Climate Change Impacts on Electricity Generation: Assessment Report

Task 8 Deliverable

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Task 8: Develop Climate Change Resiliency Roadmaps for IOUs and Policymakers

Water **UCI**

1. Task Objective

Task 8 offers a policy roadmap for Investor Owned Utilities (IOUs), state policymakers and other decision-makers to plan for, and implement, a robust greenhouse gas and renewable energy utilization planning system that is resilient against climate change.

2. Introduction

This task provides IOUs and private- and public sector decision-makers with recommendations for instituting a grid resource planning system that achieves four objectives. These are: 1) a*ccounting* for the evolution of the state's electricity generation and transmission systems in ways that make them *resilient* against climate change impacts; 2) o*utlining* steps electric utilities and policymakers should take to build resilience against climate change while also meeting state energy goals – including adapting to extreme events, engaging in community-level climate change planning, and achieving environmental justice [1]; 3) *incorporating* lessons regarding climate change impacts on electricity system performance and changes in grid resource and technology mix; and, 4) *helping* IOUs develop plans that account for the specific resources available to them, and the characteristics of their load demand, so as to better plan investment and technology deployment in their service territories. To the extent possible, we map this IOU path toward resilience over various intervals (e.g., 2030, 2040, and 2050).

Three overall themes emerged from our study. *First*, any adaptation actions taken by IOUs are unlikely to approach their full potential for cost-effective risk reduction without major investments of financial resources and some policy change. This is a major challenge because private and public entities must bear the costs of these investments. While some energy sector strategies are relatively inexpensive, others entail high capital costs, and public acceptance of climate-change response alternatives that increase energy prices could be limited [2].

Second, investments in energy efficiency and renewable energy sources are relatively simpler in the residential sector, compared to other sectors, since fewer decision-makers are directly involved in adaptation decisions. Decision-making complexity in the non-residential sectors (i.e., commercial and industrial), is attributable to the fact that multiple actors with different perspectives (e.g., plant managers, chief financial officers, chief executive officers, investors) will be involved in decisions [3]. In general, relatively inexpensive measures need fewer approvals than expensive ones. A better adapted power plant or transmission and distribution system may take years to get approved and built, and, in some cases, legislation or regulation will be needed. *If* new management policies or procedures are needed, these will also take time to bring about.

Third, because climate change adaptation solutions will require the cooperation of many different specialists and agencies, problems in coordination of policies across departments and agencies may arise. Fortunately, in the energy sector, better coordination across agencies has been occurring, and new initiatives will likely be cooperative ventures among the public and private sectors [2]. In all cases, costs incurred will include a wide-range of items: generation and transmission facilities costs as well as costs associated with storage options, conveyance facilities, and other infrastructure. Capital investments will be required to cover these costs.

3. Background – Resilience and Vulnerability in California's Electrical Energy System

Ensuring that California's electricity generation and transmission system is *resilient* in the face of climate change requires that we first define resilience. As applied to energy systems, some describe it as the ability to withstand a major disruption within well-defined degradation parameters without suffering irreversible damage, and to recover within an acceptable time-frame [4, 5, and 6]. Others characterize it as the capacity to prepare for, and respond to, changing conditions or adverse events including a range of future conditions that cannot be predicted with any certainty [7, 8, and 9]. Common to both definitions is that a *resilient energy system* is one that can withstand threats to supply (e.g., climate change) or heavy surges in demand (e.g., growing electricity use). A further characteristic of a resilient energy system is a capacity for *adaptation* – the ability to modify and/or alter operations by introducing improved technologies, more robust information, new forms of effective stakeholder engagement, and operational frameworks that enable better long-term decision-making [2, 10].

Using these synthesized conceptions of resilience as a point of departure, we argue that California's electrical energy system faces *four* significant vulnerabilities – alluded to in previous task chapters – which underscore the need for a policy roadmap for resilience. First, increases in average temperatures and higher frequency of extreme heat events, combined with new residential development across the state, will drive up demand for cooling in summertime. This growing demand will only partially be offset by decreased heating needs in wintertime and improved energy efficiency. Californians derive about 15 percent of their electricity from hydropower with more than half of this energy generation occurring above 1,000 feet MSL elevation in relatively small systems. Hydroelectricity is a premium asset during the peak-demand summer months. Studies indicate that hydropower generation is declining, and could decrease more as climate change progresses due to reduced snowpack, earlier runoff, and higher rates of evaporation [11, 12, 13, and 14]. While increased variability and decreased snowpack affecting water availability and timing remain the same in more recent as opposed to older studies, precipitation estimates vary. Previous studies suggest California drying overall but more recent data indicate the state becoming wetter or remaining the same. Figure 1 depicts anticipated energy demands by U.S. region, and underscores these issues.

Second, increases in energy demands will impose unequal impacts on the state's population, underscoring the potential environmental justice implications of efforts to address the state's electricity system's resilience (Section 6). As mentioned earlier, climate change will increase demand for cooling in the increasingly hot and longer summer season and will likely decrease demand for heating in the cooler season. While California's residential sector uses relatively little electricity for heating, it is expected that electricity demand will increase as households operate existing air conditioners more frequently. Moreover, in regions of the state where there are currently few air conditioners, more will be installed. Minorities and the poor will be especially impacted by these changes.

By projecting increases in electricity consumption due to hotter temperatures – calibrated at the ZIP code level – one set of investigators has concluded that those residential districts or zip codes comprised predominantly of non-minority, wealthier residents will experience smaller annual increases in energy consumption, while those with a higher proportion of Latino and/or lower-income residents will experience larger increases. This may in part be explained by the fact that wealthier people more often live near the coast where cooler ocean breezes reduce the amount of warming. In short, because inland areas will warm more, and are often home to less wealthy populations, energy use will grow most in the hottest areas where many who can least afford it tend to reside [15, 16]. In the near term, higher temperatures in the next decade could increase demand by up to 1 Gigawatt during hot summer months — a substantial amount that would require the construction of one large new power plant in California, or the purchase of costly peak power from external sources.

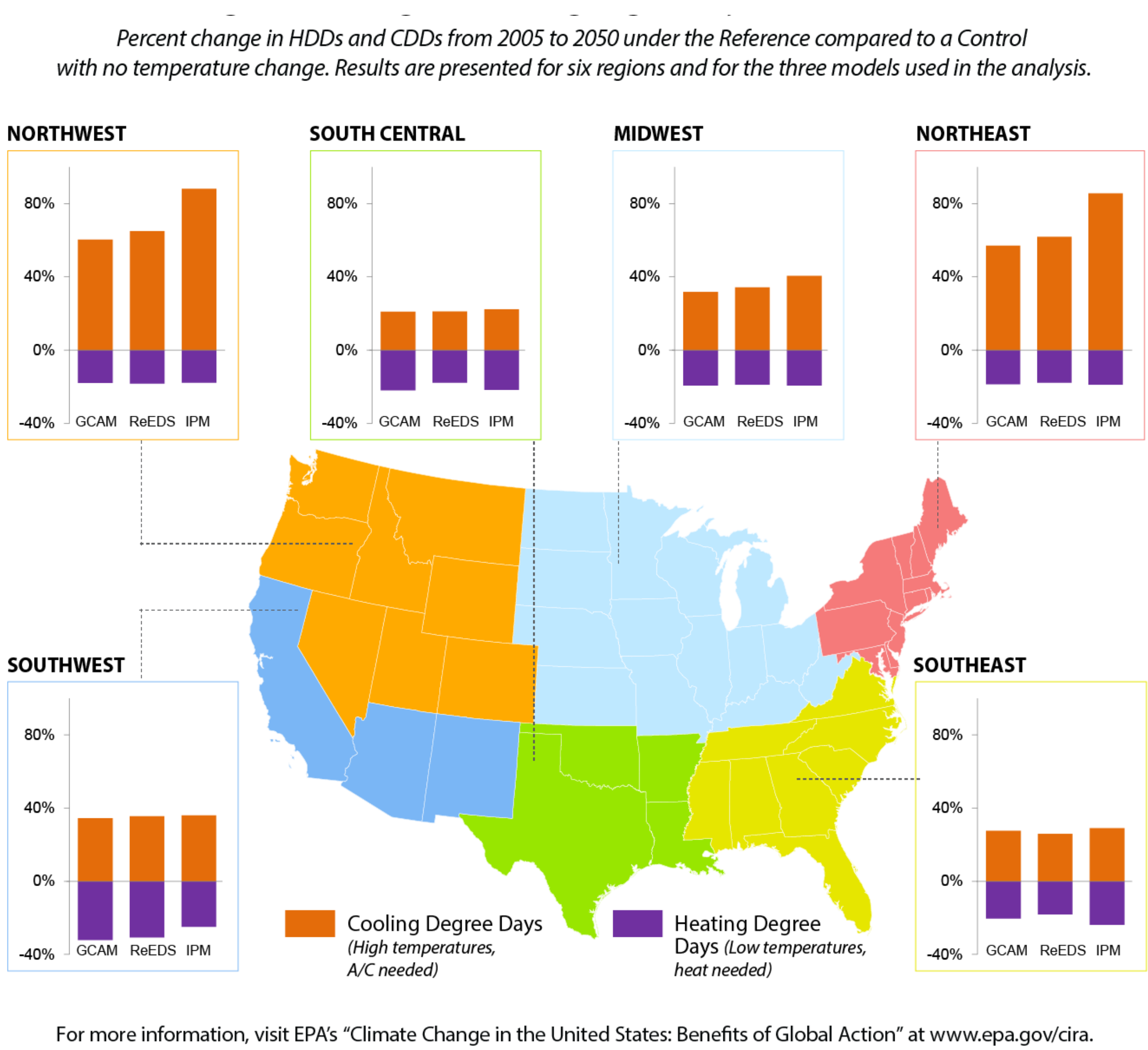

Figure 1 – Projected Impact of unmitigated climate change on regional heating and cooling

Third, as previous task report chapters note, many currently used energy sources, as well as those expected to be utilized more frequently in the future, may be especially vulnerable to climate change. Expanding on an earlier point, California's share of energy supplied by hydropower is generated by more than 150 plants which supply about 75 percent of the hydropower used in the state. The small size of many of these reservoirs allows little flexibility in operation and makes them more vulnerable to reduced snowpack. A multi-purpose water resources management simulation model has been developed for the western slope of the Sierra, from the Feather River watershed in the north to the Kern River watershed in the south. The model predicates that electricity generation from high-elevation units will be reduced substantially in the summer when hydropower is most needed to meet peak demand [11].

This latter vulnerability must be tempered, however, by the fact that the impact of climate change on regional hydrology does not directly translate to impacts on hydropower. As noted in task 3 of this study, hydropower units have varying degrees of flexibility to capture, store, and dispense available water based on demand with those systems having large storage capacities likely to realize less vulnerability than those having smaller storage capacity [11].

Other studies document this climatic vulnerability within specific regions. For the Colorado River basin, climate change is likely to reduce electricity generating capacity by about 2% in an average year, mainly due to reliance on thermoelectric facilities, for which generating capacity is linked to air temperature and available streamflow. In the Pacific Northwest by contrast, where hydroelectric power makes up a majority of generating capacity, no relationship between climate change and generation capacity is observed. Transmission infrastructure may play a greater role in ensuring electricity reliability, as traditional thermoelectric capacity is more frequently disrupted by extreme heat and drought [17].

A fourth major vulnerability relates to renewable sources of energy other than hydroelectricity [18]. While renewables are more resilient to the effects of climate change compared to conventional thermoelectric technologies, they still face considerable uncertainties with respect to impacts from a changing climate [17, 19, and 20]. Renewable energy systems are vulnerable to damage from extreme weather events because of their exposure to the natural elements (e.g., wind for windmills and solar radiation for solar panels). Moreover, given the state's goals to increase the use of biomass-based energy, climate change impacts on biomass are also of concern. For wood and forest products, there may be short- or even long-term impacts from timber kills and changes in tree growth rates. For agricultural biomass, food crop residue and growth rates of crops produced for energy production may be adversely affected [12].

In summary, challenges with respect to vulnerability and resilience fall into two principal categories: those we refer to as "known unknowns," such as decreased streamflow and water storage; as well as so-called "unknown unknowns." The latter are especially difficult to predict vulnerabilities, and thus, even more difficult to measure and include the likelihood of extreme weather events (non-linear weather-related surprises from climate change such as persistent drought punctuated by periods of high precipitation); growth patterns associated with continued urbanization; and, competing demands for power in different regions. In all cases, both sets of unknowns require evidence-based information to resolve. This is a difficult challenge to overcome because, as one study suggests: "evidence does not come in finite chunks offering certainty and security to policy decisions (but) results from a cumulative process in which the data pursue but never quite capture unfolding . . . problems" [21]. Table 1 displays the results of a recent study of self-reported climate-related vulnerabilities as recorded by California IOUs and other electricity providers and illustrates both sets of unknowns [22].

Table 1 – Results of Vulnerability Assessments by California Partner Utilities

	Approach	Scope	Climate Data	Methods	Other	Timeframe	Sources
PG&E	Internal assessment	Assets and operations	Historic and projections	Quantitative risk assessment	Average temps, extreme temps, sea level rise, water availability, flooding and precipitation, subsidence	2050 (data for 2020-2100)	Internal scenarios, FEMA, CA Climate Center, CA Coastal Commission, NOAA, CA Climate Assessment, Cal-Adapt
SCE	Internal assessment	All assets	Projections	Qualitative risk assessment	Average temps, extreme temps, sea level rise, flooding & precipitation, summer storms	2085	CEC-provided downscaled models using IPCC scenarios; literature
SDG&E	Internal assessment and literature review	Assets and operations	Historic and projections	Qualitative risk assessment	Average temp, extreme temps, sea level rise, water availability, flooding and precipitation, summer storms	2050 and 2100	IPCC, DOE, EPA, NCA, San Diego Foundation/ Scripps, NOAA, and other sources
SMUD	Internal assessment and literature review	Assets and operations	Historic and projections	Qualitative risk assessment	Average temps, extreme temps, water avail, flooding and precipitation, summer storms, regional hydrology	Mid-century, end of century, 2030s, 2085	California Climate Change Center, California Climate Action Team, region-specific academic literature

<u>*Source*</u>: Zamuda, Craig. 2016 Joint IEPR Workshop on Climate Adaptation and Resiliency for the Energy Sector Energy Sector Climate Resilience, U.S. DOE.

4. Options to Achieve Resilience – a Critique

This section discusses various options to achieve electricity system resilience with an emphasis on *policy considerations* that are likely to have the greatest impact on their adoption and management. After reviewing the various options themselves, we then explore how specific policy constraints pertaining to the availability and usefulness of energy data, the capability of energy systems to respond to extreme events, the ability of local communities to facilitate resilient energy choices, and other considerations affect energy system resilience (Section 5).

4.1 Conservation

There is wide agreement that conservation-based options should be given high priority and provided with near-term incentives to hasten their adoption due to their co-benefits for water supply stabilization and greenhouse gas emissions reduction. Despite such priority, however, meeting California's future demands for electricity—including peak power—will likely require a combination of new supplies and improved transmission and distribution facilities, in addition to enhancement of demand-side approaches. Critical to conservation efforts will be adoption of approaches that encompass not merely electricity savings but that address the water-energy nexus as well. Conservation and passive-cooling strategies, such as use of fans and flow-through ventilation, can reduce electricity demand by raising the average temperature threshold at which air conditioning is commonly turned on [23]. This is important because increases in ambient air and water temperatures reduce the thermal efficiencies of thermoelectric power plants reducing, in turn, their power output while increasing fuel consumption [24].

With respect to this energy-water nexus, an important strategic factor that should be taken into account is the connection between energy and water use and thus, the possibilities for conjoint energy and water conservation. Various technologies and approaches have long been recognized as harboring the potential for water and energy savings – an issue of growing importance in light of the impact of climate change on more frequent occurrence of drought. Specific technologies and approaches that can save both energy and water include drip and micro irrigation technologies and increased agricultural conjunctive use programs with urban areas. A critical tradeoff is that, unlike urban water systems where water conservation almost always brings about energy conservation, agricultural water conservation may in some instances lead to increased energy demand. Reuse of tailwater, for example, requires installation of additional pumps (although it may also reduce long-distance water diversion), while drip and micro-spray irrigation need more electricity than other irrigation methods [25].

With further respect to water savings and energy conservation, major gains are possible within the water utility sector. Reducing energy consumption at water and waste water treatment plants, and in water conveyance and distribution systems, can serve as major conservation vehicles in California (water-related energy use consumes nearly 20% of the state's electricity). Achieving energy conservation in this domain will require adopting more energy-efficient and energy-extracting technologies at water and wastewater treatment facilities, adoption of water-efficient technologies in distribution and treatment systems (e.g., use of efficient pumps and deployment of on-site waste-to-energy conversion facilities such as digesters and combined heat and power systems); and adoption of hot water end use conservation measures in residential and commercial sectors [25, 26].

There are tradeoffs with respect to all these options. Some measures projected to provide greater water supply in California (e.g., desalination) are energy intensive – although some contend that this intensity will lessen over time. Over the long-term, improvements in desalination technologies – as well as the potential for renewable desalination through solar energy applications – may result in energy savings as well as resilient water supplies ([26]. There are also financial barriers to adoption of these technologies. Some water utilities have only limited access to federal and state public funding sources and the rate structure of many water agencies impedes their ability to amass funding sufficient for technology purchases [27].

Finally, some suggest that more aggressive energy efficiency and demand response targets for California's investor-owned utilities such as those enacted by the California Public Utilities Commission (CPUC) can provide substantial "cushioning" of the electric power system against the effects of higher temperatures. An explicit CPUC goal is promoting development of so-called next-generation energy efficiency technologies and strategies. CPUC's Long Term Energy Efficiency Strategic Plan, as well as AB 758 addresses needs to retrofit existing buildings, for instance, as well as to promote so-called "green buildings" as a comprehensive means of minimizing the energy, water, waste, and transportation impacts of the building sector. While these proposed measures are more long-term in scope [4], some examples of feasible near-term actions include reducing urban heat island effects with the use of more reflective surfaces for roofs and pavement and planting trees to shade homes and buildings [28].

As discussed in Section 3, a combination of *known unknowns* and *unknown unknowns* can influence energy demand, and thus, pose potential barriers to conservation, including temperature and other weather conditions, population growth, changes in economic activity, energy prices, consumer behavior, conservation program effectiveness, and the characteristics of energy-using equipment. For example, while the effects of rising temperatures on overall energy demand are difficult to estimate (a known unknown), it is expected that where cooling currently accounts for the largest share of energy use in residential, commercial, and industrial buildings, such as in parts of Southern California, increases in cooling demand will exceed declines in heating, with net energy use in buildings expected to increase. The *unknown unknown* in this case is the number of new buildings that will be constructed over time [29].

4.2 Renewables

Renewable energy sources are often heralded as being smaller-scale and more easily distributed in their deployment – thus, affording more flexibility with respect to climate resilience [24, 30]. By contrast, large coal and nuclear plants are more vulnerable to blackouts, necessitating that grid managers have sufficient generation and transmission reserves on hand to immediately replace their output. Moreover, when shut down, coal and nuclear plants often require repairs that take several days or weeks before they can resume operation. By contrast, some renewable technologies such as rooftop solar panels and wind turbines rely on smaller, more distributed units, reducing impacts on the grid when weather damages them. And, many renewable energy facilities have weathered storms and heat waves better than conventional power plants. Cost-competitiveness with fossil-fueled electricity generation has also come close to realization without further subsidies: another important consideration for IOU planning [31].

The ability to develop and demonstrate utility-scale and distributed renewable generation, as well as combined heat and power technologies, in a timely manner is an important component of resilience. This includes the ability to use organic resources such as biosolids from wastewater treatment facilities, biogas from landfills, and biomass from forests and agricultural lands. Only through actual demonstration can the performance, cost effectiveness, environmental sustainability, and beneficial grid functions of baseload and dispatchable renewables be tested. For some technologies, innovative ways of testing and demonstration may be required – such as modeling the impacts of climate change on renewable sources of energy (e.g., changes in wind patterns).

In addition to scalability, there are two other slated advantages for renewables. The first is lower risk to water supply. Wind turbines and solar panels are more resilient to drought and heat because they do not require water to produce electricity. These technologies offer an important solution for regions with limited freshwater supplies, or with high concentrations of thermal plants that have run into problems related to high water temperatures. Dry-cooling systems, which use air instead of water, can dramatically reduce water use at thermal power plants. Coupling these systems with renewable technologies such as concentrated solar and biomass can dramatically reduce carbon emissions and water use [24, 32, and 33].

Second, renewable energy reduces fuel supply risks. Renewable resources are far less vulnerable to interruptions in fuel supplies stemming from extreme weather, because most renewables do not use fuels that must be extracted, processed, and transported. The fossil fuel supply chain, in contrast, entails many steps that are vulnerable to the effects of climate change. Drilling for fossil fuels and producing them often require freshwater resources, for example, which are expected to decline with climate change in many regions and some seasons. And the delivery of oil, natural gas, and coal requires transportation networks such as pipelines, railroads, and waterway barges—all vulnerable to the effects of climate change [32, 33]. Because most renewables do not rely on fuels that are subject to price spikes, they also add price stability for consumers. Some contend that the impacts of climate change on the electricity system could be mitigated by an increased penetration of photovoltaic (PV) systems, which reduce the effects of peak demand because this energy source closely matches the diurnal demand for electricity [8, 28].

There are some constraints on these purported advantages of renewables with respect to climate resiliency, however. Hydropower, bioenergy, and concentrated solar power can be affected by changing precipitation patterns, increasing frequency and intensity of drought, and higher temperatures [13]. As noted in the task 4 chapter, energy production from these sources is only available if the net available supply is positive. Regions which have a negative water balance cannot – without difficulty – support the water needs of solar thermal and geothermal development. While it is possible for water to be imported from other regions to support a solar thermal and geothermal power plant (assuming there is water available to divert), solar thermal and geothermal power plants are not often sited near water conveyance and distribution pathways and, thus, typically utilize groundwater to meet their needs [34, 35].

A policy constraint affecting renewables is the extent to which climate change considerations are incorporated into planning. Almost no hydropower planning or operating entities currently incorporate climate change effects in future planning documents, and few changes in operation are underway or anticipated. As of a decade ago, the two investor-owned utilities in California with significant hydropower resources were very involved in climate change research. Operators of water systems where water supply and flood control are primary objectives were not as focused on this issue [36]. Uncertainties surrounding the science appear to be a major factor limiting incorporation of future climate change – a continuing challenge even today (Section 7). Moreover, IOUs and water utilities are already equipped to manage a highly variable water resource. This may impede a sense of urgency in revisiting operating procedures.

Similar issues arise with respect to both solar photo-voltaics and wind power. While photovoltaic (PV) electricity generation and solar water heating are suitable for most of California, solar radiation, the energy source for these systems, may be adversely affected by climate change. Increased CO2 concentrations are associated with increased cloudiness, resulting in decreased levels of daily global radiation availability in the range of 0 to 20 percent [37]. For wind generation, at least one study linking general circulation model output to local weather in a doubling of carbon dioxide scenario predicts windier conditions in parts of the Bay Area and less windy conditions further north. In the event, increased variability in wind patterns creates additional challenges for accurate wind forecasting for generation and dispatch planning and wind generation facility siting [4, 20]. Unsurprisingly, one area of emerging consensus among IOUs regarding renewables as a means of ensuring long-term climate change resilience is the need for more demonstration projects to validate the comparative performance and environmental benefits of both baseload and dispatch-able renewables [4].

4.3 Smart Grids and Climate Change

The concept of the smart grid as a vehicle for climate change adaptation and energy system resilience has been gaining traction among a wide segment of energy policy observers over the past several years [9, 24, 38, and 39]. Smart grid technology offers climate mitigation benefits through enhanced monitoring and accounting of electricity generation and use. These can result in social changes and improved efficiencies in how individuals and communities manage and relate to electricity. While potentially valuable for climate adaptation, however, continuous system-wide monitoring and local islanding would be needed to make smart grids more robust in the face of extreme climatic events – especially since any grid, smart or not – is subject to carrying less current, and to operating less efficiently when ambient air temperatures are higher, as is expected under climate change. Grids can also be vulnerable to damage from more intense and frequent storm events or wildfires [24].

Despite their important advantages, there are institutional and policy considerations that must be embraced if smart grid technologies are to serve as means of reinforcing electrical system resiliency in the face of climate change. For one thing, the smart grid vision embraces varied and sometimes divergent goals and aspirations – including climate, air quality and water-use considerations. There are also potential tensions between mandates to protect local landscapes versus efforts to develop large-scale renewable energy projects or transmission lines, and whether large-scale centralized power generating facilities should be developed versus smaller-scale decentralized ones [38].

Another policy consideration is that the “smart grid,” while promising enhanced reliability and efficiency can – as one study points out – introduce concerns over privacy and even “cyber-physical interdependence.” In effect, every grid is ultimately controlled by human operators who are subject to error and mistake – some of which can, at critical times, trigger system “blackouts.” In addition to accidental mistakes, deliberate attacks launched remotely raise cybersecurity concerns associated with smart grids and opening up critical infrastructure to “hacking” and related threats. In short, our understanding of the interactions between human operators, protocols, automatic controls, and physical grids remains incomplete [39, 40].

Whether and how these different priorities can be integrated into the smart grid vision and its further development in ways that optimally align climate mitigation and adaptation with other societal objectives remains an open question. Various combinations of centralization and decentralization could contribute to deep GHG emission reductions and enhanced resilience for climate adaptation. An example is afforded in Task 7 through the option of energy storage through the use of a mix of pumped-storage hydropower, Lithium-ion batteries, and 8-hour flow batteries. Progress on increasing the installed capacity of battery storage energy by a factor of between 5 and 10 can be an important means of empowering communities to move to a lower-carbon and less vulnerable local energy system.

Proponents of smart grid deployment have reasons for favoring centralization or decentralization that transcend concerns with climate change – including system reliability and efficiency – key components of infrastructure resilience [41]. While climate objectives can be integrated into both centralized and decentralized systems, climate goals cannot ultimately be achieved without changes in the ways electric power is produced and consumed. Given the scale of the climate problem, social as well as technical changes in energy systems will be required. When considering such transformative change a fundamental challenge is the extent to which incremental improvement and broader system transformation can be reconciled [39].

In summary, a key *known unknown* with respect to smart grids and climate change resiliency is that the smart grid concept remains – for many – an idealized long term vision that requires practical and steady “smartening” of existing power systems. This entails IOU investment in infrastructure upgrades as particular technologies mature and their deployment makes sense within the logic of existing institutional, market and regulatory frameworks. Whether such investment capital and political will is present will depend on external factors including the overall cost effectiveness of proposed infrastructural and technology changes.

A key *unknown unknown* is the fact that smart grid technologies have the disruptive potential to transform the way we make and use electricity, achieving a step-change to address multiple energy-related problems. Until climate goals are explicitly embedded within formal electricity system decision-making structures, however, smart grid development may actually perpetuate the dominant growth paradigm of sustained increasing electricity generation and use [39]. All of these issues must be encompassed in considerations of climate resilience.

5. Toward a Roadmap for Resilience – Policy Reforms

To ensure the resilience of California's energy system in the face of climate change, several policy changes have been suggested in the literature. In the following sub-sections we discuss five of these suggested changes. These are: 1) improving the quality and relevance of energy-related data for long-term planning (including data on water integral to energy system operation); 2) enhancing the collection and management of information to facilitate its ease of retrieval and use; 3) strengthening the capability of energy systems to operate in the face of extreme events; 4) enriching community engagement in energy decision-making; and, 5) improving the adaptive capacity of energy systems and related infrastructure. Reforming the energy system in ways that help its operations better comply with environmental justice (EJ) objectives is considered so vital that we discuss this in a separate section (Section 6).

5.1 Data Quality and Availability

Among the most salient of data need for electrical system resilience is enhancing the accuracy of water-use estimates for individual power plants, conducted for a variety of technologies and cooling systems currently in operation or expected to be deployed in the future. Improvements in this domain will help IOUs better understand how climate change and variability could impact future water use [2, 4]. While some of these improvements are already being undertaken by IOUs and public agencies, more needs to be done.

Specific information needs in this domain include estimates of water use associated with energy extraction, processing, transportation, and electricity production. This information is vital for undertaking highly-accurate life-cycle assessment of water consumption for power generation among various fossil and non-fossil-fuel energy sources. High-resolution data on both energy production and water use can not only better help IOUs and others gauge the water dependency of various energy sources but, as appropriate, it can help identify ways to "decouple" energy systems from vulnerable water supplies, producing numerous regional benefits here is California and elsewhere [42, 43].

Currently available data on thermal discharges from power plants is deemed by some as "insufficient to adequately assess their impact on in stream temperatures, or their subsequent effects on aquatic ecosystems and biodiversity" [44]. Others conclude that new, consistently applied indicators are needed to empirically assess coupled water–energy systems and to identify energy-water vulnerability hot spots. Such efforts would enhance energy infrastructure resilience and system-wide planning [38].

Improving data quality and relevance also hinges on ensuring that data are accurate, consistent, and frequently updated. There is evidence that despite extensive collection, screening, and harmonization efforts for assessing water use impacts, water estimates for many generation technologies and energy life cycle stages range widely. Moreover, water withdrawal and consumptive use data in the U.S. is not always timely in its currency or usefulness. In short, consistently applied indicators are needed to empirically assess coupled water–energy systems and to identify hot spots of energy-water vulnerability [38, 44]. As an illustration of the complexity of this issue, table 2 depicts the range of energy intensities associated with different water uses in California – an example of the type of information critical to making energy and water systems more resilient in light of climate change [42].

Table 2 – Observed Energy Intensities for Different Supply Sources in California (kWh/MG)

				Range of Energy Intensities Observed (kWh/MG)				
	Functional Component	Primary Energy Drivers	Energy Intensity From Prior Studies	Northern & Central Coast	Central Valley	Southland	Desert	Statewide
Supply	Local Surface Water	Pumping		152 – 1,213				152 – 1,213
	Groundwater	Pumping	537 – 2,272	1,712 – 2,924	906 – 1,990	1,415 – 2,552	2,169 – 2,652	906 – 2,924
	Brackish Desalination	Treatment	1,240 – 5,220			1,415 – 1,824		1,415 – 1,824
	Recycled Water	Incremental Treatment	300 – 1,200	1,072 – 2,165		1,153 – 3,410		1,072 – 3,410
	Seawater Desalination	Reverse Osmosis	13,800					

Source: Bennett et al., 2010a

Noteworthy is how the estimated range of energy intensities for different water sources varies with respect to source of water supply, and with regard to region. In part, this reflects varying hydrological and climatic conditions. Such variation will likely be magnified by climate change.

5.2 Data & Information Collection and Management

Different metrics are used to describe the state of inputs and capacities for energy facilities, as well as localized energy and water supply systems. Moreover, these metrics are frequently neither standardized nor interchangeable. And, since data are collected by different organizations for different purposes, they do not always easily facilitate analyses in support of energy system resilience. Specific needs for improving collection and management of data include: being able to efficiently compare – and to quantify – options for resilience; quickly determine if data are credible and salient for addressing particular problems; and, ensuring data are easily store-able and retrievable to ensure its availability when and where it is required for decision-making [16].

A recent U.S. Department of Energy/University of California study noted [18] that in both the energy and water sectors, data on system operations is spread among disparate databases, belying the need for some kind of integrated data system accessible to IOUs, government agencies, and other stakeholders. An important challenge in instituting such a database is protecting data privacy and security. Developing an accepted methodology for anonymizing data, and providing a secure architecture and central repository for anonymized datasets are key components for achieving both. The objective should be to enable IOUs, researchers, local and state agencies, and the public to leverage large data sets while assuring that proprietary and personal information is secure – in ways comparable to that of the U.S. Department of Energy Buildings Performance Database. Agreement will also be needed as to the types of data that are publicly released versus those available by pre-arranged request. Such an archive could be housed in a neutral third-party site such as one or more UC campuses or other entities – thereby conferring legitimacy to the repository.

In addition to accessibility, standardization of data types and their resolution should be instituted to specify the types of data to be collected for energy and water systems, their desired resolution, measurement method, and clear conversions between methods. Existing data in different databases contain different data types that may be measured differently and are not synchronized in terms of temporal resolution and data formatting. Electric system operational data (i.e. generation, load, transmission/distribution system power flows) are measured and stored at hourly timescales or shorter, whereas water system operational data (i.e. water supply, water demand, reservoir flows) are usually measured and stored at daily timescales.

A further constraint on data management and collection is organizational resources. Some IOUs may be able to collect detailed information on their system as a result of having an extensive sensor network, enabling collection of data such as real-time power quality measurements in the electricity system or nodal pressure and flow measurements in the water system. Other utilities may not have this capability and will need assistance, perhaps through a third party.

5.3 System Capabilities and Performance in the Face of Extreme Events

As discussed under task 3, hydrological shifts predicted under climate change will likely impose adverse impacts on reservoir management and, thus, to hydropower contributions to power generation. Greater runoff in winter and spring requires strategies to manage increased flood risk and hydropower performance, while high inflow conditions will decrease flexibility for choosing generation versus spinning reserve. These effects are only one problem. Adverse impacts on other renewable energy sources, as well as on grid reliability, may also be expected. As we have discussed, the energy sector must adapt to these by diversifying supply sources and investing in technological change to further expand its portfolio of demand and supply options.

The goal of improving energy system resilience, however, is not only about ensuring reliable generating capacity. Other justifications include ensuring that communities remain safe, secure, and productive in the face of extreme events and protecting environmental resources [4, 24]. While the literature on outcomes of energy system resilience reflects these goals, and includes many potential outcome metrics, it does not provide much clarity about *how* to adjust capabilities and system performance to achieve these objectives. This is so for three reasons. First, the types of extreme events forecast under climate change not only affect demand for power, but they also pose impacts upon supply sources in ways that are difficult to foresee or plan for. Key transmission corridors are likely to be vulnerable to increased wildfire frequency, including those transmission lines that bring hydropower generation from the Pacific Northwest during peak demand periods. In addition, much of the state's energy infrastructure – including substations, transmission infrastructure and up to 25 current coastal power plants –may be at risk from flood or sea level rise-induced inundation – see Figure 2 [45]. Lessening these vulnerabilities will require improving design standards for various components of the smart grid, as well as adopting special protective measures against lightning, wildfires, wind, flooding, and other extreme events [37].

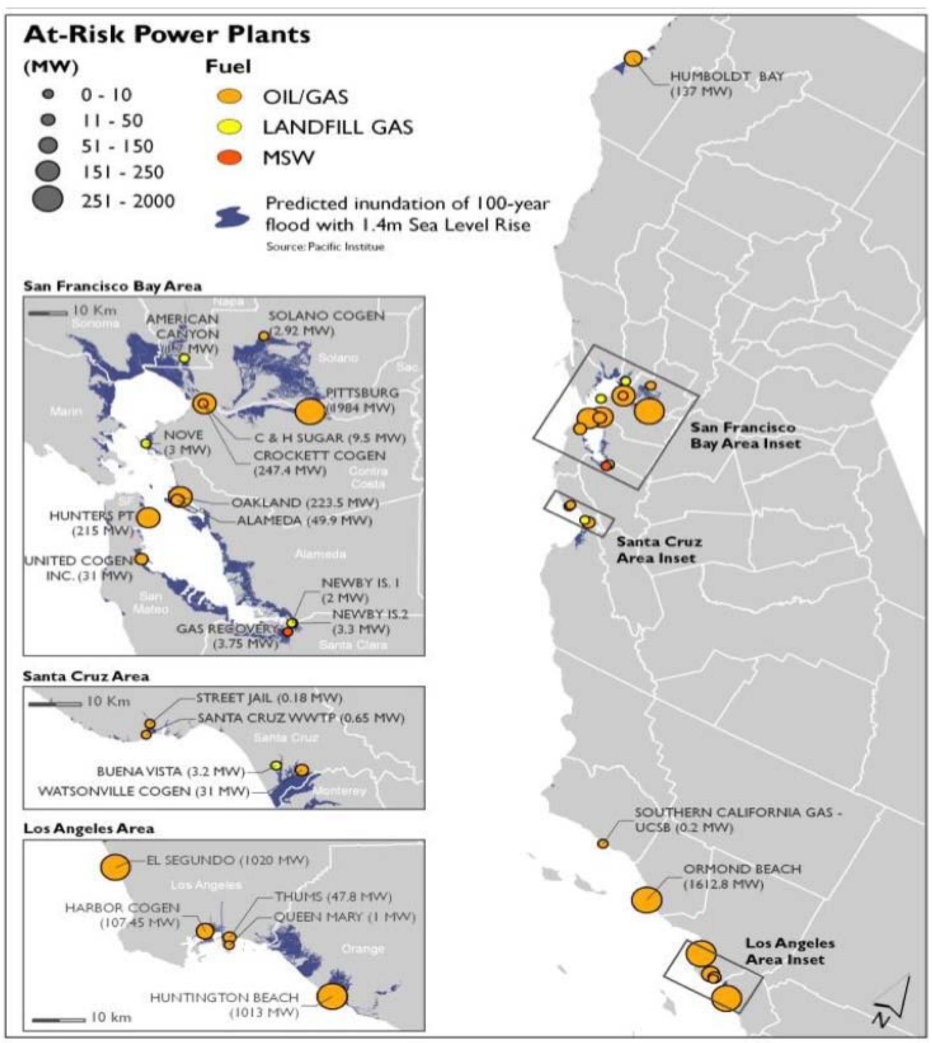

Figure 2 – California Power plants potentially at risk from a 100-year flood with sea level rise of 1.4 meters

<u>*Source*</u>: CEC 2012; reproduced in: U.S. Department of Energy. U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather, Washington, DC: DOE/PI-0013, June 2013.

Second, increased electricity demand – particularly during warmer weather periods (see Section 3), will likely impose significant stress upon both generation and distribution systems. Increases in peak demand projected to occur simultaneously across many regions of California, adding to concerns about the reliability and structural stability of the energy grid to supply the needs of all sectors and regions simultaneously. Extreme heat periods are not the only concern: so are population and economic growth. While per capita electricity use in California has been flat since 1975, in part because of enhanced energy-efficiency programs, further technological advances will have to offset increases in demand due to these growth factors [23].

Third, to fully understand and respond to these vulnerabilities, a coordinated effort must be undertaken to establish an evidence base of vital metrics for inputs, capabilities, and performance. This evidence base can serve as a means for modeling the complex technical and social interactions through which energy systems support public safety, prosperity, and environmental protection. While such an evidence base can enhance energy system performance, at the system and regional levels metrics have not been well defined, and performance data on capabilities have yet to be regularly collected.

In sum, improving IOUs' capabilities to recover from extreme events is difficult. For complex energy systems there is no consensus about what the core capabilities for a system or region should be [46]. Several measures now underway may help to enhance resilience. For instance, reservoir management could be improved with the use of modern probabilistic seasonal and short-term hydrologic forecasts and numerical decision support tools. Some suggest these tools will improve the capacity to cope with long-term climate change [8, 46, and 47].

5.4 Community Engagement

An important challenge in developing a roadmap for energy policy resilience in California is engaging communities as well as IOUs in decisions regarding climate adaptation. Resilience is a community-level issue for four reasons. First, a long-standing practice for energy and water decision-making in the Western U.S., particularly in California, is centralized, federally directed decision-making that has resulted in the building of large-scale energy and water provision systems at national expense, but with the strong support of local interests. This has been especially true with respect to hydroelectric facilities conjunctively attached to infrastructure that harnesses water for flood control and irrigation. The legacy of this decision-making system persists today in what is commonly termed *distributive politics* – the use of taxes and direct benefit transfers on behalf of identifiable regions and groups [48]. While distributive politics originates in the desire to be politically accountable to powerful interests and voter blocs, it can adversely affect community engagement in two unforeseen ways: 1) by allocating certain benefits to some regions but not to others; and, 2) moving decision-making away from localities toward distant entities viewed as less accountable to local attitudes or pressures [48]. Both issues affect under-represented groups (see Section 6).

A second reason energy system resilience is a community-level concern is because urban areas impose special demands on electricity systems. Aside from the concentrated need for electricity in cities, which poses infrastructural stress during summer-time peak loads, urban heat islands exacerbate heat wave impacts by increasing electricity demands for cooling. This effect is especially pronounced in lower income neighborhoods where higher-settlement density, lack of open space, and sparser vegetation prevail [3].

Third, communities play an important, if under-stated, role in implementing climate change resilience programs as well as in overall electricity demand. This role ranges from local government decisions regarding spatial planning, zoning codes mandating elevation requirements for infrastructure siting (e.g., preventing construction of electrical facilities in flood-prone areas), and general responsibility for imposing building regulations [3]. The latter includes requirements for fortifying against hazards (e.g., flood or wind resiliency), mandated energy consumption standards intended to moderate peak demand during heat waves, and energy conservation requirements such as use of improved insulation or green roofs – especially in commercial properties – and initiatives to strengthen local climate resilience.

Fourth, energy system resilience is a community-level concern from a normative standpoint. *If* decision-makers seek to enhance the resilience of energy systems in the face of climate change *then* – as considerable research has shown – proactive, as opposed to reactive, local approaches to decision-making are required. A growing body of literature contends that robust measures to strengthen energy systems require locally-initiated efforts to: promote holistic approaches to managing risk and assist in decentralized community-led activities that are flexible, publicly acceptable, environmentally just, creative as well as innovative, and *reversible* if ineffective [2, 16, 37, 49, and 50]. Some expand the notion of resilience in this context to mean not merely the capacity to recover from unforeseen, external stress, but the ability to "bounce forward, not just back" – a characteristic sometimes referred to as transformational capacity, or the ability to embrace experimental thinking [49].

Of special relevance to California is that in regions where the general public is highly-attuned to climate change, and views it as a bona fide threat, collaboration between private sector IOUs and local communities has been easier to initiate [51]. This may help to explain why a number of conjoint efforts have been successfully occurring among IOUs and local communities to strengthen the resilience of energy systems in the face of climate change. Some IOUs in the Bay Area and elsewhere are actively engaged with local community stakeholders on climate change adaptation projects that assess vulnerabilities from superstorms, coastal flooding, and energy infrastructure disruptions. Moreover, some local communities are assessing their vulnerability to climate change and exploring how to fortify assets most affected by sea level rise and storm events by collaborating with IOUs. These conjoint efforts can enhance the resilience of both communities and IOUs with regard to climate risk management [52].

5.5 Research Needs for Adaptation

Research on energy system resilience in California in the face of climate change is a ubiquitous enterprise. IOUs, research institutes, government agencies, and universities have been investigating elements of this issue for quite some time, and more analyses on the impacts of climate change have been undertaken in the state than probably anyplace else [53]. Wide-ranging studies are being conducted on the probable impacts of climate change and extreme weather on energy systems and water. Additional research is also being pursued on technologies for adaptation, their economic benefits and costs, the incentives for behavioral change with respect to energy use, and the feasibility of various policy options to achieve resilience. Given the wide consensus on needs for adaptation, however, there is growing appreciation for targeted research focused on how to improve the adaptive capacity of energy systems and their related infrastructure, especially since relationships between energy, water, and population are increasingly recognized as constituting a global challenge (Table 3).

Table 3 – Population, energy consumption, and water consumption for energy – 2005-3050

World	2005	2020	2035	2050
Population (million)	6290	7842.3	8601.1	9439.0
Energy consumption (EJ)	328.7	400.4	464.9	518.8
Energy consumption (GJ/capita)	52.3	51.1	54.1	55
Water for energy (billion m^3/year)	1815.6	1986.4	2087.8	2020.1
Water for energy (m^3/capita)	288.6	253.3	242.7	214.0

Source: Adapted from WEC (2010, table 1, p. 50, various data sources).

Source: UN World Water Development Report 2012

Three distinct avenues of investigation are especially valuable for adaptation: 1) estimating the impacts of climate change on existing energy infrastructure and its supporting resource base (e.g., water supplies); 2) determining how different energy technology targets, combinations of technologies, carbon budgets, and energy policy proposals (what are sometimes termed “scenario-driven settings”) affect water withdrawal, consumption, and energy use; and, 3) prospects for actually adopting various adaptation approaches, including so-called “soft adaptation” approaches or “green infrastructure,” (e.g., using wetlands instead of, or to complement, the flood protection afforded by levees).

While we know much about the impacts of climate change on the state’s energy supplies and likely future demands – as previously discussed – there is much we still need to learn [4]. As noted in task 4, for instance, and as discussed in previous sections of this chapter, water availability is a limiting factor for the utilization of virtually all energy sources – including many renewables. For hydropower, meanwhile (which accounts for nearly 15% of the electricity consumed in California, of which 62% is produced in-state), high variability is already a fact of life given the periodicity of dry and wet years [14].

Meanwhile, solar thermal and geothermal resources – components of a low-carbon based electricity portfolio – are also constrained by the spatial distribution of water availability. For California, this is especially important since the high quality solar thermal and geothermal resources are concentrated in the Colorado River and South Lahontan regions: areas that are thought to face significant water-constraints in the future and that will need to reduce future water demands to free up water allocations for these renewable energy sources. Efforts to develop integrated water/energy modeling platforms “that can facilitate tailored water-energy analyses based on a detailed representation of local conditions” are proceeding apace. Such investigations may afford policy-makers the opportunity to consider feedbacks between energy system development and changes in water policy or infrastructure so as to assess the long-term consequences of decision-making in both sectors [14].

Second, as previously noted, another important research need is scenario-driven assessments of how energy technologies and policies affect water withdrawal, consumption, and energy use. There remains much in this domain we need to learn. Different scenarios may generate divergent regional impacts on water resources available for electricity supply. One product of such research could be the ability to design adaptation strategies comprised of a broad portfolio of mitigation, adaptation, and technology approaches. Adaptation and mitigation approaches should follow the guiding principle of “resilience” – enhancing the capacity of systems to operate under a range of future environmental and socio-economic conditions that are anticipated to be possible and plausible but cannot be predicted with certainty [8, 37].

Third, a key research need is reducing scientific uncertainty so as to fortify public acceptance of measures requiring economic sacrifice. Uncertainties surrounding the timing and extent of climate change impacts affect people’s willingness to support costly programs. While overall global impacts of climate change are starting to become clearer, local impacts remain uncertain. Moreover, because the long-term benefits of adaptation are largely local to regional in scale (while the costs are more immediate and often borne by individuals), there is a critical need to develop information and education strategies to make people aware of the need for adaptation. Greater awareness should increase support for changes in individual and organizational behavior, including greater use of energy conservation tools [9]. However, any approach to achieving energy system resilience will affect different groups unequally. The implications of this fact – and measures taken to mitigate this inequality – must be borne in mind as California reckons with climate change.

6. Environmental Justice and Energy System Resilience

Environmental justice (EJ) is an essential consideration in energy decision-making in California. With regard to the formulation and implementation of policies and guidelines pertinent to the regulation of electricity markets, it is a very high priority. The California Energy Commission’s EJ policy prescribes that public participation in the power plant review process “is assured through opportunities for the public to be informed about and involved in the review of a proposed project. Public participation, including open and effective dialogue with stakeholders, fosters relationships, provides a forum to address concerns, and helps to promote actions that minimize impacts on the surrounding community and the environment as a whole” [1].

From the perspective of energy system resilience, EJ is especially pertinent because *resilience*, as we saw in Section 3, has different implications with respect to the safety, security, and fair treatment of groups affected by climate change as well as changes in energy policies [54]. Previous studies have tried to model impacts upon disadvantaged communities in California in the context of proposals to better adapt California's Independent System Operator or ISO – which oversees the state's electric grid – to climate change. While these studies are by no means conclusive, nor directly translatable to questions of environmental justice and climate-related energy decisions, they do suggest that investments in energy infrastructure, including renewable energy resources, might stimulate job creation, regional income, ratepayer savings, and even generate positive benefits to water use in disadvantaged communities. These studies also affirm, however, that energy markets have traditionally been inequitable in their allocation of benefits and costs to *disadvantaged communities* [55], underscoring the uncertainties that remain to be resolved in order to fully embrace EJ in energy system resilience efforts.

For our purposes, we define a *disadvantaged community* as one that is: 1) disproportionately affected by environmental pollution and other hazards that can lead to negative public health effects, exposure, or environmental degradation; and/or, 2) characterized by concentrations of people of low income, high unemployment, low levels of home ownership, high rent burden, sensitive health, or low levels of educational attainment [56]. The following sub-sections consider not only *outcome* effects but *process* considerations (i.e., how decisions are made).

6.1 Conceptions of Environmental Justice

Defining environmental justice (EJ) for energy systems is difficult. Determining what constitutes EJ with respect to climate change and its impacts on California's energy system is even more difficult given that few studies have examined the equity impacts endured by under-represented groups in developed, highly-industrialized societies [49]. Most studies focus on how efforts to abate greenhouse gases affect international energy services and overall trade flows from rich to poor nations. While this is an issue with important implications for future global resilience in the face of climate change [53], it does not capture the full range of EJ concerns in places such as California. We contend that EJ must embrace impacts to people, the environment, and to the process by which decisions affecting both are made – in *all* societies.

6.1.1 Environmental Justice as Protecting Nature

An equitable framework for managing energy and environmental resources must address economic, racial, gender, religious, age-based, and physical (i.e., disability-related) disparities – as well as the rights and dignity of individuals from diverse cultural backgrounds. It must also address the moral standing of non-human species [54, 57]. A long-standing tradition of environmental justice in the west generally, and in California in particular, takes as its point of departure the importance of preserving and protecting natural resources, including water – and the species and habitat that depend on them. This objective has often taken center stage in proposals to build new impoundments, energy production facilities, and even electricity transmission and distribution systems. There are two basic facets to this argument. The first, articulated by writers such as Mary Austin and Wallace Stegner [58, 59] posits that the intrinsic beauty of our natural landscapes and their awe-inspiring richness and variety shape the character of the region, while also serving to morally instruct its inhabitants in humble living. John Muir's opposition to plans to dam the Hetch Hetchy River to provide water (and power) for San Francisco in the early 20th Century exemplified this argument [54]. The second facet is represented by environmental activists such as David Brower and Edward Abbey, for whom writing about protecting landscape was an act of political as well as literary engagement.

To an under-appreciated extent (given that neither prevented building Glen Canyon Dam, for example), these writers achieved some measure of success. They articulated the position that engineered intrusions on free-flowing rivers through the building of large impoundments obliterated distinctive landscapes – and that they transformed the west into a region overly dependent on a resource-extractive economy. Moreover, Abbey, Brower, and their disciples gave voice to a political movement that, over time, placed advocates of large hydropower projects on the defensive, thwarted some projects (e.g., damming the Grand Canyon), and led to water rights reforms to accommodate the notion of water as a "public resource" which states are now obligated to manage in ways which assure that private "beneficial uses" are balanced against needs for environmental protection [60, 61, 62, 63, 64, and 65].

These voices also gave impetus to attitudinal changes in California by calling attention to the damage and societal inequities of damming or diverting rivers, and in some instances, encouraged efforts to restore harnessed rivers to more "natural" states: a view that has been embraced by local officials who increasingly view waterways as sources for urban recreation and community revitalization. Ironically, these efforts are also serving as a focal point of debate between those who view river restoration as a means of reinvigorating local economies versus those who fear gentrification of the last vestiges of open space available to low-income urban residents as an accessible amenity [66, 67, and 68].

As the urgency of climate change increases, conflicts over how to balance energy system components vital to the state while protecting environmental amenities viewed as irreplaceable will likely intensify. Such conflicts are likely to arise under at least two scenarios: 1) in demands for building additional hydropower sources further upstream within watersheds; and, 2) for fortifying coastal energy facilities through building seawalls or other measures.

6.1.2 Environmental Justice as Protecting People

For energy systems and climate change, a growing EJ concern is that policies intended to abate the production of greenhouse gases – as well as to adapt to a changing climate (e.g., aggressively introducing renewable energy) – may be regressive because they place the burden of mitigation and adaptation costs mostly on low-income households. Some studies suggest that proposed efforts to cut CO2 emissions nationally, for example, could disproportionately impact the lowest income quintile in the U.S. by a significant degree [56]. Californians as-a-whole pay nearly 50% more for electricity than the national average, making it easier to imagine how such concerns could arise. To alleviate such concerns critics argue, states must promote policies that offset such regressive impacts through tax cuts, tax-shifting, public investments in clean energy, or other measures directly benefitting disadvantaged groups.

Pollutant credit schemes under California's current "cap-and-trade" program are deliberately designed to address these concerns. Recent changes boost air pollution monitoring in an effort to pinpoint impacts to disadvantaged communities and invest more heavily in GHG reductions in disadvantaged communities. Moreover, low-income electricity customers enrolled in the Alternate Rates for Energy (CARE) or Family Electric Rate Assistance (FERA) Programs can also receive rebates under the California Climate Credit, or credit on residential and small business energy bills resulting from sale of allowances received by IOUs as part of cap-and-trade [69].

In any event, credit for boosting the adoption of renewable energy in California is clearly shared by a number of entities, and the cap-and-trade program is only partly responsible for the retiring of older, more polluting electrical generating facilities and the dramatic increase of renewable sources. Legislative mandates to compel that half the state's electricity come from renewable sources by 2030, and the CPUC's Electric Program Investment Charge (EPIC) program (Figure 3) are certainly important policy drivers as well.

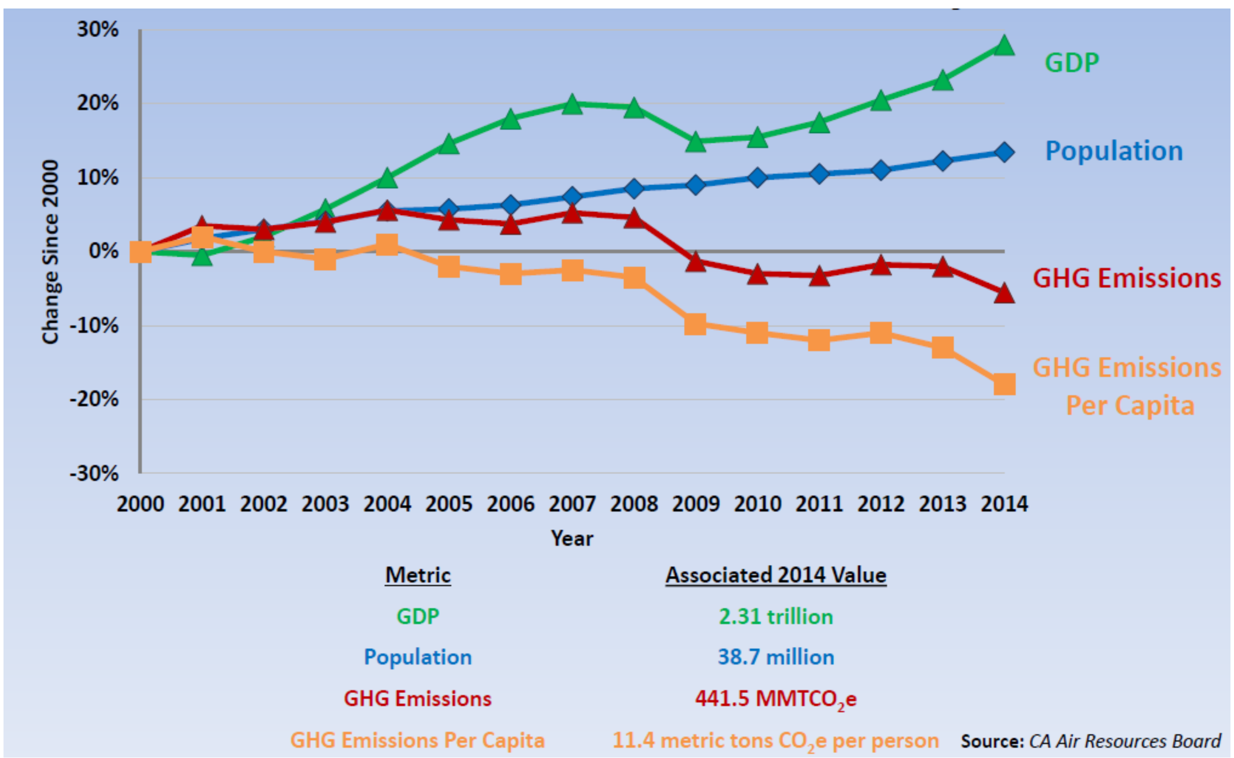

Figure 3 – California GDP growth and greenhouse gas emissions: 2000-2014

Efforts to reduce water use through encouraging its conservation – another policy with important implications for conserving energy (see Sections 4.1 and 4.2) face similar equity challenges. One popular method for reducing household water use, increasing bloc rate pricing or IBR, is an effective measure with EJ ramifications. Under IBR, customers are charged more per unit of water used once their volume of use exceeds an average-derived use or "conservation base" level. However, IBR may not account for ability to pay, especially for those on fixed incomes who, for health reasons, use more water.

In Southern California, communities where this approach has been adopted, or under serious consideration, have witnessed a flurry of concerns including: how individual household budgets eligible for conservation rates are calculated; skepticism regarding whether increased rates are revenue neutral and if customers are rewarded for efforts to conserve; the failure of water boards to communicate details of proposed rate structures; elected officials' frustration over the cost of enforcing conservation efforts and the lack of funds for appliance retrofits given utility and local government budget constraints; and the overall perceived fairness of IBR implementation (13, 70, 71).

As communities, IOUs, and state agencies seek to embrace policy innovations designed to encourage energy and water conservation, speedier adoption of efficiency innovations, and siting of new sources of renewable energy, public demands to consider their EJ implications will grow. Moreover, defining an optimal set of EJ outcomes will remain a long-term challenge. Fortunately, state policies already exist which are designed to ensure that the *processes* by which these outcomes are decided represent diverse groups, compensate for previous harms, and are inclusive in their decision-making.

6.1.3 Environmental Justice and Decision-making

Ensuring environmental justice for under-represented groups with respect to energy and water resiliency and climate change ultimately entails protecting *procedural* justice – the *process* by which decisions over resilience are made. California Assembly Bill (AB) 32 – *the California Global Warming Solutions Act of 2006* – provides a framework for achieving this objective. AB 32 came into existence in part through the efforts of two environmental NGOs that were devoted to EJ issues: the Natural Resources Defense Council (NRDC) and the Environmental Defense Fund (EDF). Most importantly, the Act itself is designed to facilitate the articulation and incorporation of EJ concerns in communities where issues of environmental equity have historically arisen with respect to air quality protection, including by implication energy facility siting, human health impacts, and climate justice [72]. Table 4 depicts these major features.

There are three significant elements in the law relevant for energy system resilience and EJ. First, in the implementation of EJ policies with respect to energy, air pollution, and climate, consultative bodies incorporating members of the affected public, especially those from under-represented communities, are empowered to formally participate on local and state-wide levels to ensure that the full-range of issues relevant to EJ pertinent to regional planning, transportation, housing, facility siting and the like are encompassed.

Second, public health issues, as well as environmental considerations are incorporated into the oversight responsibilities of consultative bodies. And third, there is continuing debate since AB 32's passage as to precisely how the goals of this legislation are to be translated into enforceable outcomes that can be assessed as just with respect to enhancing the health of minority communities, and the accountability of decision-makers to under-represented groups. This is important because it underscores that minority communities as well as local elected officials are recognizing the need to measure the equity impacts of adopting different energy policies, as well as how to assess the benefits, costs, and disparities of a green economy to low income communities of color [72].

Table 4 – Formal environmental justice elements in AB 32

Environmental Justice Element	*Relevant Legislative Language in AB 32*
Environmental Justice Advisory Committee (EJAC)	"The advisory committee shall be comprised of representatives from communities in the state with the most significant exposure to air pollution, including, but not limited to, communities with minority populations or low-income populations, or both."[i]
Public workshops for comment on the development of the Scoping Plan	*Directly specifies* the location of a portion of these workshops as being "in regions of the state that have the most significant exposure to air pollutants, including, but not limited to, communities with minority populations, communities with low-income populations, or both."[ii]
Community Empowerment Amendment	Section 38562 identifies a number of considerations the CARB must address or use as guidance when developing those regulations: including that CARB must "Ensure that activities undertaken comply with the regulations and do not disproportionately impact low-income communities."[iii] In addition, Section 38565, known as the Community Empowerment Amendment (CEA) included language designed to allow low-income communities to directly participate in and benefit from the greenhouse gas reductions regulatory plan that is created as a result of AB 32.[iv]

Source: Sze, Julie. Gerardo Gambirazzio, Alex Karner, Dana Rowan, Jonathan London, and Deb Niemeier. Best in Show? Climate and Environmental Justice Policy in California," *Environmental Justice* 2 (4) 2009.

Prior to passage of AB 32, California had long-standing experience with these questions of procedural justice and policy implementation. Many of the lessons regarding the need for – and effectiveness of – measures designed to ensure open, transparent, and inclusive decision-making for protecting the resilience of vital pubic services have previously emerged in the arena of water policy, for instance. Examples include the struggles engaged in by low income communities-of-color in the San Joaquin Valley (e.g., Kern and Tulare Counties) with respect to the safety of public water supplies. Historically, many rural, low-in-come communities – including unincorporated towns or mobile home parks – have been served by small, private, not-for-profit water systems that are entirely investor-owned.

Despite chronic threats to drinking water as a result of contaminated farm runoff and lack of resources to pay for improvements, pressures to rectify local water systems came about through bottom-up demands of local residents, assisted by non-governmental groups. This is similar to what transpired with passage of AB 32. In part, these demands led to several changes at the state level which require that, when redistricting water utilities, past actions that may have left some neighborhoods without adequate access to water supply or treatment facilities be considered when re-drawing utility district boundaries. If low income communities had been bypassed when decisions to develop water and sewer infrastructure were previously made, or rate-payer decisions formulated, measures to assist low income groups in retrofitting water appliances and repairing distribution systems must now be provided [72, 73, and 74].

As California's efforts to address energy and water system resilience in the face of climate change progress, the need to identify robust and credible EJ *processes* will be a key for achieving desired EJ outcomes. Despite the overall progress the state has made in fostering EJ policies attentive to the needs of disadvantaged and under-represented groups, many of the most important energy and water decisions – as we have seen– are generally exercised through expert power. The Flint, Michigan water crisis of 2016 sheds light on this important issue.

The crisis was partly attributable to the failure of regulators to respond to what they viewed as costly demands by ill-informed complainants. Moreover, the acting city manager was state appointed and, thus, unaccountable to local residents. Coupled with the city's widespread poverty, these factors exacerbated the crisis by denying residents power to affect change [75, 76, 77, 78, and 79]. While no Flint-like crisis has occurred in California, and while the state's energy leaders have gone to great lengths to incorporate disadvantaged communities' concerns into energy resilience plans for climate change [69] similar issues have been raised by EJ advocates. These advocates claim that open, transparent decision-making processes are needed to ensure that individuals affected by energy and water decisions can: participate without intimidation; are given access to information; have their views taken seriously; and, able to attend important meetings at times – and in places – accessible to them [56].

7. Implementing the Roadmap – Roles and Responsibilities

Major investments in policy, management, and financial resources will be needed to implement an energy resilient roadmap. The appropriate roles and responsibilities of different sectors – including IOUs – in fostering these investments and helping achieve reform will be important. We discuss three critical roles: 1) making energy systems more resilient in the face of climate change; 2) undertaking improved planning and assessment procedures; and, 3) ensuring energy system security in the face of uncertainty. At the end of this section, we evaluate the current condition of planning and assessment and energy system security among state policymakers and California IOUs – and offer additional recommendations for improving these elements of resilience. Section 8 provides recommendations for policymakers and IOUs with respect to demand-management and energy supplies, sub-divided by time-period.

7.1. Resilience – a Task for IOUs and Regulators

Resilience is not only subject to various definitions, as discussed earlier, but also has numerous components. For energy systems, three of the most important of these are: 1) supply-side hardening measures (i.e., new, more durable sources of electricity in light of climate change); 2) demand-side responses designed to lessen uses and conserve energy; and, 3) grid "intelligence" and decentralization to fortify distribution systems.

Supply-side hardening measures include constructing reinforced infrastructure or retrofitting existing infrastructure and could encompass, for example, averting coastal zone flood damage by elevating critical facilities or – in the case of transmission equipment – using submersible, saltwater-resistant equipment less susceptible to damage from inundation. It has been suggested that hardening requirements be formalized via technical standards – a long-standing practice among IOUs – that could be issued by industry groups and/or regulatory agencies. IOUs could update existing reliability codes to reflect climate change resiliency considerations while state regulation could hasten improvements to electrical infrastructure. Hospitals and other critical facilities could be required to install backup generators, for example. Moreover, since additional generating and transmission capacity will be required to prevent blackouts during peak demand, greater use of solar powered cooling and distributed cooling systems to provide additional energy for air conditioning during warmer summers could be encouraged. Temporary capacity increases might also be achieved by changing water management practices to secure hydroelectricity production during critical periods.

Demand side measures to reduce energy consumption, especially during peak demand periods, could help "shave" the peak off the energy demand during heat waves and could be facilitated by smart grids adopted by IOUs. Legal reforms by state regulators such as the CEC could hasten not only the adoption of smart grids but also encourage energy efficiency measures, educational and outreach efforts to generate greater awareness of climate change impacts on the electricity sector, and even fund additional research on climate change vulnerabilities. Furthermore, building regulations can help to reduce energy consumption, hereby helping to moderate the peak demand during heat waves. Energy reduction can be achieved through energy conservation (e.g. less intensive usage of air conditioners) or energy efficiency (e.g. newer, more efficient air-conditioning systems) [3].

Smart grids can also improve resiliency in innovative ways. One of the properties that makes electrical infrastructure especially vulnerable to climate change impacts is that it is traditionally centralized: one big generation facility produces electricity that is further transmitted and distributed to a large number of people. IOUs could prepare emergency response plans with future climate change in mind. Temporary, mobile generators could be installed which could be deployed in case of emergency. Employees trained to understand climate risks could be more able to restore service in a timely manner after a storm hits. Moreover, as a component of smart grids, early warning systems that link information about the physical climate system with the energy system could be established to communicate anticipated blackouts or brownouts to the general public, response agencies and other IOUs [3].

7.2 Planning and Assessment for Climate Change

We previously noted the need for various measures to enhance long-term planning for energy systems' resilience. These range from improved forecasting of climate variability and its impacts on energy demand and infrastructure to better deployment of grid resources and dispatching. A further means of improving long-term planning is through adopting a variant of environmental impact assessment – a "climate impact assessment" for IOUs. Such an assessment, advocates contend, could evaluate possible impacts of future climate change on electricity infrastructure by utilizing "the best available data suited to the particular geographic area" [3].

While principal responsibility for these assessments would fall to IOUs – perhaps jointly within a service region – such assessments should be combined with other reporting requirements on infrastructure reliability and proposals for infrastructure investment in renewable energy resources. Because most IOUs would have only incomplete information regarding climate forecasting, such climate vulnerability studies would also require the assistance of agencies and departments involved in long-term weather forecasting. These could range from, e.g., the California Department of Water Resources, the CEC, CPUC, the California Natural Resources Agency and others. The long-term vulnerability of the state's electrical system to climate impacts has already been incorporated into planning by multiple state agencies for some time now and has focused on the effects of increased temperatures on the efficiency of thermal power plants, transformers, and transmission and distribution lines as well as on increased electricity demands [4, 23, and 25]. Meanwhile, studies have supplemented these efforts by focusing on such issues as increased fire risk to transmission facilities from climate change [45].

In addition to these state-level assessments, climate assessment planning would also be required at local levels to better anticipate the impacts of both drought and intense periods of precipitation, to forecast the impacts of climate change on renewable energy sources at regional and local levels, and to more effectively establish effective energy and water conservation plans. A number of California cities already have recruited staffs that are charged with undertaking these types of assessments, while a number of decision-support tools for probabilistic seasonal and inter-annual hydrological forecasting have been proof-tested for the management of hydropower reservoirs [2, 16, 46, 47, 80, and 81].

As noted earlier, there is a need for modeling tools to evaluate long-term interactions and feedbacks between the electricity and water sectors to facilitate evaluation of alternative mitigation and adaptation strategies [6]. In sum, climate impact assessment can not only help California better forecast and anticipate long-term impacts of climate change on energy system resilience, but it can identify gaps in understanding for which additional research is needed.

<u>7.3 Energy Security – Adaptation as a Moving Target</u>

A frequently used descriptor in long-term energy systems' planning is "no regrets:" an approach to policy which implies that regardless of the uncertainties facing nations or regions from climate change, adopting measures that enhance the resilience of energy and water systems has numerous other benefits. For California, a no regrets approach is considered especially prudent by some given the continued occurrence of drought, uncertainties over fossil energy supply availability and price, and the overall environmental and public health benefits accruing from a low carbon-based economy. In part, such a strategy underlies the 40+ year effort on the part of the CEC and CPUC to support research on energy efficiency and clean energy generation technologies that have established the state's leadership in these areas [4].

Achieving a no regrets energy security approach will require focusing on continued innovation in clean technologies. California's acknowledged climate policy goals, discussed earlier, will require that new and innovative technologies be developed and deployed in a smart, efficient manner. Basic energy research, development and demonstration (RD&D) is required to fill critical gaps within the energy innovation pipeline considered the greatest impediments to innovative energy prototypes as well as for supporting innovative entrepreneurs entering the marketplace. Results from RD&D at these critical stages are needed to enable these technologies, including energy-efficient appliances and clean energy sources, to attract investment capital, delineate merits to potential end-use customers, and demonstrate their eligibility for market support subsidies (4) Given current budgetary uncertainties with respect to medium term (2-5 year) expenditures for federal energy research (Figure 4) – it is uncertain how rapidly such critical stages will be met for many of these technologies [82]. While this may not be a problem for technologies and other innovations that have moved beyond the proof-of-concept phase, it may remain a formidable challenge for less mature ones.

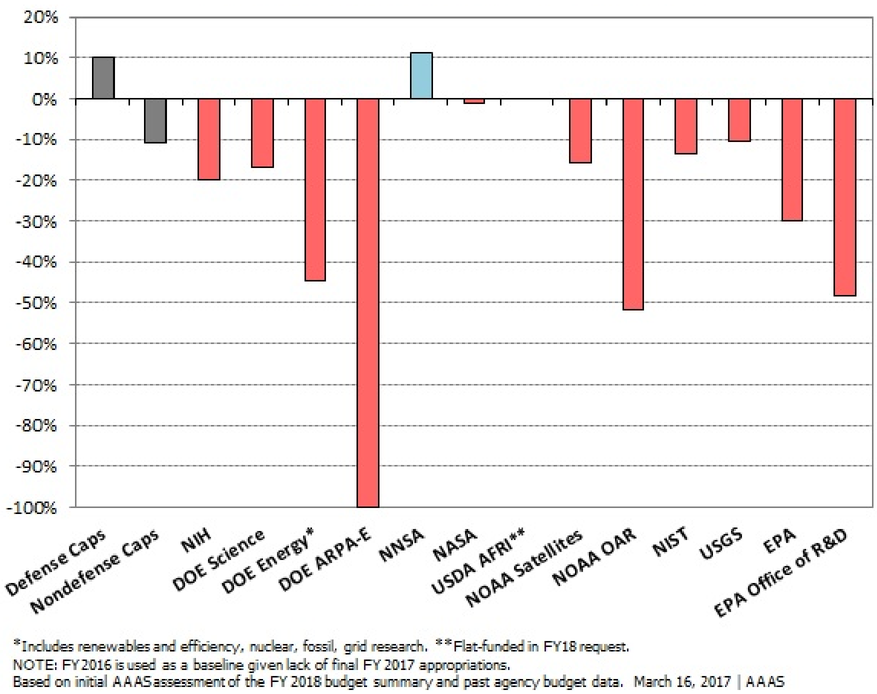

Figure 4 – Federal science agencies and offices – Preliminary estimates FY 2018 request vs. FY 2016 (estimated % change from FY 2016)

Source: Hourihan, Matt, and David Parkes. "With some exceptions, the Trump Administration is seeking major rollbacks across the science and technology enterprise - if Congress agrees to it," American Association for the Advancement of Science News March 16, 2017. https://www.aaas.org/news/first-trump-budget-proposes-massive-cuts-several-science-agencies.

Another important aspect of this problem is the pace of innovation adoption by end-users. While California's renewable energy portfolio standards and other policies are intended to encourage high penetration of technologies to achieve the goal of 50% renewably-sourced electricity generation by 2030, there may be unforeseen challenges in meeting conservation and renewable generation contributions to this goal [24]. One impediment is upfront cost. Short-term costs of adoption may be more important to some users than lifetime operation. For instance, the initial price of a high efficiency air conditioner or other energy-saving appliance might be especially burdensome for lower-income groups, despite long-term, lower operating costs. This raises EJ issues for lower-income groups, particularly if such alternative products are the only ones available to consumers at little discount [2].

For distributed energy sources in those locations where, for whatever reason, wind or solar generating capacity falls short of meeting demand, the gap may have to be filled by fossil fuels in the event that other dispatch-able resources such as hydropower or energy storage cannot do so. Moving power from windy or sunny locations to cities couples distant regions in ways that spreads risk tor grids. Lessening these risks requires the use of complex models to optimize connectivity among communities, generators, and users [40]. In short, there is no dearth of policy challenges that must be monitored, managed and evaluated to ensure energy security – even with a no regrets strategy. These challenges include continued support for advanced research, filling short-to medium term gaps in renewable energy penetration, and meeting the costs (as well as risks to certain groups) from adoption of conservation approaches.

7.4 Current Roadmap: Status and Recommendations – a California Policy Perspective

A general recommendation that emanates from our analysis is that collaboration among IOUs, state and local governments, and community groups will be required to formulate and implement an effective roadmap for energy resilience in light of climate change. Cooperation can "ease the challenge of obtaining funding for resiliency measures" [3] which will doubtless lead, in some instances, to rate increases, as well as decisions regarding direct governmental support, and private loans. The greater the comprehensiveness of this roadmap, the more likely future benefits and avoided costs of resiliency measures can be made transparent.

As noted in section 7.2, many California cities are undertaking local climate assessments using various decision tools. State and local efforts should be inter-linked to the extent possible to reinforce these resilience efforts. Although the state has limited land use authority, the policies it develops in regard to new infrastructure, utility funding, environmental review, and housing allocation are all leverage points that the state can use to assist local governments in growing in an energy-efficient and climate-friendly manner. Recently, the state Attorney General has used the California Environmental Quality Act (CEQA) as a lever to require local governments to consider climate change in general plans.

Additional steps policymakers at various levels can take with respect to planning and assessment and energy system security for climate change resilience are the following:

- ***State policymakers' commitment to a vision for the smart grid should be explicitly tied to climate change resilience***. Efforts to deploy smart grids are the responsibility of IOUs – including communications infrastructure; customer systems; grid operations, control and planning; and renewables and distributed energy resources integration. Nevertheless, the CEC recognizes the importance of ensuring grid cybersecurity and hastening workforce development in visioning its deployment. These efforts should be enhanced by policymakers encouraging education and training on grid technologies in the state's community colleges and public universities [83]. They should also be directly linked to improving workforce literacy on climate change impacts.

- ***Local governments should consider new policies to enhance energy conservation through general plans and zoning codes***. While state law does not require that general plans explicitly address energy issue, some cities and counties have adopted an “energy element,” which specifies local policies regarding energy use and efficiency [2]. AB 32 provides a useful framework for encouraging this inasmuch as it formally promotes partnering with special districts in developing climate action plans, and urges adopting incentives to spur reductions in energy demands [84].

- ***New local ordinances can help promote adoption of energy efficiency and renewable energy innovations, including retrofit conservation and solar access by publically-owned utilities.*** The state’s municipally-owned/special district owned and operated electric utilities, which provide electricity to some 20 percent of the population, can play an important role in promoting renewable energy and conservation programs – thereby *supplementing the efforts of the state’s three IOUs* [2]. Moreover, the state’s Renewables Portfolio Standard (RPS) mandate applies to these utilities as well.

7.5 Roadmap Status and Recommendations – a California IOU Perspective

Numerous measures are already being taken by the state’s three IOUs –Southern California Edison (SCE), San Diego Gas and Electric (SDG&E) and Pacific Gas and Electric (PG&E) – with respect to energy resilience and climate change. These programs encompass both supply- and demand-side measures. We highlight measures being undertaken by IOUs that: 1) incorporate planning and assessment for climate change for long-term energy system resilience; and 2) adapt resilience measures in response to climate forecasts. Specific supply- and demand-side measures being taken by IOUs – as well as further recommendations we offer to enhance those efforts, are discussed in section 8.

The core of PG&E’s climate resilience effort is a multi-pronged program based on the belief that “there is no single approach to building climate change resilience” and that “a holistic approach to better understand, plan for and respond to climate change risks” along with others is a sound approach. Several near-term emergency response procedures to address weather extremes have been adopted and PG&E reviews and integrates relevant climate science – including the recent 2015 collaboration with the Bay Area Council Economic Institute to examine the region’s vulnerability to a climate change-enhanced flooding event caused by an “atmospheric river” superstorm.

PG&E also engages with communities and state agencies on adaptation measures; and is pursuing a multi-year risk-assessment process for infrastructure improvement to better withstand climate extremes [2]. PG&E also routinely reviews global climate change studies such as Scripps studies of climate change along the Sierra and Pacific Coast. Its water management team is planning how to work with runoff change in terms of best hydroelectric scheduling practices. Observed changes over the last few decades, such as increased frequency of earlier snowmelt and greater climate variability, are considered in runoff forecasting and hydroelectric scheduling. In light of greater variability and more intense storms, PG&E now keeps its reservoirs at higher levels [36].

SCE has developed an Adaptation Planning Tool that uses time-series geospatial datasets to display climate hazard projections across its entire 50,000-square-mile service territory and is designed to assess, and thus facilitate planning for, multiple hazards including changes in temperature; precipitation, snowpack, and runoff; sea-level rise; wind; and wildfire. Climate scenarios are based on 2030, 2050, and 2085 time horizons and allows for “downscaling” of various geospatial inputs from general circulation models which will help the utility identify potential climate impacts to all its assets [85]. SCE has also participated in joint studies with the CEC on evaluations of how particulates from the Central Valley and Los Angeles Basin affect precipitation; as well as an investigation of how precipitation processes (cloud physics) change as temperature increases and how those altered processes could impact the SCE’s cloud-seeding program [36].

For SDG&E, following a series of destructive wildfires the utility began collaborating with researchers at the U.S. Forest Service (USFS) and UCLA to conduct a detailed analysis of Santa Ana winds and their influence on southern California wildfires. After a three-year analysis, a “Santa Ana Wildfire Threat Index (SAWTI)” was developed to provide a six-day forecast of wildfire threat based on meteorological and fuel moisture data. Not only does this tool SAWTI measures the likelihood of major fires and their intensity and, thus, threat to energy infrastructure, but SDG&E and firefighting agencies use SAWTI’s forecasts to anticipate potentially damaging fires and allocate shared response resources and identify potential wildfire vulnerabilities to its assets and operations [86].

In addition to urging these programs be continued, we encourage IOUs to undertake these *planning & assessment and energy security-related* steps toward climate resilience:

- ***PG&E should accelerate efforts to adapt water storage impacts from climate change already partly underway.*** These include efforts to calibrate distributed runoff forecasting models to enable improved improve planning and better manage increased variability and extremes. It has also investigated the possibility of new storage projects to mitigate snowpack decline – including pump storage projects, new reservoir capacity, and additional capacity from other energy sources [52].

- ***PG&E should accelerate efforts already partly underway to identify and adapt to risks to its facilities from sea-level rise, wildfires, and other hazards.*** These include enhancing efforts to identify site-specific sea level rise risks and mitigation measures, and risks to its assets from increased frequency and intensity of wildfires [52].

- ***SCE should accelerate efforts to apply its Adaptation Planning Tool to identifying potential climate change risks to all aspects of its operations.*** Consideration should be given to” needed system modifications or upgrades” that could be taken as anticipatory measures before the full impacts of climate change are felt [85], especially in light of potential increases in intense runoff, more frequent snowmelt, and related concerns.

- ***SDG&E should continue to refine, apply, and disseminate its Santa Ana Wildfire Threat Index (SAWTI).*** A significant contribution of this index is the lessons it affords for collaboration between government, academia, and IOUs. Fire agencies, first responders, the public, and the media “now have a (n) operational tool that determines the severity of . . . wind events.” The tool results in a more effective media response and helps the public to become more proactive in effectively responding to wildfire hazard [87].

- ***PG&E, SCE, and SDG&E should continue collaboration with CEC and EPRI on a “common utility perspective on a vision and roadmap” to spur development of California’s smart grid.*** This vision should be explicitly linked to climate resilience through enhancing efforts to develop and implement microclimate forecasting technologies to accurately forecast weather [84]. These efforts will become increasingly important as temperature and precipitation trends change.

8. Conclusions – a Roadmap for IOU Advisory Plans

To assist IOUs in developing advisory plans that account for the specific resources available to them and the characteristics of their load demand, we summarize major options as well as prescribed time periods within which actions may be prioritized. Our objective is to help IOUs better plan investment and technology deployment in their service territories in light of climate-induced vulnerabilities to both demand and supply. Specific recommendations are subject to the needs, resources, and local constraints IOUs face. To wit, it is essential to consider:

- *Vulnerabilities*
- *Specific options to alleviate vulnerabilities* (i.e., resilience components)
- *Policy reforms* (i.e., data needs, extreme events, community engagement, adaptation)
- *Environmental justice*
- *Resilience – institutional roles*
- *Planning & assessment for climate change*
- *Energy security*

Other useful frameworks exist for the purpose of helping decision-makers determine our energy future, and the sources of energy supply that should comprise it. Analysts have traditionally divided the problem of energy into two parts: supply expansion measures, which focus on energy conversion and distribution; and demand side measures, which seek to reduce energy consumption by suppressing use [31]. There has often been robust debate among those who advocate a greater stress upon one of these parts (or sets of measures) as opposed to the other. There is also growing consensus that technical, physical limitation (i.e., climate), and political barriers necessitate that innovations in *both* domains “must proceed in parallel” [2]. Table 5 depicts these domains and their respective impediments, and most importantly, how our analytical framework may be "fitted" to this traditional structure (in bold).

Table 5 – Analytical framework for energy policy (adapted from Hamilton, 2013)

Supply	***Barriers/impediments***	***How overcome (options, policy reforms, EJ)***
	Technical	Investments in RD&D and demonstration activities; integrated decision-making frameworks to assess conflicts and trade-offs for environmental quality, climate change, water conservation, and other relevant national priorities. **(Adaptation)**
	Geographical	Exploit local availability; moving resources to areas of need. **(Extreme events)**
	Economic	Determined by technical breakthroughs; regulatory constraints, as well as price signals & incentives; removal of barriers that impede transition to a climate-resilient energy sector. **(Resilience components)**
	Political	International relations; domestic attitudinal and public opinion; incentives for decentralized power generation that could expand adaptive capacity by decreasing stress on the centralized power generation system. **(EJ issues, community engagement)**
	Environmental	Air, water, land use, human health impacts; widely held public values toward environmental quality. **(EJ issues)**
Demand	Economic	Costs, availability of supply, consumer appetite.
	Political	Integration of climate risk considerations in design, siting, and operation of energy facilities, through measures such as buildings standards and codes, and the review process for replacing or repairing damaged infrastructure. **(Community engagement)**
	Technical	Intrusiveness/privacy issues. **(Data management)**
Cost	Monetary	Market costs, taxes/tax burdens, capital investment availability. **(EJ issues)**
	Security	National security issues, embargoes, cutoffs, dependence on foreign largesse.**(Energy security)**
	Environmental	Air, water, land quality issues/climate change, aesthetic/scenic issues, resource depletion; consideration of the impact of water policies on the energy sector and vice versa **(Planning & assessment)**.

The options depicted in Table 5 are subject to what are termed enabling policies – actions at local, state, or national (federal) levels that accelerate deployment of technologies and approaches needed to build a climate-resilient energy sector in a timely manner [31]. Examples include programs that help to enhance technological innovation, bring new technologies to market (e.g., demonstration projects), or remove barriers to deploying existing technologies.

8.1 Paths to Resilience – Time Frames and IOU Regions

We now enlist this information in an effort to capsulize appropriate actions within prescribed time-frames. Inevitably, some actions cannot be so narrowly constrained and transcend any given time period. Nonetheless, such time-frame scenarios allow IOUs to submit actions to a more rigorous climate vulnerability assessment. For each time-frame, actions are discussed under six major categories discussed earlier: 1) vulnerability assessment; 2) conservation; 3) renewables; 4) smart grids; 5) policy reforms (e.g., information, community engagement); and, 6) environmental justice. Implementation considerations are threaded throughout.

8.1.1 Timeframe I: 2017 – 2030 – Climate Vulnerabilities

2030 is an important "benchmark" for planning for climate change because likely impacts to energy infrastructure are more certain, and investments in resilience more likely to be made "if they are not hampered by the unknown of a longer outlook" (10). From the standpoint of GHG reduction and renewable energy adoption, 2030 is also a target year for the state's climate change goals which stipulate a 40 percent reduction in greenhouse gases by 2030 compared to 1990 levels (in order to contain rising global average temperatures to below 2 degrees Celsius). It is also a target year for the state's implementation of a 50 percent Renewables Portfolio Standard and a doubling of energy efficiency savings [69]. These goals are stipulated by Senate Bill (SB) 350 – *the Clean Energy and Pollution reduction Act of 2015* (see Table 6).

Table 6 – Proposed Scoping Plan Scenario for meeting 2030 GHG reduction goals

Policy	Primary Objective	Highlights	Implementation Time Frame
SB 350[45]*	Reduce GHG emissions in the electricity sector through the implementation of GHG emission reduction planning targets in the Integrated Resource Plan (IRP) process.	• Load-serving entities file plans to achieve GHG emission reduction planning targets while ensuring reliability and meeting the State's other policy goals cost-effectively. • 50 percent RPS. • Doubling of energy efficiency savings in natural gas and electricity end uses statewide.	2030

Source: California Air Resources Board. *The 2017 Climate Change Scoping Plan Update – the Proposed Strategy for Achieving California's 2030 Greenhouse gas target*. Sacramento, January 20, 2017.

There is growing agreement that significant impacts to such factors as mountain snowpack, coastal inundation through sea level rise and – most of all – rising temperatures will clearly and unalterably be visible by 2030. Significant divergence from conditions existing in, say, 2010 will clearly be visible by then. Higher temperatures specifically mean that daytime highs will be demonstrably higher while nighttime lows also will be higher as well (10).

8.1.1.1 Electricity Demand – general policymaker recommendations

For California's IOUs to remain on track to achieve targeted GHG reductions and a 50% renewable power portfolio, adoption of measures to conserve water and energy must continue unabated. This is reflected in proposals to meet most new demands for water through increased conservation and water use efficiency, improved coordination of surface and groundwater management, greater use of reclaimed water, and adoption of new technologies in drinking water treatment and groundwater remediation [69].

As an example the Metropolitan Water District (MWD) provides water to 19 million customers in Southern California. While historically benefitting from inexpensive hydroelectricity from Hoover Dam – used to transport, treat and deliver water to its customers – MWD's contract with the U.S. Government to purchase that power expires in 2017, after which date power costs are expected to increase dramatically. As discussed earlier, the availability of hydropower on the Colorado River is likely to be reduced due to climate change. MWD has been engaged in a collaborative planning process to reduce electricity purchases on the retail market and eliminate greenhouse gas emissions associated with its water operations by 2030 [14].

Other policy reforms with respect to demand-side measures could be considered. Alongside the 2030 GHG reduction goal is doubling of energy efficiency savings from existing building stock. To achieve this objective, engagement with local governments, planning agencies, the building trades industry and others will be required. Equitable adoption of weatherization objectives will require collaboration with community planning agencies and affected groups [69].

Additional Roadmap Recommendations: Three additional steps should be pursued by state policy-makers to attenuate electricity demand – both alone and in conjunction with IOUs. NOTE: these same programs should continue during the 2030-2040 and 2040-2050 periods – with the understanding that their introduction now will create a reservoir of programmatic experience that can be enhanced over time as climate impacts become more pronounced.

- ***Collaboration between IOUs and water utilities should be encouraged to reduce electricity and, thus, water consumption.*** Because some water agencies have limited access to public funding sources to purchase water-energy nexus conserving technologies, efforts to identify funding sources through grants and low-interest loans should be encouraged, and appropriate regulatory relief considered (i.e., more rapid permitting processes for new innovations.

- ***Engagement with local governments, planning agencies, the building trades industry and other stakeholders should be encouraged to hasten adoption of next-generation efficiency approaches.*** State officials should help communities identify opportunities for adopting next-generation efficiency technologies, accelerate retrofitting of older buildings, and promote green buildings. A directory of best practices and successful local experiences could be produced to encourage innovation diffusion. This is important because as building shells become more energy efficient, building loads will become less sensitive to climate change temperature impacts.

- ***Equity considerations benefitting disadvantaged communities – and reducing economic or other burdens – should be encompassed in energy demand programs.*** Programs aimed at reducing GHGs should explicitly embrace the needs of disadvantaged communities in all aspects of their management. Policies should be adopted that reduce GHGs while serving the needs of vulnerable populations and improving the well-being of disadvantaged communities. Programs that currently provide funds and services for GHG reduction in low income communities (e.g., low-income weatherization programs, energy efficiency, renewable energy, ZEVs, transit, housing retrofits) should be expanded to target needy individuals and households to help them reduce energy-related costs.

8.1.1.2 Electricity Demand – IOU recommendations

For Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E), the largest impacts on electricity demand due to climate change are likely to be felt most dramatically in the populous regions of Southern California which encompass their territories. While the largest temperature increases occur in the inland southern areas, the vast majority of the population is located in the urban coastal areas. Coastal southern populated areas can be expected to see an increase in annual electricity demand of between 3-5% for the combined residential and commercial sectors. This will occur due to significant increases in cooling demand during the daytime from increased temperatures, and also causes increased peak demands.

Pacific Gas & Electric (PG&E), meanwhile, has identified the primary climate change risks as encompassing a broad set of problems, ranging from including flooding from storm events to sea level rise, land subsidence, heat waves, changes in precipitation patterns and wildfire danger [52]. PG&E service territory will exhibit increased electric loads due to increased cooling loads, but not to the same extent, percentage wise, as the SCE and SDG&E service territories. The electrification of heating systems, however, may affect the PG&E service territory more strongly than the SCE and SDG&E. This service territory can have larger heating loads during the winter due to cooler temperatures and additionally increased precipitation. Electrification of space and water cooling systems will shift the peak of utility electric demand towards the winter months instead of the summer months.

All three of California's major IOUs acknowledge the importance of demand-side innovation as a vehicle to encourage resilience. The introduction of real-time pricing programs for effective demand response has been one innovation introduced – and should continue. Real-time pricing is being addressed in regulatory proceedings at the CPUC, and the infrastructure is being laid with the installation of advanced (smart) utility meters that provide information about what energy is costing at particular times during the day.

SCE has been field-testing advanced meters and started large scale meter installations in January 2009 through June 2012. And PG&E has been installing advanced meters since 2007 and hopes to install 10 million advanced meters by 2012 [2]. SDG&E has a one-year trial program designed to measure the financial impact of time-of-use programs. In 2016, SDG&E began a program to use dynamic pricing to incentivize the charging of electric vehicles when energy, particularly renewable energy, is abundant. A proposal in review by the California Public Utilities Commission (CPUC) would introduce an accurate price signals program. Similar to "congestion pricing," this would permit customers to pay less for energy when it is most abundant and more when demand on the grid is high. The program is expected to be introduced in 2019 [88]. These measures should be encouraged to enhance overall resilience.

Because both SCE and SDG&E can expect higher power flows through their distribution system equipment in addition to higher temperatures causing equipment problems, investment in more robust equipment to mitigate this issue is recommended. In addition, the potential electrification of building heating systems in an effort to reduce natural gas usage and increase overall building efficiency will decrease site-level energy use. This should not be construed to mean, however, that heating loads – which historically have not depended strongly on the electricity system in California – will not be needed to be upgraded in the future.

The impacts of space and water heating electrification will further increase electricity demands in excess of that caused by climate change up to 18.6% statewide. This effect is stronger than that of climate change alone. Heating demands are expected to decrease statewide on a total energy basis due to the efficiency improvement of electrification, but it still represents a large, new electric loads. Electrification of heating systems will also have the effect of shifting the peak electricity demand to the winter months, which can affect rate structures and seasonal infrastructure planning.

Additional Roadmap Recommendations: The state's IOUs should pursue additional measures to encourage efficient electricity use and reduce peak demand – in conjunction with state officials and other stakeholders. NOTE: these measures should continue during the 2030-2040 and 2040-2050 periods – with the understanding that their introduction now will create a base of experience that can be enhanced over time as climate impacts become more pronounced.

- ***Institute advanced metering and time-of-use programs as opportunities for their introduction arises.*** While this will likely be more easily achieved for new construction, retrofits of existing residential and commercial building stock may afford an opportunity for this. State regulatory relief and expedited approvals should be sought to ensure near term (e.g., 2030) progress. Smart Meter data can be applied in near real-time during heat events. PG&E is making noteworthy efforts in adopting many of these innovations already, while SCE and SDG&E are also beginning to do so.

- ***Give high priority to encouraging adoption of – and investment in – passive-cooling strategies.*** These include greater use of fans and flow-through ventilation to reduce electricity demand by raising the average temperature threshold at which air conditioning is commonly turned on. Collaboration with water agencies and state officials should be pursued under this option by *all three IOUs*.

- ***SCE and SDG&E should invest in robust, durable distribution system equipment – as routine replacements are undertaken – to compensate for possible temperature-induced equipment failures.*** Because these IOUs will experience especially high flows of power due to increases in warm-weather peak electricity demands, prudent investments through the 2030 period will also fortify their distribution systems as mean average temperatures – and peak demand loads – increase in later periods.

- ***All three IOUs should work with water utilities to reduce electricity consumption at water and waste water treatment plants, and in water conveyance and distribution systems***. This is particularly important for PG&E, given its large hydroelectricity reliance and physical presence in a region where long-distance water conveyance is a major issue. While less important for SCE, this strategy should also be pursued as appropriate. All three IOUs, meanwhile, including SDG&E, should work with communities to encourage adoption of hot water end use conservation measures in the residential and commercial sectors.

- ***While agricultural activities vary within each IOU's operating region, energy and water saving innovations in that sector should be encouraged.*** These include drip and micro irrigation technologies and agricultural conjunctive use programs with cities. Efforts should be made to determine – on a site-specific basis – when and where agricultural water conservation, as well as drip and micro-spray irrigation, may actually increase energy demand in order to avoid these applications.

- ***Incorporate meteorological data such as "heat storm" models that provide IOUs with advance forecasts of heat storm intensity***. Such data can help IOUs better estimate outages; provide state-of-the-art guidance to emergency response teams; reduce power restoration times, and increase system reliability. These can also be connected to public outreach programs that will help mitigate impacts to disadvantaged communities through providing special "cooling centers" as needed. While SDG&E has devoted particularly noteworthy efforts in this domain (e.g., SAWTI), SCE's adaptation planning tool also is relevant to this effort.

8.1.1.3 Impacts on renewables generation – policymaker recommendations

To increase adoption of renewable energy options to 50% by 2030 several recommendations have been offered by state officials, including a diverse portfolio comprised of greater deployment of solar roofs, wind, and other distributed generation sources; greater use of low carbon fuels; integrated land conservation and development strategies; and coordinated efforts to reduce emissions of short-lived climate pollutants (methane, black carbon, and fluorinated gases). In addition to accommodating the climate change challenges earlier discussed, other challenges must also be addressed, such as mitigating possible land use disturbances from adopting some renewable sources [69].

One key issue that will need to be addressed is the synergy between the renewable energy adoption goals of the state for electricity generation on the one hand, with the transportation-related goal of massively increased electric vehicle use – whose power demands will need to be met by these new sources of electricity generation – on the other. Successful and rapid adoption of inexpensive renewable energy alternatives will help to reduce GHGs while also providing a dependable power source to recharge an every-expanding electric vehicle fleet.

Additional Roadmap Recommendations: There are a number of additional steps that state policy-makers can pursue in support of renewables adoption. NOTE: again, as with the other options previously discussed, commencing these programs as soon as possible will generate programmatic experience valuable for the 2030-2040 and 2040-2050 periods.

- ***Address the synergy between renewable energy adoption with the transportation-related goal of increased electric vehicle (EV) use.*** Conjoint planning between IOUs and the transportation sector should be encouraged. Concerted planning by the CEC, CPUC and California DOT should take account of potential impacts from growth in EVs, and ways in which the demands imposed by these vehicles can be met by new sources of electricity generation. Because demands will vary in different parts of the state (with urban areas likely most affected at least in the short term) efforts should focus on cities.

- ***Address issues associated with deployment of more electric vehicles and charging stations.*** Drivers' charging behavior will affect the extent to which additional electric generation capacity and ancillary services are needed to maintain a reliable grid. Given the further goal of a portfolio of 50 percent renewable electricity by 2030, attention will need to be given to adopting charging control and optimization technologies in order to ensure integration of the electric and transportation sectors. Attention must also be paid to how, for instance, wide-spread use of electric vehicles as storage for excess renewable generation, as well as vehicle- to-grid, smart charging may be pursued [69].

- ***There is a continuing need to respond to climate change vulnerabilities through a California-centric evidence base of vital metrics for inputs, capabilities, and renewable energy sources' performance.*** As federal research funding becomes uncertain, California must be prepared to fill in research gaps for less-mature technologies. This should include helping IOUs develop comprehensive data, metrics, and an analytical framework for energy infrastructure resilience, reliability, and asset security – as well as renewable technology penetration.

8.1.1.4 Impacts on renewables generation – IOU recommendations for hydropower

For San Diego Gas & Electric (SDG&E), no specific impacts are anticipated with respect to hydropower generation during this time period for the simple reason that SDG&E does not incorporate hydropower generation as a part of its energy mix. For its part, hydropower is not only an important component of Southern California Edison's (SCE's) mix, but its hydropower units are experiencing consistent decreases in inflows and reservoir levels as well as subsequent decreases in generation and spinning reserve across all climate models. Even in wetter models, the southern units serving SCE are not able to take advantage of the extra statewide precipitation. This is important because SCE owns, operates, and maintains the Big Creek Hydroelectric System within the Sierra National Forest. The system produces hydropower and also supplies water for municipal and agricultural purposes throughout the San Joaquin Valley [36]. Because this system generates about 1,000 MW of hydro,

SCE is concerned with how precipitation may change its operations. SCE currently conducts 13 cloud seeding programs which on average increase precipitation by 5 percent. Moreover, SCE is participating with the CEC on two climate change studies to: 1) evaluate how man-made particulates from the Central Valley and Los Angeles Basin affect precipitation; and, 2) a planned study to investigate how precipitation processes may change as temperature increases; thus affecting SCE's cloud-seeding program.

Northern California hydropower units in PG&E's operating region may see increased overall inflows due to potentially increased precipitation, but the delivery of these inflows will be more variable. Moreover, it is likely that timing of peak inflows shifted to earlier months due to decreased snowpack and increase in direct runoff. In addition, PG&E will have to prepare for increased spillage events and balance spillage with water storage and flood control. Currently, PG&E owns and operates the nation's largest privately held hydropower system with some 68 powerhouses, 110 generating units, and 99 reservoirs with 3,896 MW of total generation capacity and 2.3 million acre-feet of storage capacity [36].

PG&E has examined global climate change effects to its system. It is well known that snowmelt produced runoff has decreased over the last 65 years as compared to 1900-1950 attributable to decreasing trend in low elevation snowpack, and a corresponding increase in rainfall from lower elevations. Studies also have established that spills past diversion dams may possibly increase in frequency and quantity in the future while high runoff events during the winter and early spring may require shut down of the Feather River facilities to prevent facility damage [36]. While as of a decade ago, PG&E did observe any significant change in hydroelectric production that could be specifically tied to global climate change, beyond the near future it is expected that changes will be perceptible. PG&E believes that because its systems have been "designed to accommodate a large wetness variance, and most of its reservoirs are located at mid-to-high elevations," fewer effects depending on how the snowmelt timing changes by elevation should be felt. By contrast, both Central Valley Project and State Water project reservoirs – being designed principally for water supply, and thus sited at lower elevations, could experience greater hydropower impacts [36].

Additional Roadmap Recommendations: The state's IOUs should pursue additional measures with respect to hydropower and climate change resilience:

- ***While "climate hardening" measures are being pursued by the state's two hydropower-reliant IOUs, more can be done.*** Modified design and operational standards for hydroelectric systems should be adopted based on climate change forecasts. For PG&E, this means continued investigation of whether 2030 (and beyond) climate impact projections will adversely affect the mid- to high-elevation hydropower reservoirs which comprise the bulk of its hydropower system. While negative impacts are expected to be few, given increased overall demands on the PG&E system, continued study is prudent. For SCE, consideration of how warmer temperatures and changes in cloud cover could affect cloud-seeding efforts is warranted [36].

- ***One climate-change related threat to hydropower that must be alleviated is wildfire risk to transmission systems.*** One assessment predicts a 40 percent increased probability of wildfire exposure for the transmission line bringing hydropower from the Pacific Northwest to California [8]. PG&E's existing vegetation management programs – ranging from redundant air, ground and LiDAR remote sensing patrols in high fire hazard areas, re-inspecting overhead wires, trimming or removal of trees and cleared vegetation, and funding of fuel density reduction activities [52] should be enhanced and budgetary allocations adjusted to compensate for increased fire-hazard risks from climate change. SCE should undertake similar plans, as warranted.

- ***Improvements to runoff forecasts should be pursued to enable better planning for new – and operational changes to existing – hydropower projects.*** Development and calibration of distributed runoff forecasting models have enabled PG&E to improve planning and better manage increased variability and extremes. However, it is recognized that new storage projects to help mitigate expected snowpack decline may be needed, including pump storage projects, new reservoir capacity, and additional capacity from other energy sources. Such forecasts can be useful to these efforts.

8.1.1.5 Impacts on Thermally-based renewables – policymaker recommendations

As the state's electrical energy sector continues to decarbonize, both the behavior of individual facilities and the design of the grid itself will change, with important distributional effects. Some power plants may operate more flexibly to balance renewables, emerging resources (including storage) will become more prevalent, and aging facilities may retire and be replaced. In turn, this may shift patterns of criteria pollutant emissions at these facilities. Moreover, delicate tradeoffs may arise between economic and environmental issues that will need to be weighed.

For example, California's effort to move toward greater renewable energy project deployment is partly animated by an aspiration to spur direct economic benefits. In support of this aspiration, the Governor's Clean Energy Jobs Plan, for instance, calls for adding 20,000 MW of new renewable capacity by 2020, including 8,000 MW of large-scale wind, solar, and geothermal resources, and an additional 12,000 MW of localized electricity generation [89].

At the same time, there are environmental impacts associated with geothermal that will need to be assessed. The biggest geothermal facility in the world is located in the Geysers region of California with a 2 GW nameplate capacity. In part because no outside source of water is used at the Geysers, groundwater overdraft has significantly reduced the steam pressure and has reduced the capacity of the power plant. This suggests that one serious constraint on geothermal in California is groundwater depletion [90]. Moreover, though possibly of less import, geothermal facilities will consume nominal amounts of land – on average 6 acres per MW of energy [55].

While the section below enumerates specific impacts and potential benefits of geothermal renewable resources to the state's IOUs, there are some general considerations that be embraced by state policymakers in formulating decisions in support of thermally-based renewables and climate resilience.

Information and data considerations also play important roles in policy reforms in this domain especially. Explicit direction contained in AB 197, for example, provides additional direction to the state's Air Resources Board regarding providing easier public access to air emissions data, including posting of GHG, criteria, and toxic air contaminant data, organized by local and sub-county level for stationary sources. Such easier and accessible data is important for building pubic confidence and trust in energy resilience measures.

Additional Roadmap Recommendations: There are a number of additional steps that state policy-makers can pursue in support of thermally-based renewables. NOTE: as with the other options previously discussed, commencing these programs as soon as possible will generate programmatic experience valuable for the 2030-2040 and 2040-2050 periods.

- ***In deploying thermally-based renewables decision-makers should take into account the need to rectify adverse impacts of previous energy decisions.*** Many existing power plants are in or near disadvantaged communities, making it important to ensure that transition to a cleaner grid does not result in further unintended negative impacts – such as groundwater depletion or other effects. Similarly, changes to energy infrastructure that possibly threatens environmental resources (e.g., aesthetic or endangered or threatened species concerns from solar thermal and geothermal deployment) must be addressed.

- ***Federal tax policy may have difficult to forecast impacts upon geothermal deployment by 2030 – making it incumbent on state policymakers to consider new strategies to encourage their deployment.*** The federal renewable investment tax credit (ITC) and production tax credit (PTC) will likely be reduced by 2030 according to current federal policy, with the federal PTC and ITC phased out by 2021 for geothermal. Depending on deployment costs and return-on-investments for geothermal energy after these tax changes occur, other economic incentives may need to be introduced (see Figure 5).

8.1.1.6 Impacts on Thermally-based renewables – IOUs recommendations

Geothermal energy constitutes less than 2% of the energy mix in SDG&E as of 2014 and ~9% in SCE as of 2015. While a small portion of SCE's electricity generation base, local geothermal resources and resource potential are very large, a significant consideration for future planning in light of climate change. Geothermal facilities also have a relatively high capacity factor (up to 90%) compared to wind, biomass and small-scale hydro (35, 85, and 50%, respectively) [91]. A significant challenge is that these geothermal resources are technically within the operational territory of the Imperial Irrigation District, which is a POU. However, the geothermal potential in IID is relatively large (~9.05 GW of unidentified potential) and development of this potential may at least in a significant fraction be for exporting geothermal power to <u>SCE and SDG&E.</u>

Resource	Geography		Capacity Factor (%)	Capital Cost (2015 $/kW)		LCOE (2015 $/MWh)	
				2015	2030	2015	2030
California Geothermal	Imperial		90%	$ 5,142	$ 5,142	$ 76	$ 96
	Northern California		80%	$ 3,510	$ 3,510	$ 59	$ 81
California Solar PV	Central Valley & Los Banos		30%	$ 2,174	$ 1,826	$ 58	$ 76
	Greater Carrizo		33%	$ 2,174	$ 1,826	$ 53	$ 69
	Greater Imperial		31%	$ 2,174	$ 1,826	$ 56	$ 73
	Kramer & Inyokern		34%	$ 2,174	$ 1,826	$ 50	$ 66
	Mountain Pass & El Dorado		34%	$ 2,174	$ 1,826	$ 50	$ 65
	Northern California		29%	$ 2,174	$ 1,826	$ 59	$ 78
	Riverside East & Palm Springs		32%	$ 2,174	$ 1,826	$ 53	$ 70
	Solano		29%	$ 2,174	$ 1,826	$ 59	$ 78
	Southern California Desert		34%	$ 2,174	$ 1,826	$ 51	$ 67
	Tehachapi		33%	$ 2,174	$ 1,826	$ 52	$ 68
	Westlands		31%	$ 2,174	$ 1,826	$ 55	$ 72
OOS Solar PV	Arizona		34%	$ 2,001	$ 1,711	$ 45	$ 56
California Wind	Central Valley & Los Banos		30%	$ 2,069	$ 2,008	$ 51	$ 76
	Greater Carrizo		31%	$ 1,914	$ 1,857	$ 49	$ 74
	Greater Imperial		35%	$ 2,083	$ 2,022	$ 43	$ 68
	Riverside East & Palm Springs		33%	$ 2,047	$ 1,987	$ 57	$ 82
	Solano		27%	$ 1,992	$ 1,933	$ 58	$ 82
	Tehachapi		35%	$ 2,087	$ 2,025	$ 47	$ 72
OOS Wind	New Mexico	1	46%	$ 1,738	$ 1,687	$ 21	$ 46
		2	42%	$ 1,738	$ 1,687	$ 26	$ 51
		3	39%	$ 1,738	$ 1,687	$ 30	$ 55
	Oregon		32%	$ 1,943	$ 1,885	$ 49	$ 74
	Wyoming	1	46%	$ 1,738	$ 1,687	$ 21	$ 46
		2	42%	$ 1,738	$ 1,687	$ 26	$ 51
		3	39%	$ 1,738	$ 1,687	$ 30	$ 55

* OOS = out-of-state, LCOE = levelized cost of energy . Solar capital cost is expressed with respect to AC capacity with assumed inverter loading ratio of 1.3; i.e. the cost per kW-AC is 1.3 times higher than the cost per kW-DC.

Figure 5 – Renewable Resource Cost and Performance Assumptions for California

<u>Source</u>: figure is reproduced from Brattle Group/Energy + Environmental Economics/BEAR/Aspen Environmental Group. *SB 350 Study Aggregated Report – the Impacts of a Regional ISO-Operated Power Market on California. Regional Grid Operator and Governance* - TN #: 212271: July, 2016. Data in this table are derived from the so-called Renewable Energy Solutions (RESOLVE) model developed by Energy and Environmental Economics, Inc.

Solar thermal follows a somewhat similar trend, except in this case the largest fraction of the high quality solar thermal potential is located directly in <u>SCE's</u> territory, making it easier to procure since it is located near their transmission corridors. A large amount of potential is also located in IID's territory, but much more than IID's potential demand, so this is likely to be exported to the larger IOUs as well. A key difference between solar thermal and geothermal, however, is that the unconstrained potential of solar thermal resources is much larger than that for geothermal.

<u>Additional Roadmap Recommendations</u>: The state's IOUs should pursue additional measures with respect to thermally-based renewables and climate change resilience:

- ***SCE and SDG&E should either work for a solution to potential water availability constraints if they are planning to procure more geothermal to meet their compliance targets for current and future renewable portfolio standard goals.*** If this goal proves to be unattainable, then both IOUs should consider reducing their reliance on geothermal.

- ***SCE and SDG&E should focus on solutions for potential water availability constraints in order for solar thermal to be a part of its Renewables Portfolio Standard***. If solutions to this problem cannot be identified and implemented, then it may be more prudent for both IOUs to use the land for solar photovoltaic, which uses almost no water.

- ***PG&E has geothermal resources that should be exploited, as appropriate.*** These are located in relatively wet areas and are not under threat of having insufficient cooling water. However, PG&E may still need to consider the use of extra available water to recharge groundwater basins that are depleted by open loop dry-steam plants. An important consideration for PG&E is that renewable procurement cost savings could be potentially high, according to one study, in light of PG&E's decision to close the Diablo Canyon nuclear plant in 2025 and replace its output with renewables [55].

8.1.2 Timeframe II: through 2040 – Climate Vulnerabilities

2040 is the halfway point between the two planning boundaries for California's aspirations to reduce GHGs and move toward a renewable energy- based electricity system (i.e., GHG emissions are to be reduced to at least 40 percent below 1990 levels by 2030 and 80 percent below this level by 2050). More than this, however, it is also a significant climate vulnerability benchmark in its own right. Studies strongly suggest that uncertainty bands associated with surface temperatures diverge widely in the period 2040-2050 because cumulative carbon emissions are expected to have dramatic impacts on temperature [10]. Other studies predicate dramatic changes will occur to hydropower production in California by around 2040 – on the order of 5% in firm power reliability -- due to diminished snow-pack, earlier snowmelt runoff, and reduced summer and fall flows. Meanwhile, sea level rise impacts affecting energy infrastructure especially in the San Francisco Bay Area, the coast south of Santa Barbara, and the Oxnard Plain of Ventura County significant storm surge impacts [36].

8.1.2.1 Policymaker Recommendations

For our five criteria, the same basic parameters and strategies as for the 2030 horizon apply. However, there is one additional consideration of note – as the mid-point for the more ambitious 2050 target for GHG reduction, renewables adoption, and conservation progress, a nearly continuous trajectory of aggressive adoption of new technologies in these three domains must continue. Figure 6, which depicts this trajectory, is predicated on a further assumption: continuation of a state-wide cap-and-trade program with *declining annual caps* [69].

As discussed earlier, the ability of the state's three IOUs to achieve this objective depends upon several variables related to financing, public acceptance, and technical feasibility. Nonetheless, general guidance can be suggested with regard to the 2040 timeframe. Of greatest import, particularly as regards meeting the limits imposed by declining annual caps in a cap-and-trade program, several options have already been slated for policy-maker and IOU attention.

These options include Increased use of renewable energy through long-term agreements between customers and utilities; adoption of clear rules for electricity storage; adoption of a zero net energy (ZNE) standard for residential buildings by 2018-2019 and commercial buildings by 2030; expansion of the Low-Income Weatherization Program (LIWP) to improve energy efficiency in residential buildings for low-income households; decreased usage of fossil natural gas through a combination of energy efficiency programs, fuel switching, and the development and use of RNG in the residential, commercial, and industrial sectors; greater use of heat pumps; enhanced energy efficiency appliance standards for high efficiency air conditioners, light-emitting diode (LED) lamps, industrial process cooling and refrigeration, and efficient street lighting; promoting programs that support third-party delivered energy efficiency projects; support for more compact development patterns to promote reduced per capita energy demand; and target dates and pathways for a zero carbon building policy.

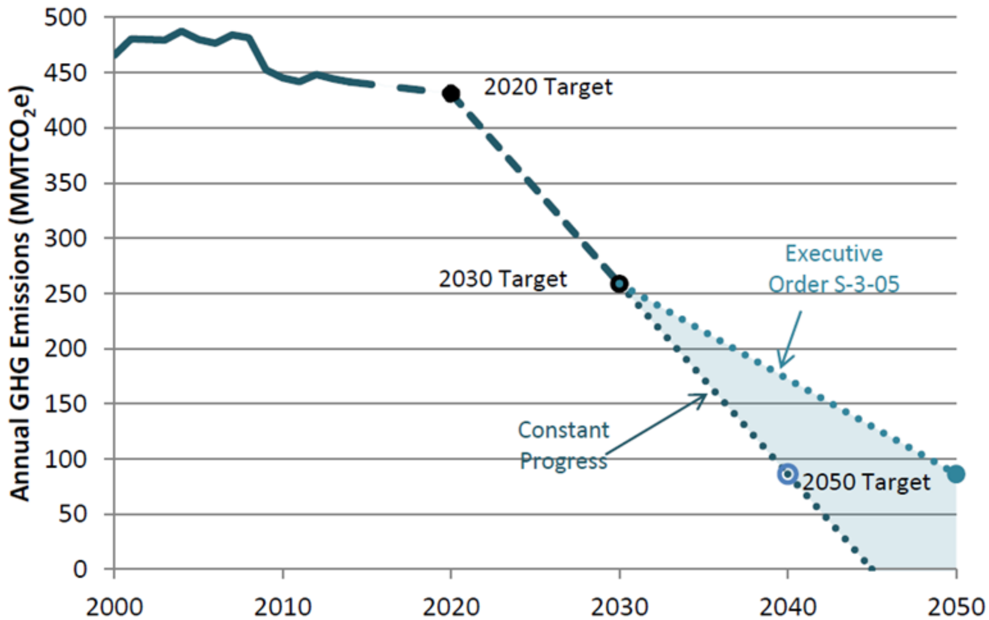

Figure 6 – Plotting California's Path Forward

<u>Source</u>: California Air Resources Board. The 2017 Climate Change Scoping Plan Update – the Proposed Strategy for Achieving California's 2030 Greenhouse gas target. Sacramento, January 20, 2017.

While most of these can be achieved in relatively short time frames – the lattermost of these (i.e., promoting third-party delivered energy efficiency projects; supporting more compact urban development; and pathways for a zero-carbon building policy) will likely take longer. Thus, a 2040 timeframe is probably the correct milestone for these. This is because they require *institutional changes* as well as gradual transitioning from previous programmatic directions.

Additional Roadmap Recommendations: Below are recommendations specific to 2030-2040.

- ***Decision-makers must become more alert to smart grid vulnerabilities.*** State assistance in modifying design standards, and in advancing protective measures against lightning, wildfires, wind, flooding, and other extreme events will be needed.

- ***Local policies to enhance energy conservation and renewable energy innovations must continue to be refined.*** These steps are needed for the state to meet its GHG reduction and renewable energy deployment targets.

- ***Collaboration with water utilities and local governments and stakeholders should continue*** to help ensure that water conserving technologies are introduced, together with next-generation efficiency technologies, retrofits, and green buildings.

- ***It is expected that state milestones for IOUs' renewables procurement by 50% by 2030 will be met in disadvantaged communities –*** thus efforts to improve energy efficiency, Low-Income Weatherization Programs, renewable energy adoption, ZEVs, transit, housing retrofits, and related programs should be easier to continue, but the need to rectify past adverse impacts will continue [92].

- ***Accurate predictions regarding electric vehicle (EV) adoption are needed.*** One forecast predicts that by 2040, 12% of all motor vehicles in the state will be plug-in EVs [93]. Another study states that if all gasoline automobiles are replaced with EV and plug-in hybrid vehicles the state could save 287 GWh devoted to gasoline refining (50% of electricity use). However, some 1.1 million public charging stations must be installed to accommodate the change and several power stations must be built to provide adequate electricity for the State's needs [94]. Given wide uncertainties, the need for conjoint interagency planning will become more urgent.

8.1.2.2 IOU recommendations

Previously discussed uncertainty bands associated with surface temperatures, diminished hydropower potential, and sea-level rise impacts all make IOU planning challenging.

Additional Roadmap Recommendations: Below are recommendations specific to 2030-2040.

- ***PG&E will likely find that climate change water storage, sea-level rise, and wildfire impact assessment - and adaptation efforts will increase in Importance.*** Of special importance will be how uncertainty bands affect temperature, precipitation, stream-flow, fire hazards, and other variables. Climate hardening measures may need to be adjusted as more is learned.

- ***SCE will likely find that its Adaptation Planning Tool will help in instituting major modifications and upgrades as climate severity impacts its system.*** Of special importance, we suggest, are measures regarding runoff, precipitation, and snowmelt.

- ***SDG&E will likely encounter greater wildfire threats, increasing the need to refine and improve the Santa Ana Wildfire Threat Index (SAWTI).*** As threats grow, continued collaboration with key regional stakeholders – already in place – should be refined.

8.1.3 Timeframe III: through 2050

Previous research suggests that even if the state's 2030 GHG reduction goal is reached – emissions that are 40 percent below 1990 levels – the impact of temperature and other climate related changes on GHG reduction efforts longer term (i.e., 2050), as well as effects on overall electricity system resilience, is likely to be problematical. As the Task 6 analysis discovered, water supply constraints on renewable energy utilization, especially geothermal resources, will likely be the largest single contributor to increasing GHG emissions in the proposed 2050 electricity mix. Thus, efforts to meet the 80% emissions reduction target may fall short. In addition, high temperatures predicted by some models (Task 6) may exacerbate this problem.

By mid-century (2040 - 2060), climate change may reduce average summertime generating capacity by 1.0 - 2.7 GW, with potentially disruptive impacts occurring in California and the desert Southwest. Vulnerable facilities account for 46% of existing capacity in the WECC region and, among individual facilities, impacts range from a 4% increase in capacity to a 14% decrease in capacity [17].

Other investigations have identified complementary problems. By 2050, Los Angeles could experience two feet of sea level rise. This is a significant uptick from a planning perspective – and some models forecast an even greater rise in sea level, particularly post 2050 – of up to 30 inches (10). For San Diego model projections suggest an increase in the number of extreme heat days (where temperatures exceed 87 degrees Fahrenheit) from four days per year to approximately 38 days per year between 2050 and 2060 on average (with a predicted range of from 17 to as many as 59 extreme heat days). On top of these forecast climate changes, California's population is projected to grow to 50 million people by 2050 [69].

8.1.3.1 Policymaker and IOU Recommendations

Putting these predicted trends together – threats to coastal zones; lower water availability; higher average temperatures; and, a larger population – the upshot is that even with progress toward reductions in GHGs, and a steady trajectory toward greater adoption of renewable energy sources, demand pressures on the state's IOUs are likely to be considerable at precisely the same time that pressures on many renewable supply sources (e.g., hydropower, wind energy) are likely to reach a point of high stress. As a result, critical to the state's achievement of the 2050 goals previously mentioned are long-term measures not yet discussed. We combine policy maker and IOU recommendations in this instance due to the long-term nature of the recommendations being proposed:

Additional Roadmap Recommendations: Below are recommendations specific to 2040-2050 – which address vulnerability and long-term resilience planning.

- ***An enhanced role for carbon sequestration strategies by state policymakers is warranted.*** These strategies should include state-wide adoption of new guidelines for land development and protection of green space and forests, as well as land restoration activities. A second component involves implementation of a Net Carbon Buildings strategy to help achieve the 2050 GHG target [69].

- ***For all three IOUs, sequestration strategies could have long-term implications beyond actions prescribed in previous sections of this chapter.*** This is so in two respects: 1) IOU efforts to work with communities to develop stronger DSM programs, in conjunction with state officials, will be needed to accelerate adoption of proven approaches for building energy use & conservation; and, 2) expanding and managing green space in urban areas could become a cornerstone of an adaptation strategy supported through the state's cap-and-trade program. In effect, the use of carbon-offsets as a means of meeting GHG reduction targets is one possible strategy worth considering for IOUs.

- ***IOU efforts to more innovatively utilize biomass resources such as harvested wood and excess agricultural and forest biomass may also help to advance statewide objectives for renewable energy adoption.*** They also may provide benefits with respect to and fuels, wood product manufacturing, agricultural markets, and soil health – all of which may also result in avoided GHG emissions [69].

- ***PG&E efforts to assess the impacts of a possible 24 inch sea level rise on its assets should be continued.*** PG&E is undertaking a more robust coastal flood risk analysis of at-risk assets from high tides and storm surges [52]. As climate and sea level rise models are better refined, threats to electric infrastructure assets should be revisited.

- ***PG&E efforts to assess long-term (i.e., 2050) risks to hydropower and transmission and distribution systems from higher temperatures, lower precipitation, and increased wildfire risk also should continue*** [52]. As climate models encompassing temperature and precipitation improve, these results should be incorporated in long-term plans.

- ***SCE should be encouraged to incorporate 2050 and beyond climate projections into its Adaptation Planning Tool.*** Current efforts to incorporate 2050 projections through use of geospatial datasets provided by Cal-Adapt has been enormously useful for identifying multiple hazards including average, maximum, and minimum temperatures; precipitation, snowpack, and runoff; sea-level rise; and wildfire [85].

- ***SDG&E's robust 30 year data set on fuel moisture and drought via the Santa Ana Wildfire Threat Index (SAWTI) should be refined for long-term future planning.*** SAWTI provides an invaluable foundation for understanding these factors and proposed efforts to undertake future studies on the climatology of such events should be pursued [87]

In conclusion, the goal of resilience for the state's energy system requires not merely the pursuit of a set of long-term policies and strategies for renewables, conservation, and grid stability by IOUs. It must also encompass a variety of societal goals to ensure that the state's electrical energy system become relatively immune to vulnerabilities. These goals include the ability to withstand major unanticipated disruptions, and adaptability to changing conditions that are difficult to precisely enumerate. As with all energy system investments, whether financial, institutional, or infrastructural, decision-makers will need to balance rewards against risks, likely long-term benefits, public acceptability and equity considerations, and feasibility. Long-term management strategies which include infrastructure improvements that increase resiliency of critical systems and improve system reliability is a goal the state should aspire to.

9. References

1. California Energy Commission. *Environmental Justice (homepage).* http://www.energy.ca.gov/public_adviser/environmental_justice_faq.html 2017.
2. Vine, Edward. *Adaptation of California's Electricity Sector to Climate Change.* San Francisco, CA: Public Policy Institute of California, November 2008. Available at: http://www.ppic.org/main/publication.asp?i=755.
3. Nierop, Sam C.A. *Envisioning Resilient Electrical Infrastructure: A Policy Framework for Incorporating Future Climate Change into Electricity Sector Planning.* Center for climate change Law, Columbia University, December, 2013.
4. California Environmental Protection Agency. *Climate Change Research Plan for California – climate action team*. Sacramento, February, 2015.
5. Haimes, Y. Y. On the definition of resilience in systems, *Risk Analysis* 29 (4), 498–501, 2009.
6. Willis, Henry H., and Kathleen Loa. *Measuring the Resilience of Energy Distribution Systems.* Santa Monica, CA: RAND, 2015.
7. Committee on Increasing National Resilience to Hazards and Disasters; Committee on Science, Engineering, and Public Policy; and the National Academies. *Disaster Resilience: A national imperative.* Washington, DC: National Academies Press, 2012.
8. Franco, Guido and Alan H. Sanstad. *Climate Change and Electricity Demand in California.* Sacramento: California Climate Change Center, California Energy Commission. CEC-500-2005-201-SF, February 2006.
9. Weiss, Charles and William B. Bonvillian. *Structuring an Energy Technology Revolution.* Cambridge: MIT Press, 2009.
10. Douglas, Kristin Ralff. *Climate Adaptation in the Electric Sector: Vulnerability Assessments & Resiliency Plans*. Sacramento: California Public Utility Commission, Policy & Planning Division, January 6, 2016.
11. Madani, K., M. Guégan, and C. B. Uvo, "Climate Change Impacts on High-Elevation Hydroelectricity in California," *J. Hydrology*, vol. 510, pp. 153–163, March, 2014.
12. Moser, S., J. Ekstrom, and G. Franco. *Our Changing Climate – Vulnerability & Adaptation to the Increasing Risks from Climate Change in California. A Summary Report on the Third Assessment from the California Climate Change Center.* July 2012. CEC500-2012-007.
13. Tarroja, Brian Amir AghaKouchak, Reza Sobhani, David Feldman, Sunny Jiang, Scott Samuelsen. "Evaluating options for Balancing the Water-Electricity Nexus in California: Part 1 – Securing Water Availability," *Science of the Total Environment* 497-8: 697-710, 2014. http://dx.doi.org/10.1016/j.scitotenv.2014.06.0780
14. Yates, David and Kathleen A. Miller. Integrated Decision Support for Energy/Water Planning in California and the Southwest, *The International Journal of Climate Change: Impacts and Responses* 4 (1): 50-63, 2013. http://on-climate.com/ISSN 1835-7156.
15. Auffhammer, Maximilian and Anin Aroonruengsawat. *Hotspots of Climate-driven increases in residential electricity demand: A simulation exercise based on household level billing data for California*. Sacramento, CA: California Energy Commission's California Climate Change Center. CEC- 500- 2012- 021, 2011.

16. Moser, S.J., and J. Eckstrom. "A framework to diagnose barriers to climate change adaptation," *Proceedings of the National Academy of Science* 107 (no. 51) December 2010. www.pnas.org/cgi/doi/10.1073/pnas.1007887107.
17. Bartos, M. D., and M. V. Chester. "Impacts of climate change on electric power supply in the Western U.S.," *Nature – Climate Change*, DOI: 10.1038/NCLIMATE2648, May 18, 2015.
18. U.S. Department of Energy and University of California Irvine. *Capturing the Benefits of Integrated Resource Management for Water & Electricity Utilities and their Partners*. May, 2016. Principle authors: Brian Tarroja, Sandra Jenkins, Michael A. Berger, Lifang Chiang http://energy.gov/epsa/downloads/capturing-benefits-integrated-resource-management-water-electricity-utilities-and.
19. Bull, S., D. Bilello, J. Ekmann, M. Sale, and D. Schmalzer, "Effects of Climate Change on Energy Production and Distribution in the United States," in E*ffects of Climate Change on Energy Production and Use in the United States,* Eds. T. Wilbanks, V. Bhatt, D. Bilello, S. Bull, J. Ekmann, W. Horak, Y.J. Huang, M. Levine, M. Sale, D. Schmalzer, and M. Scott, Office of Biological and Environmental Research, U.S. Department of Energy, Washington, D.C., 2007.
20. Moser, S. "Adaptation, mitigation, and their disharmonious discontents: an essay," *Climatic Change* 111: 165-175, 2012. DOI 10.1007/s10584-012-0398-4
21. Pawson, Ray, Geoff Wong, Lesley Owen. "Known Knowns, Known Unknowns, Unknown Unknowns: The Predicament of Evidence-Based Policy," *American Journal of Evaluation* 32 (4) 518-546, 2011. DOI: 10.1177/1098214011403831.
22. Zamuda, Craig. J*oint IEPR Workshop on Climate Adaptation and Resiliency for the Energy Sector.* Energy Sector Climate Resilience, Washington, D.C.: U.S. DOE, 2016.
23. Miller, Norman, Katherine Hayhoe, Jiming Jin, Maximilian Auffhammer. "Climate, Extreme Heat, and Electricity Demand in California," *Journal of Applied Meteorology and Climatology* 47: 1834-44, 2008. DOI: 10.1175/2007JAMC1480.1
24. U.S. Department of Energy. *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather*. Washington, DC: DOE/PI-0013, June 2013.
25. California Energy Commission. C*alifornia's Water – Energy Relationship: Final Staff Report. Prepared in Support of the 2005 Integrated Energy Policy Report*. Proceeding (04-IEPR-01E). CEC-700-2005-011-SF, November 2005.
26. The Partnership for Energy Sector Climate Resilience and U.S. Department of Energy. *Accelerate Energy Productivity 2030: A Strategic Roadmap for American Energy Innovation, Economic Growth, and Competitiveness*, prepared by Keyser, D.; Mayernik, J., M.; McMillan, C., Agan, J., Kempkey, N., Zweig, J. 2015. http://energy.gov/epsa/partnership-energy-sector-climate-resilience.
27. Quesnel, K., Ajami, N.K., and Wyss, N. *Tapping into Alternative Ways to Fund Innovation and Multi-purpose Water Projects: A Financing Framework from the Electricity Sector.* Stanford Woods Institute for the Environment, 2016.
28. Borenstein, Severin. *Valuing the Time - Varying Electricity Production of Solar Photovoltaic Cells.* University of California Energy Institute CSEM WP-142, March, 2005.
29. ORNL (Oak Ridge National Laboratory). Climate Change and Energy Supply and Use. Technical Report for the U.S. Department of Energy in Support of the National Climate Assessment Report. Oak Ridge, TN: Oak Ridge National Laboratory, 2012. http://www.esd.ornl.gov/eess/EnergySupplyUse.pdf.

30. Davis, Michelle and Steve Klemmer. *Power Failure: How Climate Change Puts Our Electricity at Risk— and What We Can Do*. Cambridge, MA: Union of Concerned Scientists, April, 2014. http://www.ucsusa.org/global_warming/science_and_impacts/impacts/effects-of-climate-change-risks-on-our-electricity-system.html#.V7tb2GD2ZaQ
31. Hamilton, M. S. *Energy Policy Analysis – a Conceptual Framework*. Armonk, NY: M.E. Sharpe, 2013.
32. Cruz, A., and E. Krausman. Vulnerability of the oil and gas sector to climate change and extreme weather events. Climatic Change 121:41–53, 2013.
33. Epps, D. Blizzard, river issues among contributors to UP's coal volume decline in Q4 '13. SNL Financial, January 23, 2014.
34. *Abengoa Mohave Solar Project: Licensing Proceedings* (09-AFC-05C), California Energy Commission, 2014.
35. *Salton Sea Geothermal Unit #6 Power Project - Application for Certification* (02-AFC-2), California Energy Commission, 2003.
36. Phinney, S. and R. McCann. *Potential changes in Hydropower production from Global Climate Change in California and the Western U.S.* Prepared in support of the 2005 Integrated Energy Policy Report Proceeding (Docket # 04-IEPR-01G). Prepared by Aspen Environmental Group and M. Cubed, California Energy Commission – CEC-700-2005-010, June 2005.
37. Venema, Henry David, and Ibrahim Hafeezur Rehman. "Decentralized renewable energy and the climate change mitigation-adaptation nexus," *Mitigation and Adaptation Strategies for Global Change* 12:875–900, 2007. DOI 10.1007/s11027-007-9104-7.
38. Spang E.S., Moomaw W.R., Gallagher K.S., Kirshen P.H. and Marks, D.H. "The water consumption of energy production: an international comparison," *Environ. Res. Lett*. 9 105002, 2014.
39. Stephens, Jennie C., Elizabeth J. Wilson, Tarla R. Peterson, and James Meadowcroft (2013). "Getting Smart? Climate Change and the Electric Grid," *Challenges* 4, 201-216, 2014, DOI: 10.3390/challe4020201.
40. Brummitt, Charles D., Paul D. H. Hines, Ian Dobson, Cristopher Moore, Raissa M. D'Souzab. "Transdisciplinary electric power grid science," Proceedings of the National Academy of Science 110 (30): 12159, 2013. www.pnas.org/cgi/doi/10.1073/pnas.1309151110.
41. White House. *Presidential policy directive 21: Critical infrastructure security and resilience*, February 12, 2013.
42. Bennett, B., L. Park and R. Wilkinson. *Embedded Energy in Water Studies: Water Agency and Function Component Study and Embedded Energy − Water Load Profiles*. California Public Utilities Commission, 2010.
43. Frumhoff, Peter C., Virginia Burkett, Robert B Jackson, Robin Newmark, Jonathan Overpeck, Michael Webber. "Vulnerabilities and opportunities at the nexus of electricity, water and climate," *Environ. Res. Lett.* 10, 2015: 080201. Doi: 10.1088/1748-9326/10/8/080201.
44. Averyt, K., J. Macknick, J. Rogers, and N. Madden, J. Fisher, J. Meldrum, and R. Newmark. "Water use for electricity in the United States: an analysis of reported and calculated water use information for 2008," *Environ. Res. Lett.* 8 015001. Doi:10.1088/1748-9326/8/1/015001, 2013.

45. Sathaye, Jathye, Larry Dale, Peter Larsen, Gary Fitts, Kevin Koy and Sarah Lewis, Andre Lucena. *Estimating Risk to California Energy Infrastructure from Projected Climate Change.* Public Interest Energy Research (PIER) Program – Final project report CEC-500-2012- 057, July 2012.
46. Carpenter, T. and K. Georgakakos, “Assessment of Folsom Late Response to Historical and Potential Future Climate Scenarios: 1. Forecasting,” *Journal of Hydrology* 249: 148-175, 2001.
47. Yao, H., and A. Georgakakos. “Assessment of Folsom Lake response to historical and potential future climate scenarios 2. Reservoir management.” *Journal of Hydrology* 249: 176–196, 2001.
48. Golden, M. and B. Min. Distributive Politics around the World. A*nnual Review of Political Science* 16: 73-99, 2013.
49. Shaw, Keith and Louise Maythorne. “Managing for local resilience: towards a strategic approach,” *Public Policy and Administration* 28 (1): 43-65, 2011.
50. Shaw, Keith and Kate Theobald. “Resilient local government and climate change interventions in the UK,” *Local Environment* 16: 1, 1 — 15. 2010. DOI: 10.1080/13549839.2010.544296 http://dx.doi.org/10.1080/13549839.2010.544296.
51. Baldassare, M., D. Bonner, J. Paluch, S. Petek, *PPIC Statewide Survey: Californians and the Environment,* Public Policy Institute of California, San Francisco, California, July 2007.
52. Pacific Gas and Electric Company. *Climate Change Vulnerability Assessment*. PG&E, 2016.
53. Wilbanks, Thomas J., Vatsal Bhatt, Daniel E. Bilello, Stanley R. Bull, James Ekmann, William C. Horak, Y. Joe Huang, Mark D. Levine, Michael J. Sale, David K. Schmalzer, Michael J. Scott (2008). *Effects of Climate Change on Energy Production and Use in the United States,* Synthesis and Assessment Product 4.5. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, February 2008.
54. Rolston, Holmes. *Environmental Ethics: Duties to and Values in the Natural World.* Philadelphia, PA.: Temple University press, 1988.
55. Brattle Group/Energy + Environmental Economics/BEAR/Aspen Environmental Group. *SB 350 Study Aggregated Report – the Impacts of a Regional ISO-Operated Power Market on California. Regional Grid Operator and Governance* - TN #: 212271: July, 2016.
56. Shonkoff, Seth B., Rachel Morello-Frosch, Manuel Pastor, and James Sadd. “Minding the Climate Gap: Environmental Health and Equity Implications of Climate Change Mitigation Policies in California,” *Environmental Justice* 2 (4) 2009. DOI: 10.1089=env.2009.0030.
57. Morgan, Anne. Vice President of Public Lands, Wilderness Society, Remarks at the University of California, Berkeley, *As If Equity Mattered Symposium, Panel on Land and Fairness,* October 1, 2009.
58. Austin, Mary. *The Land of Little Rain.* New York: Penguin Books, 1903; 1997 reprint.
59. Stegner, Wallace. *The Sound of Mountain Water: the Changing American West.* New York: Doubleday, 1969.
60. Abbey, Edward. *Desert Solitaire: A Season in the Wilderness.* New York: McGraw-Hill, 1968.
61. Abbey, Edward, and Philip Hyde. *Slickrock: Endangered Canyons of the Southwest*. New York: Sierra Club/Scribner’s, 1971.

62. EcoWatch. Landmark Ruling Rejects Disastrous Water Diversion Project in Nevada and Utah. *EcoWatch—Transforming Green*. December 12, 2013. Available at: http://ecowatch.com/2013/12/12/ruling-rejects-water-diversion-project-nevada-utah/
63. Farmer, Jared. *Glen Canyon Dammed: Inventing Lake Powell and the Canyon Country.* Tucson: University of Arizona, 1999.
64. MacDonnell, L. J., and D. Fort. Policy Report − *A New Western Water Agenda: Opportunities for Action in an Era of Growth and Climate Change.* University of New Mexico Law School: Albuquerque, NM, February 2008.
65. Powell, James L. *Dead Pool—Lake Powell, Global Warming, and the Future of the American West.* Berkeley: University of California, 2008.
66. Gumprecht, Blake. "Who Killed the Los Angeles River?" In *Land of Sunshine: an Environmental History of Metropolitan Los Angeles,* eds. William Deverell and Greg Hise, 115–134. Pittsburgh: University of Pittsburgh, 2005.
67. Kibel, Paul Stanton, ed. *Rivertown: Rethinking Urban Rivers.* Cambridge, MA: MIT Press, 2007.
68. Orsi, Jared. "Flood Control Engineering in the Urban Ecosystem," In *Land of Sunshine: An Environmental History of Metropolitan Los Angeles,* eds. William Deverell and Greg Hise, 135–151. Pittsburgh: University of Pittsburgh Press, 2005.
69. California Air Resources Board. *The 2017 Climate Change Scoping Plan Update – the Proposed Strategy for Achieving California's 2030 Greenhouse gas target*. Sacramento, January 20, 2017.
70. Feldman, David. "Integrated Water Management and Environmental Justice – Public Acceptability and Fairness in Adopting Water Innovations," *Water Science and Technology - Water Supply* 11 (2): 135- 141, 2011. DOI: 10.2166/ws2011.035.
71. Tarroja, Brian, Amir AghaKouchak, Reza Sobhani, David Feldman, Sunny Jiang, Scott Samuelsen. "Evaluating options for balancing the water–electricity nexus in California: Part 2—Greenhouse gas and renewable energy utilization impacts," *Science of the Total Environment* 497-8: 711-724, 2014.http://dx.doi.org/10.1016/j.scitotenv.2014.06.071
70. Feldman, David. "Integrated Water Management and Environmental Justice – Public Acceptability and Fairness in Adopting Water Innovations," *Water Science and Technology - Water Supply* 11 (2): 135- 141, 2011. DOI: 10.2166/ws2011.035.
71. Tarroja, Brian, Amir AghaKouchak, Reza Sobhani, David Feldman, Sunny Jiang, Scott Samuelsen. "Evaluating options for balancing the water–electricity nexus in California: Part 2—Greenhouse gas and renewable energy utilization impacts," *Science of the Total Environment* 497-8: 711-724, 2014.http://dx.doi.org/10.1016/j.scitotenv.2014.06.071
72. Sze, Julie. Gerardo Gambirazzio, Alex Karner, Dana Rowan, Jonathan London, and Deb Niemeier. "Best in Show? Climate and Environmental Justice Policy in California," *Environmental Justice* 2 (4) 2009. DOI: 10.1089=env.2009.0028.
73. Burch, Marsha A. *Water Rights: Supply Issues for Local Agency Formation Commissions.* Paper presented at California Local Agency Formation Commission annual conference, Monterey, CA, 2005.
74. Environmental Justice Coalition for Water. T*hirsty For Justice: A People's Blueprint for California.* Oakland, CA: Environmental Justice Coalition for Water, June 2005.

75. Gardner, T. U.S. House passes bill requiring EPA actions on lead- laced water. *Reuters.com,* February 10, 2016. Available at: http://www.reuters.com/article/michigan-water-house- idUSL2N15P32N
76. Hennessy-Fiske, M. "A Water Crisis in a City of Crises," *Los Angeles Times*, January 15, p. A9, 2016.
https://www.aaas.org/news/first-trump-budget-proposes-massive-cuts-several-science-agencies
77. Pearce, M. A 'Man- made' Disaster in Flint, *Los Angeles Times*, January 23, 2016, p. A10.
78. Schragger, R. Flint Wasn't Allowed Democracy: That's part of the reason nobody acted when its water was poisoned. *Slate.* February 8, 2016. http://www.slate.com/articles/news_and_politics/jurisprudence/2016/02/a_big_reason_for_the_flint_water_crisis_no_democracy_there.html
79. Smith, M. Flint Wants Safe Water and Someone to Answer for Its Water Crisis. *New York Times*, January 9, 2016. Available at: http://www.nytimes.com/2016/01/10/us/flint- wants-safe- water- and- someone- to- answer- for- its- crisis.html
80. Georgakakos, K., N. Graham, T. Carpenter, A. Georgakakos, and H. Yao, "Integrating Climate-Hydrology Forecasts and Multi-objective Reservoir Management for Northern California," *EOS* Vol. 86, No. 12: 122, 2005.
81. Hanak, Ellen, and Jay Lund. *Adapting California's Water Management to Climate Change*. San Francisco, CA: Public Policy Institute of California, November 2008.
82. Hourihan, Matt, and David Parkes. "With some exceptions, the Trump Administration is seeking major rollbacks across the science and technology enterprise - if Congress agrees to it," *American Association for the Advancement of Science News,* March 16, 2017.
83. Chuang, A., D. von Dollen, M. McGranaghan, X. Mamo. *California Utility Vision and Roadmap for the Smart Grid of 2020.* Electric Power Research Institute; California Energy Commission. 1022220. CEC-500-2011-034, 2011.
84. California Environmental Protection Agency, Air Resources Board. "Potential role for Local government in Reducing Greenhouse gases," *Fact sheet – AB 32 and Climate Change,* July 20, 2017. https://www.arb.ca.gov/cc/facts/facts.htm
85. U. S. Department of Energy. *Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning,* Washington, DC, September 2016.
86. Vine, Edward. "Adaptation of California's electricity sector to climate change," *Climate Change* 111: 75-99. 2012. DOI 10.1007/s10584-011-0242-2.
87. Rolinski, T., Capps, S.B., Fovell, R.G., Cao, Y., D'Agostino, B., Vanderburg, S. "The Santa Ana Wildfire Threat Index: Methodology and Operational Implementation," *Weather and Forecasting 31.* December 2016: 1881-1897. DOI: 10.1175/WAF-D-15-0141.1
88. "SDG&E Viewpoint: Affordability Key to Addressing Climate Change." May 12, 2016. https://www.sdge.com/newsroom/2016-05-12/sdge-viewpoint-affordability-key-addressing-climate-change
89. Pennington, G. William, P. Saxton, S. Neidich, S. Taheri, F. Nasim, J. Folkman. 2013. *Guidelines for California's Solar Electric Incentive Programs (Senate Bill 1), Fifth Edition.* California Energy Commission. CEC-300-2013-008-ED5-CMF.

90. Water in the West. *Water and Energy Nexus: A Literature Review*, prepared by the Stanford Woods Institute for the Environment and Bill Lane Center for the American West, August 2013.
91. KEMA. 2008. *The Progress of California's Publicly-Owned Utilities in Implementing Renewables Portfolio Standards.* California Energy Commission. Publication number: CEC-300-2008-005.
92. California Public Utility Commission. *Programs Targeting Disadvantaged Communities* (DACs) Sacramento. 2017. http://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/MeetingEventsInformation/17/DACPrograms17.pdf
93. Hostick, D.; Belzer, D.B.; Hadley, S.W.; Markel, T.; Marnay, C.; Kintner-Meyer, M. (2012). *End-Use Electricity Demand. Vol. 3 of Renewable Electricity Futures Study. NREL/TP-6A20-52409-3. Golden, CO: National Renewable Energy Laboratory*
94. Papaioannou, Sotirios-Aris. *Electric Vehicles: A future Projection – Interactive Qualifying Project*. Worcester Polytechnic Institute (no date). https://web.wpi.edu/Pubs/E-project/Available/E-project-010416.../IQP_FINAL.pdf