” facilitates nighttime cooling within the district and represents an excellent example of a regional issue requiring more detailed modeling than is conventional for statewide vulnerability studies. SMUD is developing its own safeguarding strategy and is pursuing opportunities for collaborative research on climate change impacts and strategies to reduce risk.

*Pacific Gas and Electric Company (PG&E)*—This investor-owned utility has studied the impacts of climate change on its system since 1989 and routinely incorporates new climate science into its risk management, business planning, and operating processes (Garrett 2012). According to Ezra Garrett, Vice President and Chief Sustainability Officer for PG&E in a 2012 report to the not-for-profit Carbon Disclosure Project (CDP), the company reviews the climate change risks identified in the Energy Commission’s three climate change assessments and other reports. Members of a cross-functional team “communicate the results of these reviews to their respective business units so that they can re-evaluate the risks and impacts to our facilities that may result from climate change, and develop the necessary adaptation strategies” (Garrett 2012). PG&E also conducts its own assessments. For instance, it has studied the vulnerability of its system to sea-level rise (Pacific Gas and Electric Company 2013). PG&E has also assessed the impact on its hydroelectric system, finding decreased spring runoff and greater March runoff in the Sierra Nevada, particularly at the lower elevation, northern end (Bolger 2013). This trend leads to more spills from reservoirs to prevent flooding later, but this also reduces hydropower generation. Relicensing agreements try to mimic the natural rate of flow over time and maintain instream flows for aquatic species, which can be more challenging with climate change and the other demands on water management in California. PG&E believes that, at the current rate of change, hydroelectric generation will remain mostly unchanged for 12-13 years before it experiences declines in production. PG&E is willing to share information about its climate change assessments with the Energy Commission and encourages the Commission to consult with utilities about its assessments and strategies to prepare for the risks from climate change (Pacific Gas and Electric Company 2013). The U.S. Government

Accountability Office is writing a report about climate change planning in the energy sector; PG&E was selected as one of four case studies for this report.

*Research on Seasonal and Decadal Forecast for the Energy System*—The Energy Commission has an ongoing research project with Scripps Institution of Oceanography to explore the development and use of probabilistic seasonal (months in advance) and decadal (10 to 20 years) forecasts to aid in the management and planning of the electricity system (Pierce and Cayan 2013a).

Before every summer, the California ISO issues a technical document titled the *Summer Loads & Resource Assessment*, which is an “assessment of the adequacy of resources to meet California’s summer peak electricity demand.” These assessments are done using historical ambient air temperatures in California. However, under a changing climate, using historical data may not capture future more extreme events. In addition, some studies have shown that a probability distribution of summer temperatures can be predicted a few months in advance (Alfaro et al. 2004). One purpose of the ongoing research project with Scripps is to explore the practical use of enhanced probabilistic seasonal extreme temperature forecasts to improve preparatory activities that the state can take to ensure that enough capacity is available to satisfy extreme electricity peak demand. Obviously, this activity can be an excellent measure to prepare for the risks from climate change.

With respect to decadal probabilistic forecast, Scripps Institution of Oceanography is investigating how well different research centers around the world can predict, in a probabilistic sense, climatic conditions of importance for California. Research centers developing global climate projections start their simulations with conditions that existed more than 100 years ago (for example, early 1900s) to find out how well the models simulate historical conditions. This type of simulation reproduces only historical conditions in a statistical sense. For example, the 2006 California heat wave would not occur exactly in 2006 in the modeled climate scenarios. At the same time, there are features of the climate that evolve relatively slowly, such as the condition known as the Pacific Decadal Oscillation (PDO), which is characterized by warm (positive phase of PDO) or cold (negative phase of PDO) distribution of ocean temperatures in the Pacific Ocean. In the positive phase of PDO, the eastern part of the Pacific Ocean is warmer than average, while the western part is cooler. The opposite occurs during the negative phase of the PDO<sup>8</sup>. In theory, if the global climate models are initialized with current conditions of the ocean and other factors, the models could produce better simulations of conditions in the next 10 years than the simulations with global climate models initialized with conditions 100 years ago. Several research centers around the world are working on these decadal forecasts, and Scripps Institution of Oceanography is investigating the applicability of these probabilistic forecasts for California. Future energy forecasts for California looking at 10 to 20 years into the future may use these decadal probabilistic forecasts as a tool for the energy system to reduce climate risks.

---

<sup>8</sup> [http://sealevel.jpl.nasa.gov/science/el\\_nino/pdo/](http://sealevel.jpl.nasa.gov/science/el_nino/pdo/).

*Short-term probabilistic forecast of the Delta Sea-Breeze*—The Delta Breeze brings relatively cool air from the San Francisco Bay to the Sacramento and San Joaquin Valleys in summer afternoons, rapidly lowering temperatures in these regions starting with the areas that are close to the Carquinez Strait and including the cities of Sacramento and Stockton. In days when the Delta Breeze does not materialize, afternoon and evening temperatures can rise substantially, increasing peak electricity demand. The California ISO and electric utilities are interested in short-term forecasts of the Delta Breeze because a lack of this breeze can increase demand by as much as 5,000 MW, and incorrect forecasts convey economic penalties and risk of power curtailments. For example, on May 28, 2003, an incorrect forecasted load of 35,012 MW became an actual load of 39,577 MW. As a result, a Stage 1 alert had to be declared (Scripps Institute of Oceanography and Science Applications International Corporation 2004).

In a project sponsored by the National Oceanic and Atmospheric Administration and supported by the Energy Commission, Scripps Institution of Oceanography developed a statistical method that was shown to outperform conventional forecasts under certain circumstances. The new probabilistic forecast would be issued at 7:00 a.m. for the same day conditions using meteorological data available from in the Sacramento-San Joaquin Delta (Pierce and Gaushell 2014). An ongoing Energy Commission research project is further evaluating these types of statistical forecasts and comparing them with modern forecasts available from groups providing these forecasts to the affected electric utilities.

## CHAPTER 4: Research Needs

California has developed an unmatched legacy of state-level research on climate change and its impacts, and the Energy Commission has been committed to this progress and will continue to support energy-related regional climate science. This chapter is not intended to be a comprehensive survey of all research needs in this area, but rather to highlight selected key topics. Some of the forthcoming research will support California's Fourth Climate Change Assessment with the understanding that many details of the assessment are being worked out at the time of this staff paper, but it is expected that energy research will be included. Because most planning activities at the local, regional, and state levels have time horizons of 20 to 30 years, future research will attempt to illuminate impacts and options to reduce risks from climate change over the next few decades without losing sight of what may happen in the second part of this century.

The following is a partial list of energy-related areas for research in need of support:

- ***Advances in Fine-Scaled, Probabilistic Climate Change Projections:*** Local-level studies will require a higher level of geographical resolution and the use of new methods that can translate the outputs from the new suite of global climate models to the California region. These projections can be used for demand forecasts critical to energy-sector planning.
- ***Vulnerability to Extreme Events:*** Climate change is increasing the frequency and severity of extreme events, which can disrupt energy supplies as well as exacerbate demand. Studies on vulnerabilities to extreme events are valuable in preparing for a more extreme climate in the future.
- ***Economic Impacts and Costs of Preparing for Climate Change:*** Although they are essential in informing decisions and priorities, there is very little information about the economic impacts of climate change, the cost of strategies to reduce risk, and implications for the energy sector.
- ***Modeling and Analysis of Sectors and Systems:*** Further development and sensitivity testing of potential energy scenarios for Californians are needed, with in-depth consideration on reducing the climate vulnerability of the energy system.
- ***Funding Mechanisms for Preparing for Climate Change:*** This research will investigate ways to finance measures for the energy sector to reduce climate risk with the final objective of identifying economically efficient and robustly effective paths.
- ***Incorporate Climate Considerations in Public and Private Sectors:*** This research will analyze how the public and private sectors can better implement climate considerations into day-to-day activities so that California can overcome institutional impediments and better adopt climate change strategies to reduce GHG emissions and climate change risk.

- ***Overcoming Regulatory and Legal Barriers:*** Past research shows that there are major legal and regulatory barriers to reaching climate change goals. For example, the rapid transformation of the electricity system represents an opportunity to California to develop a system that is resilient to climate impacts, but institutional, regulatory, legal, economic, and other barriers may impede visionary design of energy systems. Research is needed to identify barriers, as well as means of overcoming them to support long-term consideration of climate change in energy system planning.
- ***Support Sustainable Renewable Generation:*** The deployment of power plants making use of renewable sources of energy can require substantial amounts of land (for example, solar units in the southeastern California desert) with potentially large ecological and environmental impacts. Further study is needed for potential new geographical areas that may experience large deployment of renewable sources of energy in the near future (for example, the southwestern part of the San Joaquin Valley that is being considered for major solar and bioenergy projects).
- ***Impacts of Climate Change on Renewable Sources of Energy:*** Climate change will not only increase ambient temperatures, but may change wind regimes, cloudiness, and therefore solar radiation reaching ground level, and the availability of biomass. Prior exploratory studies have been unclear about the potential impacts of climate change on renewable sources of energy in California.
- ***Impacts and Options to Reduce Climate Risks for Hydropower Generation:*** Several studies have looked into this issue. However, past studies have limitations, such as separating the analysis of high-elevation hydropower units (designed mostly for electricity generation) from “rim” hydropower units associated with low elevation water reservoirs (for example, Shasta Lake and Folsom Lake). In practice, both systems are hydraulically connected, and the climate impacts and responses should be considered simultaneously. For example, past studies suggest that water spills in high-elevation units will increase substantially in the winter, but these excess spills were not fully considered in climate change studies of downstream low-elevation units that are designed mostly for flood control and water supply.
- ***Adapting to Current Levels of Climate Variability:*** Some studies (for example, INFORM integrated management of five of the largest water reservoirs in Northern California) suggest that developing tools to adapt to current levels of climate variability can also substantially reduce damages from future warming and increased climate variability. Follow-up studies to INFORM and similar studies could be supported. For example, the investigation of probabilistic seasonal forecast of summer temperatures to prepare the electricity system to unusually high peak load could be pursued. The purpose of the selected studies is to inform the development of a more robust energy system.
- ***Vulnerability of the Electric and Natural Gas Infrastructure in the Sacramento/San Joaquin Delta Region:*** The 2012 Vulnerability and Adaptation Study (third California Climate Assessment) discovered a general subsidence of the levee system making use of Interferometric synthetic aperture radar (InSAR) satellite data. However, due to data limitations (for example, InSAR cannot detect subsidence rates

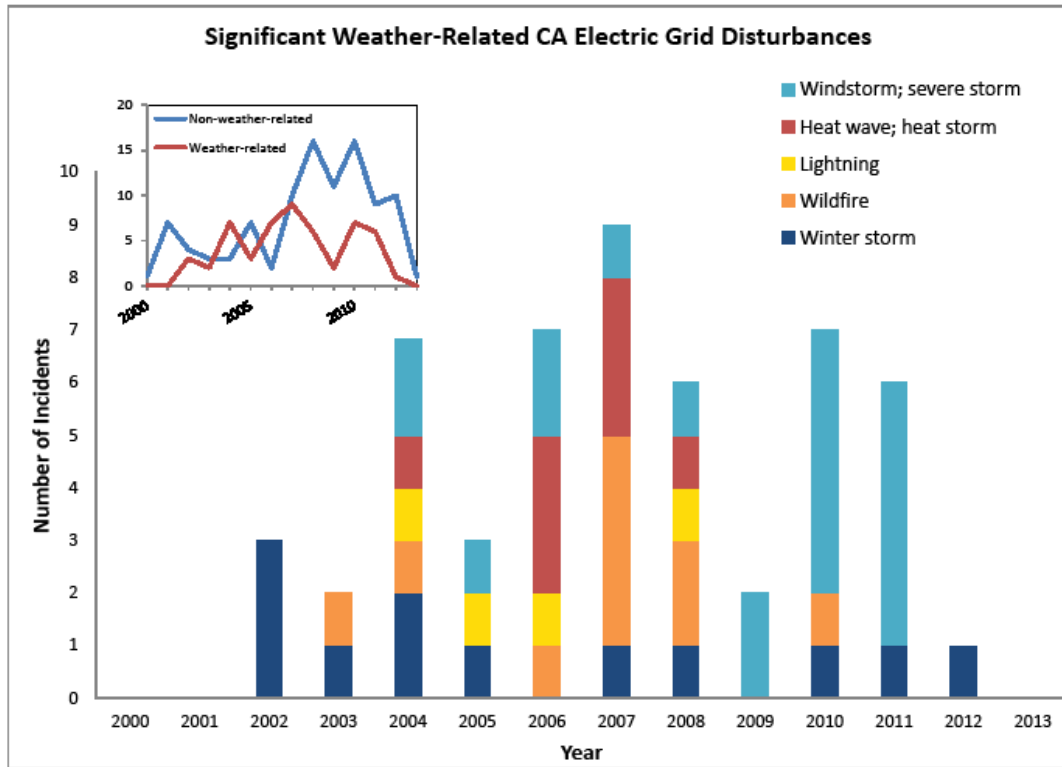
above a given threshold), the results were not as detailed as necessary and can only be considered as preliminary. Subsequent measurements using a novel low-cost, ground-based LIght Detection And Ranging or LiDAR technique performed by the research team demonstrated that high-quality measurements are possible. These low-cost measurements should substantially improve the prior Energy Commission study. This study will include not only new measurements of the vertical movement of the levees, but the estimation of the vulnerability of electricity and natural gas transmission lines and underground natural gas reservoirs to sea-level rise. This study may also include simulations to determine how sea-level rise in the California coast translates into water levels in the Delta, considering potential increases in fresh water flows in the winter from the Sacramento and San Joaquin rivers.

- ***Energy Scenarios for California and Potential Environmental Consequences:*** Past research supported by the Energy Commission has developed multiple energy scenarios for California. These scenarios show that there are multiple options to fulfill the state's goal of reducing GHG emissions by 80 percent from 1990 levels by 2050 (Wei et al., 2013). They also provide information about potential mid-term targets, such as a GHG target for 2030. This work should be substantially enhanced, considering issues such as potential financial constraints to the rapid transformation of the energy system, the impact of climate change on energy demand and generation, and consideration of electricity distribution networks at the regional/urban scales. Scenarios with relatively high geographical and temporal resolutions should be used to avoid unanticipated environmental impacts.

## **Improve and Update Climate Change Indicators**

Indicators of climate change can help the state track, evaluate, and report on the climate change issues it is working to address, as well as the outcomes of its efforts. The Office of Environmental Health Hazard Assessment periodically publishes a set of indicators (Office of Environmental Health Hazard Assessment 2013). The indicators serve as tools for communicating technical data in relatively simple terms. Taken collectively, the indicators help portray the interrelationships among climate and other physical and biological elements of the environment. Finally, many of the indicators reveal evidence of the already discernible impacts of climate change, highlighting the urgency for the state, local government, and others to undertake strategies to reduce GHG emissions and climate change risks. Research projects funded by the California Energy Commission provided notable contributions. There are opportunities to improve current indicators and develop new ones to track the resilience and vulnerability of the energy sector. For example, Figure 5 shows that wildfires are an important source of power interruptions in California. The figure below could be substantially improved with additional information about events before 2002 and with detailed information about the occurrence of these events. Unfortunately this type of information is not readily available, and the authors of this staff paper had to obtain the data used to create the figure below from federal authorities.

Figure 5: Significant Weather-Related California Electric Grid Disturbances.



Data Source: U.S. Energy Information Administration, [http://www.eia.doe.gov/OE417\\_annual\\_summary.aspx](http://www.eia.doe.gov/OE417_annual_summary.aspx).



## **CHAPTER 5: Priority Issues and Recommendations**

### **Climate Change Research and Policy Coordination With Other State Agencies**

As mentioned in Chapter 1, state agencies work to coordinate climate change policies in response to legislation, regulation, and Executive Orders. The State publishes dozens of policy documents with climate change policies, including the *2013 IEPR*. The foremost of these documents are the *AB 32 Scoping Plan*, the *Climate Adaptation Strategy*, the *Environmental Goals and Policy Report*, and the *Climate Change Research Plan*. All of these are undergoing major updating except for the research plan, which will be an original document.

The Energy Commission works primarily on policy coordination on climate issues through its participation on the Climate Action Team (CAT). The CAT members are state agency secretaries and the heads of agencies, boards and departments, led by the Secretary of the California Environmental Protection Agency. The Chair of the Energy Commission serves as the lead of the CAT Research Working Group, which is developing the *Climate Change Research Plan*. Moreover, the Energy Commission has coordinated with sister energy agencies (California Public Utilities Commission and the California Independent System Operator) in drafting the energy chapters of the *AB 32 Scoping Plan Update* and the *Safeguarding California Plan* (the update of the *2009 Climate Adaptation Strategy*). The Energy Commission also recognizes the cross-sector links of energy with water, agriculture, transportation, public health, forestry, and biodiversity sectors, among others. For example, water delivery, treatment, and use constitute one of the largest energy use sectors; at the same time, energy generation consumes large amounts of water. Therefore, conservation and efficiencies in one resource can leverage great savings in the other. The Water-Energy Team of the Climate Action Team (WET-CAT) is a state-level interagency effort tasked with implementing various measures contained in the Air Resources Board's (ARB) *2008 Scoping Plan* and the *2009 Climate Adaptation Strategy*. It coordinates efforts on both greenhouse gas emission reduction and safeguarding actions affecting the portion of the energy sector that supports the storage, transport, and delivery of water for agricultural, residential, and commercial needs.

The energy sector discussion in the forthcoming *Climate Change Research Plan* will be fully compatible with efforts in the Energy Commission and the CPUC via the Electric Program Investment Charge (EPIC) Program and research supported by the Air Resources Board and others on this topic. The strength of the *Climate Change Research Plan* will be in its capability to link different programs to complement each other.

## **Actions That Both Safeguard the Energy System And Reduce GHG Emissions**

The Energy Commission has a legacy of research, development, and demonstration for successful safeguarding activities that also reduce GHG emissions, strengthen the green economy, and maintain California's leadership in energy technology innovation, including transportation. Examples include energy storage; renewables; microgrid resilience; and efficiency improvements for buildings, industry and agricultural processes, vehicles, and low-carbon transportation fuels. Distributed generation allows the utility grid to reduce the need to call on high-peak demand generation resources, which historically have the highest levels of GHG emissions. Most of these innovations would be beneficial in making the energy system more resilient, reliable, and efficient, even without climate change.

## **Informing Local Planning Efforts About Energy Sector Vulnerabilities and Capacity to Prepare for Climate Risk**

Climate change is an unprecedented threat for energy sector producers, regulators, planners, and consumers. Sharing information about vulnerabilities, planning tools, and safeguarding strategies will help all of California successfully prepare for the uncertainties of the future. The Energy Commission has actively supported local governments and utilities with information about energy sector vulnerabilities and tools for climate safeguarding planning. One of the major challenges facing the members of the climate change risk community is the scarcity of tools and methods to convey these risks posed by climate change to a wider audience. There is a serious bottleneck in delivering relevant information, much of which is map-based, to decision makers in a manner that allows them to turn climate change research results into effective decisions and policies to reduce risk.

To address this problem, the Governor's *2009 Climate Adaptation Strategy* (CNRA 2009) ordered continued development and updating of Cal-Adapt, a Web-based interactive visualization tool developed to convey the risks of climate change to Californians who live in affected communities and to local decision makers. The Energy Commission supported these new capabilities of Cal-Adapt<sup>9</sup>.

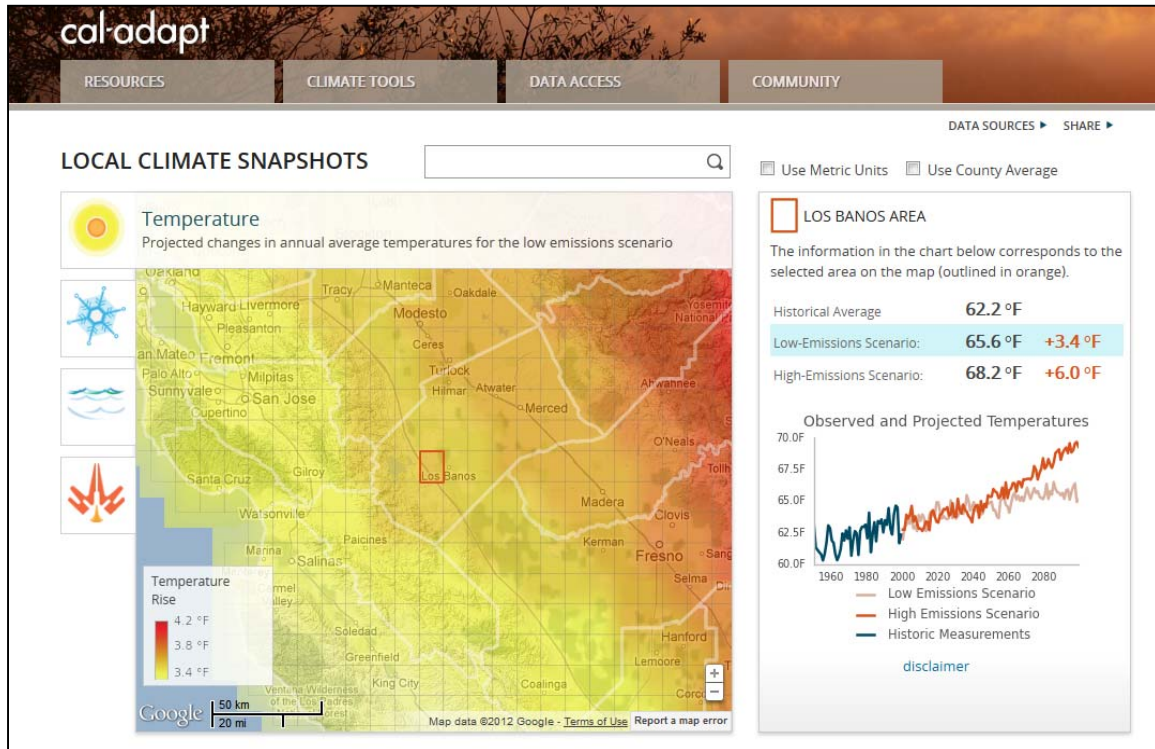
Because California has diverse climate and ecological zones, plans to safeguard the energy sector must be tailored to local conditions. Cal-Adapt allows the public to see impacts of climate change for their hometown (Figure 6) and allows technical staff to perform statistical analyses and produce graphs and other visual materials (Koy et al. 2011). The goal is to generate research products on which communities can base choices and to make research results available with a geographical context. All these functions contribute toward the state becoming better equipped with locale-specific safeguarding strategies, ultimately benefitting California residents. Recently, the California Natural Resources Agency issued a guidance document to local agencies recommending the use of Cal-Adapt as one of its main

---

<sup>9</sup> <http://cal-adapt.org/>.

tools to obtain climate change information at the local level (Cal-EMA and CNRA 2012). Therefore, maintaining Cal-Adapt and increasing its capabilities relevant to the energy sector will become increasingly valuable.

**Figure 6: Cal-Adapt Website**



Source: Screen shot from website, <http://cal-adapt.org/>

The Commissioners approved a new agreement for Cal-Adapt at the June 12, 2013, Business Meeting. The objectives of this agreement are to enhance the Cal-Adapt website in the following ways: (1) providing map coordinates of the research projects and reports in a manner that allows users to find all available products relevant to a given geographical location; (2) generation of an open application programming interface or API that will allow third-party developers to create their own applications using Cal-Adapt data; and (3) running models interactively via Cal-Adapt, allowing users to change model parameters. The selected models will be examples of successful studies to prepare for climate change risks.

The Energy Commission assists local agencies in preparing for all aspects of emergency situations that impact energy via the Commission-sponsored California Local Energy Assurance Planning (CaLEAP) project (Figure 7). CaLEAP helps local governments throughout the State prepare plans to ensure that key assets are resilient to disasters that impact energy. The CaLEAP project covers all aspects of emergency management (prepare for, respond to, recover from, and mitigate against). Extreme events exacerbated by climate

change are included in the set of emergencies considered. The CaLEAP method helps communities blend energy assurance into their existing planning processes<sup>10</sup>. As of the June 4, 2013, IEPR workshop, 45 local governments are participating (Petrow 2013).

**Figure 7: CaLEAP Website to Help Communities Plan for Energy Assurance in the Face of Emergencies, Including Extreme Weather Events**



Source: Screen shot of home page, <http://www.caleap.org/>

Some local governments and utilities have the capacity to conduct their own vulnerability studies and safeguarding planning. These higher resolution findings make valuable contributions to understanding climate change impacts and to the toolbox of strategies and complement the broader statewide analyses. For example, PG&E conducted its own assessment of sea-level rise and concluded that its facilities are not highly vulnerable (Pacific Gas and Electric Company, 2013). Coordination among state agencies and local and utility entities and sharing this kind of information will be valuable for identifying the level of risk to energy assurance.

It will be crucial to incorporate the results of California’s Fourth Climate Change Assessment about energy sector vulnerabilities into Cal-Adapt and CaLEAP so that communities are aware of the latest scientific findings.

## Summary of Recommendations

- **Sponsor research on regional climate projections, energy sector vulnerability, and strategies to reduce climate risk.** Continue to sponsor climate change research on regional climate projections, the vulnerability of the energy sector, strategies to

<sup>10</sup> <http://www.caleap.org/>.

prepare for climate risks, and barriers that can hamper implementation of promising measures.

- **Fund research, development, and demonstration for technologies that reduce greenhouse gas emissions.** Continue funding research, development, and demonstration on technologies that reduce greenhouse gas emissions and that need public support in California.
- **Support actions that provide both reductions in GHG emissions and preparation for climate risks.** California should emphasize climate mitigation actions to reduce greenhouse gas emissions that also make the energy system more resilient, reliable, and efficient in the face of climate change.
- **Expand support for Cal-Adapt and CaLEAP, tools that assist local planning efforts.** Sustain and expand Cal-Adapt (a Web-based interactive visualization tool developed to convey the risks of climate change to local decision makers and Californians who live in affected communities) and CaLEAP (a program that local governments use in preparing plans to ensure that key assets are resilient to disasters that impact energy). These tools have proven to be valuable to local communities in planning for climate change.
- **Assess the vulnerability of transportation fuel infrastructure to climate change.** The Energy Commission will assess the vulnerability of the transportation fuel infrastructure, such as refineries, pipelines, marine terminals, underground storage tanks, and fueling stations, to extreme weather events and other climate impacts.
- **Continue to coordinate climate change research by California agencies.** The Energy Commission will continue to provide coordination support to climate change research sponsored by state agencies via the Climate Action Team Research Working Group.

## REFERENCES

- Abatzoglou, J.T., K.T. Redmond, L.M. Edwards. 2009. "Classification of Regional Climate Variability in the State of California." *Journal of Applied Meteorology and Climatology*, 48, 1527-1541.
- Alfaro, A., A. Gershunov, D. Cayan, A. Steinemann, D. Pierce and T. Barnett, 2004: "A Method for Prediction of California Summer Air Surface Temperature." *EOS*, 85(51), 553, 557-558.
- ARB. 2008. California Air Resources Board, *Climate Change Scoping Plan*. December 2008. Available at: <http://www.arb.ca.gov/cc/scopingplan/scopingplan.htm>.
- Ault AP, Williams CR, White AB, Neiman PJ, Creamean JC, Gaston CJ, Ralph FM, Prather KA. 2011. "Detection of Asian Dust in California Orographic Precipitation." *Journal of Geophysical Research – Atmospheres*, 116, D16205.
- Bartholomy, O., and Kathleen Ave. 2013. *Climate Change Impacts and Readiness Planning*. Website at [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/11\\_ave\\_2013\\_iepr.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/11_ave_2013_iepr.pdf).
- Bolger, Craig. 2013. *Water Supply and Hydroelectric Generation: Potential Impacts of Climate Change* (Pacific Gas and Electric Company), website: [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/06\\_Bolger\\_CEC\\_Water\\_Supply\\_and\\_Hydro\\_Gen\\_June%202013.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/06_Bolger_CEC_Water_Supply_and_Hydro_Gen_June%202013.pdf).
- Bonfils, C., P. B. Duffy, B. Santer, D. Lobell, Thomas J. Phillips, T.M.L. Wigley, Charles Doutriaux, 2007. "Identification of external influences on temperatures in California." *Climatic Change*. 87 (Suppl 1): S43–S55.
- Bonfils, C. and D. Lobell. 2007. "Empirical evidence for a recent slowdown in irrigation-induced cooling." *Proc. Natl. Acad. Sci. U. S. A.*, 104(34), 13582-13587.
- Bromirski, P. D., D. R. Cayan, N. Graham, R. E. Flick, and M. Tyree (Scripps Institution of Oceanography). 2012. *Coastal Flooding-Potential Projections: 2000-2100*. A White Paper from the California Energy Commission's California Climate Change Center. Publication number: CEC-500-2012-011.
- Cal-EMA and CNRA. 2012. *California Adaptation Planning Guide* (four documents). [http://resources.ca.gov/climate\\_adaptation/local\\_government/adaptation\\_planning\\_guide.html](http://resources.ca.gov/climate_adaptation/local_government/adaptation_planning_guide.html).
- Cayan, D. 2013. [Untitled PowerPoint presentation] (Scripps Institution of Oceanography, University of California, San Diego), website: [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/03\\_cayan\\_2013\\_iepr.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/03_cayan_2013_iepr.pdf).

- Cayan, D.R., P.D. Bromirski, K. Hayhoe, M. Tyree, M., D. Dettinger and R.E. Flick. 2008a. "Climate change projections of sea level extremes along the California coast." *Climatic Change*, 87, (Suppl 1): S57-S73.
- Cayan, D.R., A.L. Luers, G. Franco, M. Hanemann, B. Croes and E. Vine. 2008b. "Overview of the California climate change scenarios project." *Climatic Change*, 87, (Suppl 1): S1-S6.
- Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham and R. Flick. 2009. *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. California Climate Change Center, publication #CEC-500-2009-014-F, 64 pages, August 2009.
- Cayan, Dan, Mary Tyree, David Pierce, Tapash Das (Scripps Institution of Oceanography). 2012. *Climate Change and Sea Level Rise Scenarios for California Vulnerability and Adaptation Assessment*. California Energy Commission. Publication Number: CEC-500-2012-008.
- CNRA. 2009 *California Climate Adaptation Strategy*.  
[http://resources.ca.gov/climate\\_adaptation/docs/Statewide Adaptation Strategy.pdf](http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy.pdf).
- Creamean J. M., K. J. Suski, D. Rosenfeld, A. Cazorla, P. J. DeMott, R. C. Sullivan, A. B. White, F. M. Ralph, P. Minnis, J. M. Comstock, J. M. Tomlinson, K. A. Prather. 2013. "Dust and Biological Aerosols from the Sahara and Asia Influence Precipitation in the Western U.S." *Science*, 29, 1572-1578.
- Das, T., M.D. Dettinger, D.R. Cayan and H.G. Hidalgo. 2011. "Potential increase in floods in California's Sierra Nevada under future climate projections." *Climatic Change*, 109, 71-94.
- Dettinger, M. D. 2005. "From climate-change spaghetti to climate-change distributions for 21st Century California." *San Francisco Estuary and Watershed Science*, 3(1).  
 jmie\_sfews\_10965. Retrieved from <http://escholarship.org/uc/item/2pg6c039>.
- Duffy, P.B., J. A. Taylor, K. E. Taylor. 2005. *Protocol for Projects for Simulation of Present and Future Climates for California*. Public Interest Energy Research Program. California Energy Commission. CEC-500-2005-019.
- Esque, Todd and Ken Nussear. 2013. *Endangered species, climate change, and renewable energy*. Website: [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/08\\_esque\\_and\\_nussear\\_2013\\_iepr.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/08_esque_and_nussear_2013_iepr.pdf).
- Florsheim, J., and M. Dettinger. 2007. "Climate and floods still govern California levee breaks." *Geophysical Research Letters*, 34, doi:10.1029/2007GL031702,2007, L22403, 5p.
- Franco, G., R. Wilkinson, A. H. Sanstad, M. Wilson, E. Vine. 2003. *Climate Change Research, Development, and Demonstration Plan*. Public Interest Energy Research Program. California Energy Commission. P500-03-025FS.

- Franco, G., D.R. Cayan, S. Moser, M. Hanemann and M.-A. Jones. 2011. "Second California Assessment: integrated climate change impacts assessment of natural and managed systems." Guest editorial. *Climatic Change*, 109S1, S1-S19.
- Garrett, Ezra. 2012. *Carbon Disclosure Project--CDP 2012 Investor CDP 2012 Information Request: PG&E Corporation*. Retrieved from <https://www.cdproject.net/en-US/Results/Pages/responses.aspx>.
- Gemmrich J., B. Thomas, and R. Bouchard. 2011. "Observational changes and trends in northeast Pacific wave records." *Geophys. Res. Lett.*, 38, doi:10.1029/2011GL049518.
- Georgakakos, K. P., Graham, N. E., Carpenter, T. M., & Yao, H. 2005. "Integrating climate - hydrology forecasts and multi - objective reservoir management for northern California." *Eos, Transactions American Geophysical Union*, 86(12), 122-127.
- Georgakakos, K.P., N. E. G., F.-Y. Cheng, C. Spencer, E. Shamir, A.P. Georgakakos, H. Yao, M. Kistenmacher. 2011a. "Value of adaptive water resources management in northern California under climatic variability and change." *Dynamic Hydroclimatology*, Elsevier, 19.
- Georgakakos, A.P., H. Y., M. Kistenmacher, K.P. Georgakakos, N.E. Graham, F.-Y. Cheng, C. Spencer, and E. Shamir. 2011b. "Value of adaptive water resources management in Northern California under climatic variability and change." *Reservoir management*, Elsevier, 13.
- Graham, N.E., D.R. Cayan, P.D. Bromirski and R.E. Flick. 2012. "Multi-model projections of twenty-first century North Pacific winter wave climate under the IPCC A2 scenario." *Climate Dynamics*, 1-26.
- Hardison, Gretchen. 2013. *LADWP: Climate impacts and adaptation*. Website at [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/10\\_hardison\\_2013\\_iepr.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/10_hardison_2013_iepr.pdf).
- Hidalgo, H.G., M.D. Dettinger and D.R. Cayan. 2008. *Downscaling with Constructed Analogues: Daily Precipitation and Temperature Fields over the United States*. CEC PIER Project Report CEC-500-2007-123.
- Hidalgo H.G., Das T., Dettinger M.D., Cayan D.R., Pierce D.W., Barnett T.P., Bala G., Mirin A., Wood, A.W., Bonfils C., Santer B.D., and Nozawa T. 2009. "Detection and attribution of stream flow timing changes to climate change in the western United States." *J Clim.*, 22, 3838–3855.
- Koy, K., Van Wart, S., Galey, B., O'Connor, M., Kelly, M. 2011. "Cal-Adapt: Bringing Global Climate Change Data to a Local Application." *Photogrammetric Engineering and Remote Sensing*, 77(6): 546-550.



- Krawchuk, M., M. Moritz. 2012. *Fire and Climate Change in California: Changes in the Distribution and Frequency of Fire in Climates of the Future and Recent Past (1911–2099)*. California Energy Commission. Publication number: CEC-500-2012-026.
- Kueppers, L. M., M. A. Snyder, L. C. Sloan, D., Cayan, J. Jin, H., Kanamaru, M. Kanamitsu, N. L. Miller, M. Tyree, H., Du, and B. Weare. 2008. "Seasonal temperature responses to land-use change in the western United States." *Global and Planetary Change*, 60, 250–264.
- Lobell, D. B., C. Bonfils. 2008. "The Effect of Irrigation on Regional Temperatures: A Spatial and Temporal Analysis of Trends in California, 1934–2002." *J. Climate*, 21, 2063–2071.
- Maulbetsch, John. 2013. *Thermal power plants and hot days*. Website: [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/09\\_maulbetsch\\_2013\\_iepr.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/09_maulbetsch_2013_iepr.pdf).
- Maurer, E.P., and H.G. Hidalgo. 2008. "Utility of daily vs. monthly large-scale climate data: an intercomparison of two statistical downscaling methods." *Hydrol. Earth Syst. Sci.*, 12, 551-563.
- Maurer, E.P., H.G. Hidalgo, T. Das, M.D. Dettinger and D.R. Cayan. 2010. "The utility of daily large-scale climate data in the assessment of climate change impacts on daily streamflow in California." *Hydrol. Earth Syst. Sci.*, 14, 1125-1138.
- Miller, N.L., J. Jin, N. J. Schlegel, M. A. Snyder, T. O'Brien, L. C. Sloan, P. B. Duffy, H. Hidalgo, Kanamaru, M. Kanamitsu, K. Yoshimura, and D.R. Cayan. 2009. *An analysis of simulated California Climate using multiple dynamical and statistical techniques*. Public Interest Energy Research Program. California Energy Commission. CEC-500-2009-017-F.
- National Research Council. 2012. *Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. National Academies Press, Washington, DC.
- Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. *Indicators of Climate Change in California*, August 2013. Available online at <http://www.oehha.ca.gov/multimedia/epic/2013EnvIndicatorReport.html>.
- Pacific Gas and Electric Company. 2013. *Comments of Pacific Gas and Electric Company re Joint Lead Commissioner Workshop on Climate Change and the Energy Sector*, website: [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/comments/PGE\\_Comments\\_re\\_Joint\\_Lead\\_Commissioner\\_Workshop\\_on\\_Climate\\_Change\\_and\\_the\\_Energy\\_Sector\\_TN-71315.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/comments/PGE_Comments_re_Joint_Lead_Commissioner_Workshop_on_Climate_Change_and_the_Energy_Sector_TN-71315.pdf).
- Pierce, D. W., Ed., 2012. *California Climate Extremes Workshop Report*. Scripps Institution of Oceanography. 32 pp.
- Pierce, D., Barnett, T., Hidalgo, H., Das, T., Bonfils, C., Santer, B., Bala, G., Dettinger, M., Cayan, D., Mirin, A., Wood, A., Nozawa, T., 2008. "Attribution of declining western US snowpack to human effects." *J. Climate*, 21, 6425–6444.

- Pierce, D. W., T. Das, D. R. Cayan, E. P. Maurer, N. L. Miller, Y. Bao, M. Kanamitsu, K. Yoshimura, M. A. Snyder, L. C. Sloan, G. Franco, M. Tyree. 2012. "Probabilistic estimates of future changes in California temperature and precipitation using statistical and dynamical downscaling." *Climate Dynamics*, 40, 839-856.
- Pierce, D and D. Cayan. 2013a. *Probabilistic Forecasts for the Energy Sector (Scripps Institution of Oceanography, University of California, San Diego)*, Website: [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/02\\_pierce\\_2013\\_iepr.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/02_pierce_2013_iepr.pdf).
- Pierce, D. W., and D. R. Cayan. 2013b. "The uneven response of different snow measures to human-induced climate warming." *J. Climate*, 26, 4148-4167.
- Pierce, D. W., D. R. Cayan, T. Das, E. P. Maurer, N. L. Miller, Y. Bao, M. Kanamitsu, K. Yoshimura, M. A. Snyder, L. C. Sloan, G. Franco, and M. Tyree. 2013. "The key role of heavy precipitation events in climate model disagreements of future annual precipitation changes in California." *J. Climate*, 26, 5879-5896.
- Pierce, D., D. Gaushell. 2014. *The California Delta Breeze, Part II: Statistical versus Dynamical Sub-Daily Forecasts*. Unpublished report from Scripps Institution of Oceanography.
- Petrow, Andrew. 2013. *California Local Energy Assurance Planning*, Website: [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/12\\_petrow\\_2013\\_iepr.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/12_petrow_2013_iepr.pdf).
- Radke, John, and Greg Biging. 2013. *Potential effects of sea-level rise on energy infrastructure in the Sacramento-San Joaquin Delta*. Website: [http://www.energy.ca.gov/2013\\_energypolicy/documents/2013-06-04\\_workshop/presentations/07\\_Radke\\_and\\_Biging.pdf](http://www.energy.ca.gov/2013_energypolicy/documents/2013-06-04_workshop/presentations/07_Radke_and_Biging.pdf).
- Rosenfeld D., W.L. Woodley, D. Axisa, E. Freud, J.G. Hudson, A. Givati. 2008. "Aircraft measurements of the impacts of pollution aerosols on clouds and precipitation over the Sierra Nevada." *J. Geophys. Res.*, 113, D15.
- Sathaye, J.A., L. L. Dale, P. H. Larsen, G. A. Fitts, K. Koy, S. M. Lewis, A. Frossard Pereira de Lucena. 2013. "Estimating impacts of warming temperatures on California's electricity system." *Global Environmental Change*, 23: 499-511.
- Sathaye, Jayant, Larry Dale, Peter Larsen, Gary Fitts, Kevin Koy, Sarah Lewis, and Andre Lucena. 2012. *Estimating Risk to California Energy Infrastructure From Projected Climate Change*. California Energy Commission. Publication Number: CEC-500-2012-057.
- Scripps Institute of Oceanography (SIO) and Science Applications International Corporation (SAIC). 2004. *Improving Weather and Load Forecasting for The California Independent System Operator (CAL ISO): Case Study 1 – Improving the Forecast of Delta Breeze and Determining The Economic Value*.

- Snyder, M.A., L.M. Kueppers, L.C. Sloan, D. Cayan, J. Jin, H. Kanamaru, M. Kanamitsu, N.L. Miller, M. Tyree, H. Du and B. Weare. 2006. *Regional Climate Effects of Irrigation and Urbanization in the Western United States: A Model Intercomparison*. CEC PIER Project Report CEC-500-2006-031.
- Thorne, J. H., R. Boynton, L. Flint, A. Flint, T. N. Le. 2012. *Development and Application of Downscaled Hydroclimatic Predictor Variables for Use in Climate Vulnerability and Assessment Studies*. CEC-500-2012-010.
- Wei, M., J. H. Nelson, J. B. Greenblatt, A. Mileva, J. Johnson, M. Ting, C. Yang, C. Jones, J. E. McMahon, D. M. Kammen. 2013. "Deep Carbon Reductions in California Require Electrification and Integration Across Economic Sectors." *Environmental Research Letters*, 8(1): 014038.