Stockholm Environment Institute

Water and energy in California: planning for a sustainable future under political and climatic change

SEI report
February 2020

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Acknowledgements
This work was supported by the U.S. Department of Energy and The Regents of the University of California under Award No. DE-IA0000018.

Contents

KEY FINDINGS:

- California's water and energy sectors are deeply connected. Hydropower provides a significant amount of the state's electricity generation, and the water sector – through heating, pumping, and treatment – uses a significant amount of electricity.
- Climate change is already affecting the state's water and energy security, with persistent droughts, increased wildfires, and warmer average temperatures.
- Policy-makers are facing risks that may not remain under their control, not only from an uncertain climate future but also from differing perspectives from federal counterparts.
- An integrated modeling of California's water and energy systems shows that water conservation is a compelling response to these risks. In addition to ecological benefits, conservation strengthens the role of hydropower in the state's energy system, facilitating the attainment of climate and clean energy goals.
- Massive growth in solar, wind, and energy storage systems is key to achieving carbon neutrality in California.

Introduction

A changing climate has already begun to transform California. In the past decade, the state has experienced persistent droughts, intense and sprawling wildfires, and average temperature increases that exceed 2°C in some regions (Wilson 2019).

To respond to these escalating impacts, California needs to plan pro-actively, not only within sectors but across them. This is especially important when it comes to water and energy, which are particularly intertwined in California. The water sector, including water heating, treatment, and distribution, accounts for approximately 20% of the state's electricity consumption and 30% of its natural gas consumption (PPIC 2018). Energy production also depends partly on water; hydropower supplies an average of 15% of statewide electricity generation, except for 2014–2015, when a drought halved this share (CEC 2019).

For three years, SEI has modeled both water and energy systems in California, in order to inform the creation of climate-resilient infrastructure and policies. This work – funded by the U.S. Department of Energy, together with the University of California and the Swedish International Development Cooperation Agency – is part of a research and development partnership between the U.S. and China called the U.S./China Clean Energy Research Center for Water-Energy Technologies (CERC-WET).

The process included two workshops with California's Water-Energy Team of the Climate Action Team, a group known as WET-CAT that includes numerous state agencies.[1] These workshops used SEI's Robust Decision Support process, which helps stakeholders create a shared mental model of the available opportunities and potential trade-offs for various policies.

SEI then modeled California's water supplies and energy infrastructure with its widely used modeling tools: WEAP (Water Evaluation and Planning)[2] and LEAP (Long-range Energy Alternatives Planning).[3] In LEAP, we forecasted energy demands through 2050 across all key sectors, including households, commercial, transport, industry, agriculture, and utilities for all fuels. We then used WEAP results on electricity demands for irrigation, water treatment, and distribution, as well as future hydropower generation projections, as inputs to LEAP. On the supply side, the LEAP model includes a fully specified electricity system, including distributed, centralized, and imported electricity generation.

Using this model, SEI explored the level of interconnectedness between California's water and energy systems and the risks inherent in this linkage in the future due to climate change. In this report, we review the results of that study, as well as evaluate how the state could make its energy and water systems more resilient to climate change and the cost of inaction.

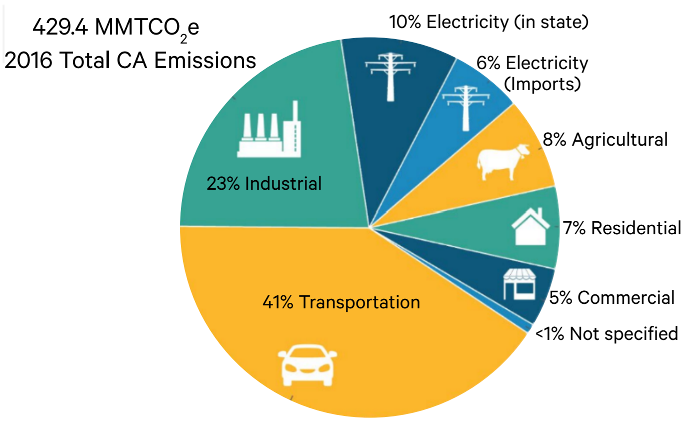
We examined a number of scenarios, relative to a Policy Baseline Scenario, and then ran 20 different climate projections to examine the water and energy system vulnerabilities across different climates. The Policy Baseline Scenario does not assume business-as-usual but includes relevant climate mitigation policies, as described in the following section. The scenarios evaluate climate change challenges in the energy and water sectors.

1 WET-CAT members include the California Environmental Protection Agency, Department of Water Resources, California Energy Commission, State Water Resources Control Board, Air Resources Board, and Governor's Office of Planning and Research.
2 http://www.weap21.org/
3 https://www.energycommunity.org/

Policy context

California has set aggressive emissions targets and policies to mitigate and adapt to climate change. Here, we provide a summary of the key policies, several of which are incorporated into the model's Policy Baseline Scenario.

Figure 1: 2016 Emissions by Sector



Source: California Air Resources Board 2018

Emissions reduction target

California ranks second-highest in carbon dioxide emissions in the US (among states) and represents 1% of global emissions (EIA 2018). On a per-capita basis, it consumes less energy than almost any other state; its high emissions are driven by a large population of approximately 40 million people and substantial energy production. California is a major producer of crude oil, has significant refining capacity, and is the biggest consumer of jet fuel in the United States (EIA 2018).

Figure 1 shows the sources of California's carbon dioxide equivalent (CO_2e) emissions in 2016, with most originating from transportation, industry, and electricity generation (both in-state and imports) (CARB 2018). To reduce overall emissions, in 2016, California's Senate Bill 32 (SB 32) set an emissions target of 40% below 1990 levels by 2030 and 80% by 2050. In addition to SB 32, California's governor issued Executive Order (EO) B-55-18 in 2018 to achieve carbon neutrality by 2045, including through carbon sequestration. Several of the policies described below are to meet these ambitious emissions reduction goals.

Renewable energy and low-carbon power supply target

Diversifying the energy mix is necessary to reduce emissions and dependency on imports and natural gas power generators. Currently, natural gas plants supply 46% of California's electricity needs (CEC 2019). The state's Renewables Portfolio Standard Program (SB 100) sets a renewable target of 50% by 2026 and 60% by 2030, and a carbon-free target of 100% by 2045 (California State Senate 2018).

We incorporated these electricity system targets into the model's Policy Baseline Scenario and, through the use of least-cost optimization modeling, explored the electricity system mixes that can achieve these targets. We allowed the model to import clean energy to meet energy demands if sufficient in-state generation was not possible.

Expansion of energy storage systems

California has seen an explosive growth in solar photovoltaic (PV) and wind, with capacities growing to 21 and 6 gigawatts (GW), respectively, in 2018. To ensure a constant and reliable source of clean energy supply, California's Assembly Bill 2514 (AB 2514) requires investor-owned electric utilities (IOUs) to procure and install 1.3 GW of energy storage systems by 2024 (CEC 2018). Commercially available energy storage technologies include batteries, flywheels, compressed air systems, pumped storage, and thermal energy (such as molten salt and ice).

Currently, California has 4,517 megawatts (MW) of pumped storage capacity dating back to 1967, 36 MW of thermal storage, and 177 MW of battery storage systems (CEC 2018). As of 2018, a total of 1,497 MW of transmission-connected, distribution-connected, and customer-side storage has been procured by IOUs, above the legislated target of 1.3 GW (CEC 2018).

The expansion of energy storage systems to achieve this target is included in the Policy Baseline Scenario.

Zero-emission vehicle target

California considers the electrification of the transportation sector critical to meeting its emissions target. Through Executive Order B-16-2012, Executive Order B-48-18 and zero-emission regulations, the state has set a target of 1 million zero-emission vehicles (ZEVs) by 2020, 1.5 million ZEVs by 2025, and 5 million ZEVs by 2030. Such policies also set goals for the supporting infrastructure, such as 200 hydrogen fueling stations and 250,000 ZEV chargers by 2025, including 10,000 direct current fast chargers (CARB 2019).

The Policy Baseline Scenario ramps up ZEV growth from the historical growth rate to meet the ZEV targets. The implications of increased ZEVs on the electricity supply system are analyzed.

LA’s Green New Deal

Los Angeles Mayor Eric Garcetti has set out an ambitious plan for sustainability. This includes targets to locally source up to 70% of the city’s water and recycle 100% of its wastewater by 2035 (City of Los Angeles 2019). The city also aims to reduce greenhouse gases by 73% by 2035 (compared to 1990 levels) and to reach net-zero carbon emissions by 2050, with 100% renewable energy by 2045. Stakeholders emphasized the importance of these goals in SEI’s RDS workshops. The final model does not include these targets, but the resulting analysis may still be illuminating to LA policy-makers, as the model’s state-level goals exceed the city’s water and energy targets.

Scenarios of the future

This section provides an overview of the scenarios evaluated in the study. We developed these scenarios from an analysis of both the critical concerns about how water supply could impact the energy system in the future, as well as potential solutions to these concerns. We did not evaluate consumer-side water efficiency measures – despite the large amount of energy that goes to water heating and irrigation – because it is clear that any reductions in water use can have significant reductions in energy supply capacity, emissions, and costs (for example, see Spang et al. 2018).

Policy Baseline Scenario

This scenario assumes that the State of California successfully implements existing policies on renewables, zero-emissions vehicles, energy storage systems, and low-carbon power supplies, as described above.

No Hydropower Scenario

Climate change is leading to rising temperatures and changes to seasonal and annual precipitation patterns, which exacerbate water availability issues in California (Swain et al. 2018; Ullrich et al. 2018). This affects hydropower, which is highly vulnerable to changes in water supply. On average, hydropower generates 15% of California’s electricity supply. This scenario phases out hydropower from the electricity system by 2025 to see how this change could affect the electricity generation mix.

Water Reuse and Desalination Scenarios for Southern California

Southern California receives as much as 2.5 million acre-feet per year from the State Water Project (SWP). This water originates in the Sacramento and San Joaquin River basins and is transported over 400 miles south via the California Aqueduct. It requires massive amounts of energy; the water is first pumped from the Sacramento-San Joaquin Delta at the Harvey O. Banks Pumping Plant, and then pumped 2,000 feet over the Tehachapi Mountains at the Edmonston Pumping Plant.

We considered a Policy Baseline Scenario in which the water delivery system continues to operate under the current guidelines and regulations, as well as two additional scenarios that consider reducing SWP deliveries to southern California by as much as 25%. The first scenario introduces additional capacity for desalinated seawater to replace reduced SWP deliveries, and the second scenario considers that these reduced deliveries would be replaced by a program to treat municipal effluent and reuse it for potable use.

Wildfire Reduction Scenario

The deadliest wildfire in California's history, Camp Fire, occurred in late 2018 after a tree fell onto a power line during high winds (Penn et al. 2019). It was only the latest in a string of California wildfires that are spreading further and faster, thanks to drier conditions and poor maintenance and safety measures around power lines and gas pipelines. Until the power system is more secure and resilient, there are plans to cut power on extremely windy days to prevent the occurrence of wildfires (Chediak and Eckhouse 2019). To avoid these potential blackouts, residents and companies have already begun to build distributed energy systems, including rooftop solar and increased battery storage. This scenario evaluates a 30% increase in rooftop solar capacity by 2030 and a 50% increase by 2050, relative to the Policy Baseline Scenario. We also evaluate the impacts of increasing energy storage systems at a faster rate.

Federal Policy Interference Scenario

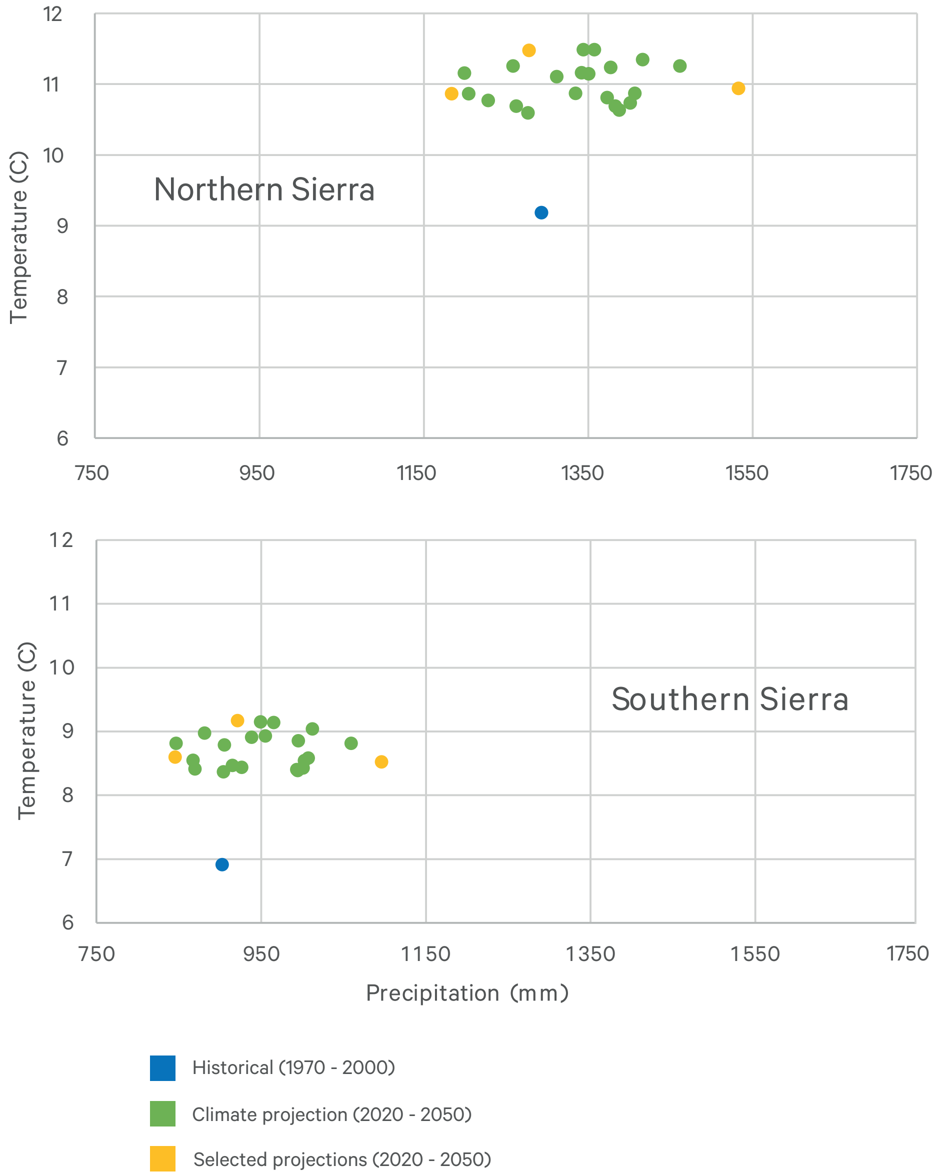
There is the possibility that the federal government may strip California of its authority to implement various emissions reduction policies. In addition to the power system targets described above, California has established aggressive tailpipe emissions requirements and fuel economy standards to meet its greenhouse gas emission objectives. This scenario assumes this policy interference, by analyzing the impacts of keeping vehicle fuel economy standards at the 2020 rate with no future reduction and by ignoring the power system targets that were incorporated in the Policy Baseline Scenario. We assessed the resulting impacts on the electricity mix.

Climate Projections

California has selected a number of climate projections that are officially used in the context of setting state policy. Figure 2 shows the temperature and precipitation levels of these projections in the Northern and Southern Sierras, which are located in Northern California and represent the primary water sources for the State. These levels – shown as green and orange dots – are far warmer and wetter than the historical average (blue dots). Differences in water availability between Northern and Southern California are important to evaluate as Northern California has two-thirds of the state's precipitation (or 70% of the state's total stream runoff) while Southern California holds two-thirds of the population (or 80% of water demand) (Klein et al. 2005).

In the context of the analysis, we chose three climate projections to capture the range of hot, dry and wet climates, highlighted in orange in Figure 2, to get a sense of the range of expected impacts and to identify the most critical vulnerabilities.

Figure 2: Climate Projections in Northern and Southern Sierras. Temperature is projected to be higher than historical values in both regions. Precipitation levels appear to be higher than historical climate across many projections. Selected projections used for this analysis capture hot, dry and wet scenarios.



Results

SEI developed a model of California's interconnected water and energy systems to explore climate solutions, engage with stakeholders, and help agencies implement successful policies. The results of the model are described in this section, starting with the Policy Baseline Scenario, followed by the future scenarios described above.

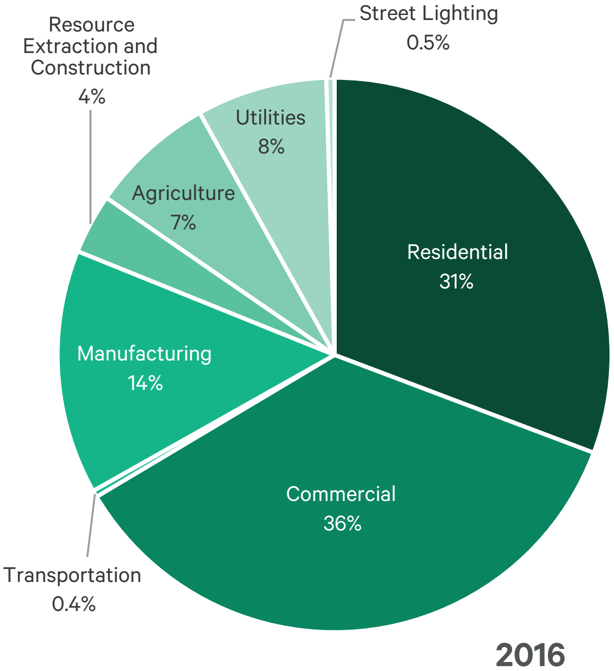
Policy Baseline Scenario

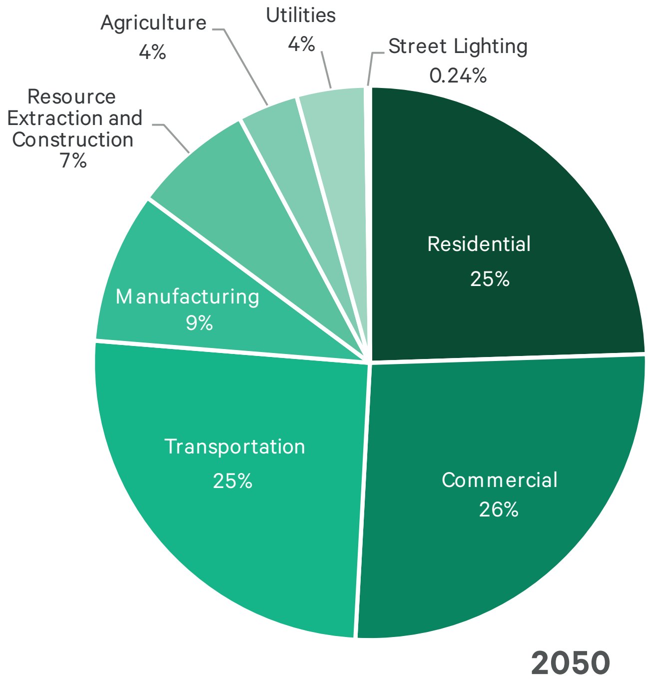
Electricity Demands

The Policy Baseline Scenario shows a doubling of electricity demands from 292 terawatt hours (TWh) in 2016 to 572 TWh in 2050 (Figure 3). The electricity demand for water (excluding industrial water demands)[4] makes up 6.6% of overall electricity demands in 2050. Of this, 12% is from residential water heating, 3% is from commercial heating, 23% is from agricultural water pumping, and the remaining 62% is from water treatment and distribution (part of the utilities sector).

The electricity demands for agricultural water pumping and water treatment and distribution vary across the years depending on water availability in a given climate. A drier climate increases electricity demands for water treatment and distribution by an average of 4.2% between 2017 and 2050, compared to the Policy Baseline Scenario. A hot or wet climate has a smaller impact of 1.5% and -0.3%, respectively. The change in these demands are even smaller when compared to total electricity demands.

Figure 3: Electricity demand breakdown in the baseline scenario in 2016 (292 TWh) (left) and 2050 (572 TWh) (right). Water sector electricity demands represent 6.6% of total electricity demands in 2050 from residential water heating, commercial water heating, agricultural water pumping, and water treatment and distribution (industrial water demands not included in this value).





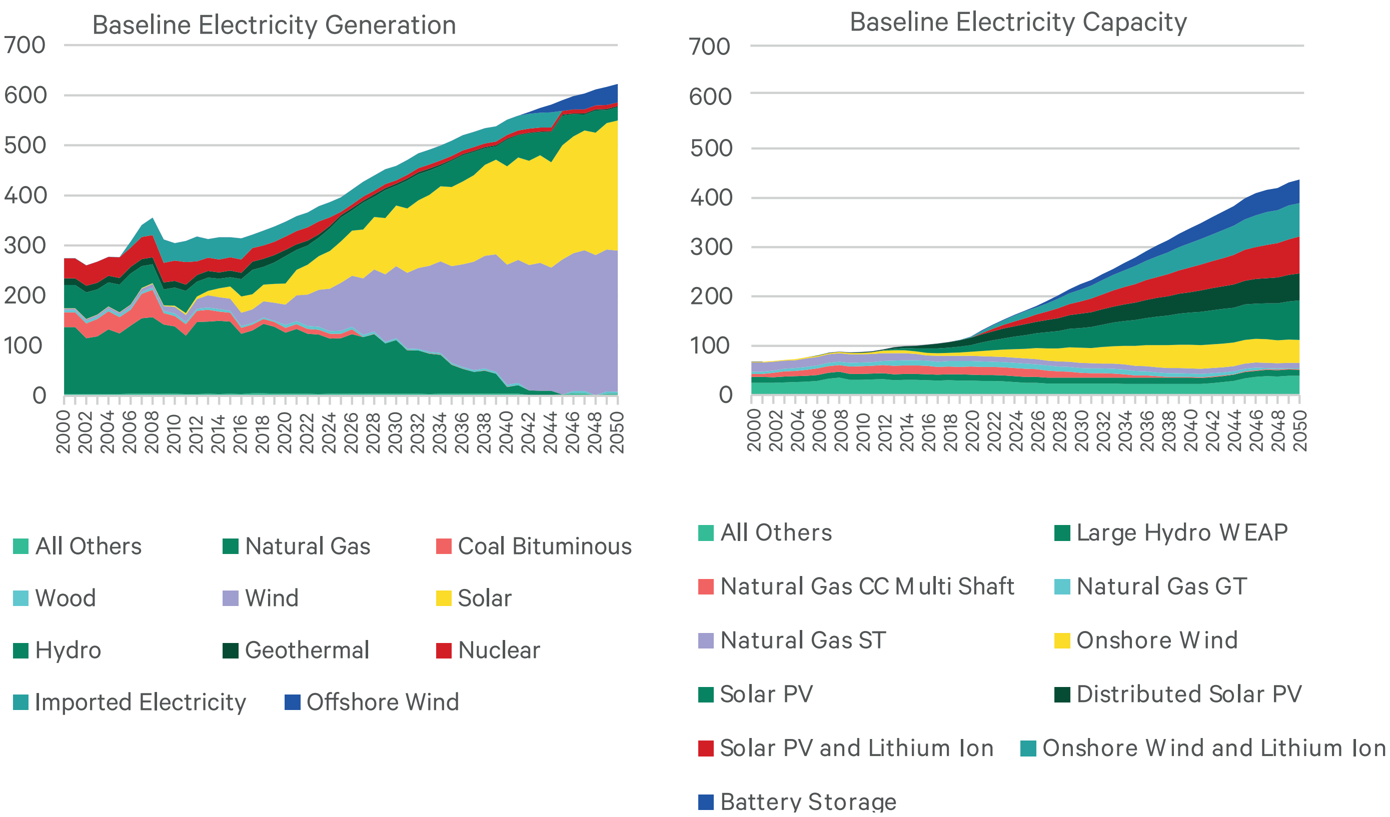
4 The model does not breakdown electricity demands by end use in the industrial sector.

Growth in zero-emission vehicles (ZEVs) dominates long-term electricity demand projections. Transportation electricity demands increase from essentially nothing today to 25% of final electricity demands in 2050. To achieve the 2030 target of 5 million passenger and light-duty ZEVs, annual ZEV sales are assumed to increase by 379% compared to current purchase rates. Beyond 2030, the model shows that by 2050, there would be 15.85 million ZEVs on the road if ZEV sales continue at the same rate.

Electricity Supply

Targets for renewable and carbon-free power drive a massive transformation of the electricity system in the Policy Baseline Scenario – from a gas-dominated system providing around 40% of production, to a system in 2050 where onshore wind and solar PV play leading roles (48% and 41% of production). Battery storage also plays a large role to support renewable growth. Hydropower output does not increase significantly over the period. The prominence of hydropower reduces over the years with the share of hydropower dropping to less than 5% by 2050.

Figure 4: The left graph shows the make-up of electricity generation under a scenario where California implements existing policies (2050 = 623 TWH). The right graph shows the electricity capacity under the same scenario (2050 = 436 GW).



Future Electricity Supply Scenarios

When looking across scenarios, we see that in several cases, the renewable target of 60% is met or slightly exceeded, as shown in Table 1. Due to projected cost reductions, renewable technologies continue to grow under the Federal Policy Interference Scenario, but they miss the 2030 and 2045 targets. In 2050, around 12% of the electricity generation in this scenario is from fossil fuel resources, as shown in Table 2, primarily from natural gas combined-cycle plants and imports. Low-carbon technologies that are not renewable include large hydropower and nuclear power plants (imported nuclear). These technologies appear to play an important role in the power system in meeting future clean electricity requirements across all scenarios, with the exception of No Hydropower.

Table 1: Output Shares by Scenario in 2030 under the Renewables Portfolio Standard Program (SB 100) with a 60% renewable target in 2030.

Type of Output	Policy Baseline	Desalination	Water Reuse	Wildfire Reduction	Federal Policy Interference	No Hydropower
Low Carbon	7%	7%	7%	7%	8%	2%
Fossil	31%	32%	31%	30%	42%	37%
Renewable	61%	61%	61%	62%	50%	61%

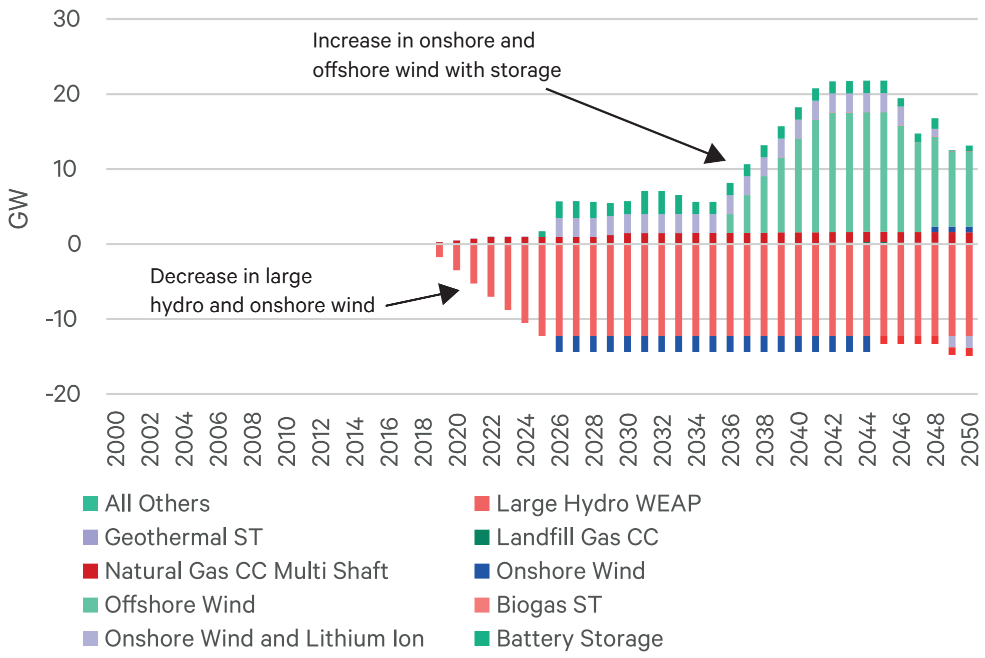
Table 2: Output Shares By Scenario in 2050 under the Renewables Portfolio Standard Program (SB 100) with a 100% carbon-free target in 2045.

Type of Output	Policy Baseline	Desalination	Water Reuse	Wildfire Reduction	Federal Policy Interference	No Hydropower
Low Carbon	5%	5%	5%	5%	4%	1%
Fossil	0%	0%	0%	0%	12%	0%
Renewable	95%	95%	95%	95%	84%	99%

No Hydropower Scenario

The phase-out of large hydropower in the No Hydropower Scenario shifts the addition of new capacity towards higher-cost wind (particularly offshore) and more storage. As a result, the costs of meeting the clean energy goals are around $31 billion higher in this scenario compared to the Policy Baseline (based on cumulative, discounted electricity production costs through 2050). This scenario demonstrates the importance of hydropower and its ability to provide dispatchable electricity at a reasonable cost, which is an important attribute in a system with high shares of variable renewable energy (VRE).

Figure 5: Difference in capacity between the Policy Baseline and No Hydropower Scenario



Water Reuse and Desalination Scenarios

Water reuse and desalination also have meaningful impacts on the costs of future electricity demands and electricity supply. This is particularly true when there is a high penetration of variable renewable energy (VRE), which carries a high marginal cost of electricity production. Each scenario reduces imports by an average of 320,000 acre-feet per year, thus also reducing the energy required to transfer water from the State Water Project. In the Water Reuse Scenario the net effect is a reduction in water treatment and conveyance needs, which decreases energy demands by 2 TWh/year. This saves $2 billion in electricity production costs,[5] when compared to the Policy Baseline Scenario.

Water conservation strategies not only lower electricity production requirements, but can free up water for low-cost hydropower generation. This benefit is especially valuable in high-VRE, high climate change scenarios. With water reuse, there is no net loss of hydropower generation in very dry/hot climate change scenarios (as compared to historical climate projections). Cumulative hydropower generation through 2050 actually increases. Without water reuse, electricity production costs rise in very dry/hot climate change scenarios compared to the historical climate projections (from $0.5 billion to $1 billion). With water reuse, these costs are between $1 billion and $2 billion less than they are in the historical climate projections.

Desalination is more energy intensive than conventional water treatment processes. Unlike the Water Reuse Scenario, the Desalination Scenario results in an increase of overall energy demands by 1.45 TWh/year and a $2 billion increase in the cumulative cost of electricity production, compared to the Policy Baseline.

Wildfire Reduction Scenario

The Wildfire Reduction Scenario increases energy system resiliency, though the extent of this is unclear. Distributed solar generation and energy storage are increasingly available at lower prices, and these technologies could address the impact of wildfires and associated loss of

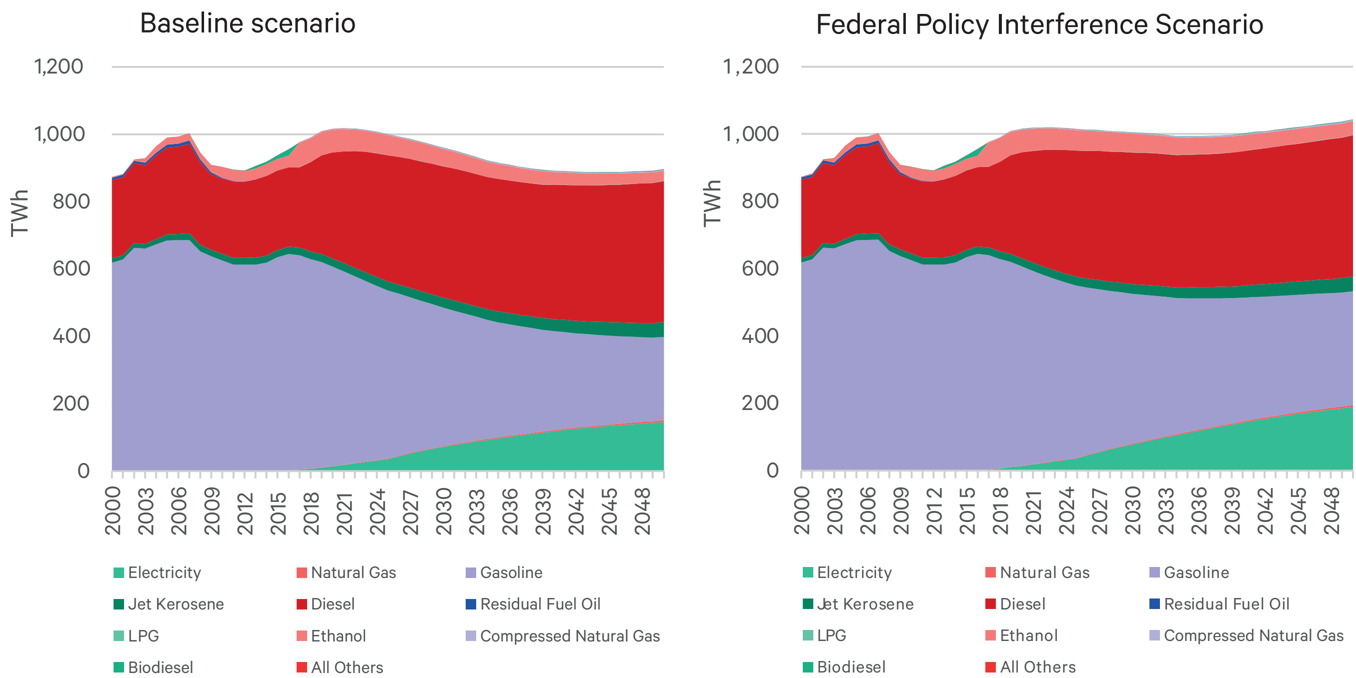
5 All costs are presented as cumulative costs discounted to 2012 US dollars.

power. However, more detailed modeling is needed to predict the cost (and potential savings) of implementing this scenario.

Federal Policy Interference Scenario

The Federal Policy Interference Scenario shows a 15% increase in total transportation energy demands (including electricity demands), compared to the Policy Baseline Scenario. Due to substantial increases in ZEV purchases in recent years, we assumed that the 5 million ZEV target could remain despite federal interference with fuel economy standards. Under this assumption, transportation emissions would still decrease in the Federal Policy Interference Scenario – but only by 7%, compared to 17% in the Policy Baseline Scenario. Despite the current suite of climate change mitigation policies, gasoline and diesel appear to be dominant fuels in both scenarios.

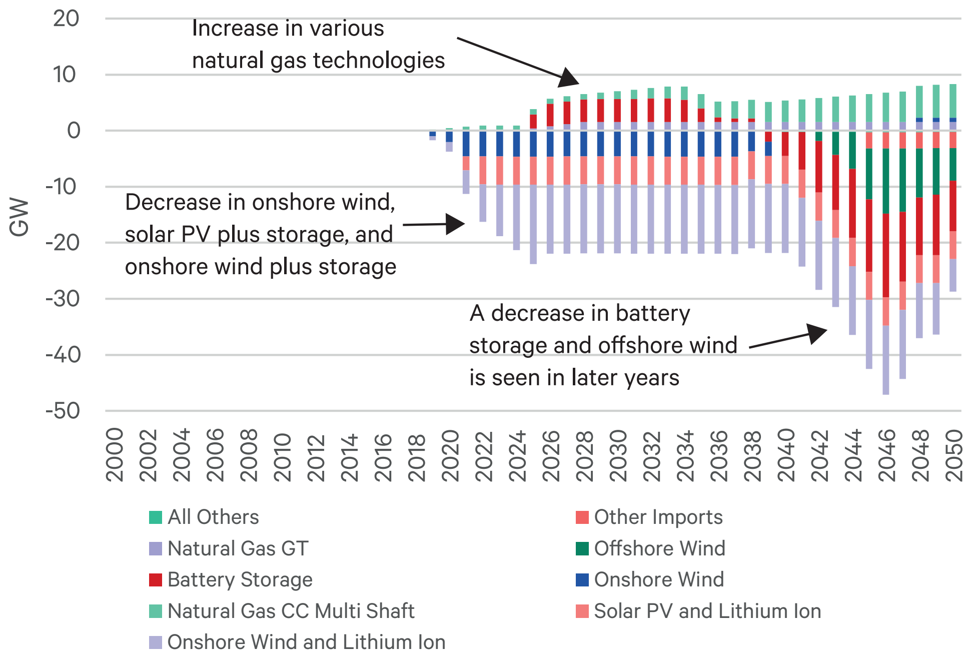
Figure 6: Comparison of transportation fuel demands in the baseline scenario (left) and Federal Policy Interference Scenario (right). Overall energy demands grow in the Federal Policy Interference Scenario.



As a result of the higher demands and removal of the renewable and low-carbon targets, there is a shift from wind and solar toward gas in electricity production, which increases electricity production costs by approximately $23 billion dollars higher than the Policy Baseline Scenario (based on cumulative, discounted electricity production costs through 2050). Carbon dioxide emissions increase by 54 million metric tons, or 16%, compared to the Policy Baseline Scenario.

This shift towards gas is small. Because of their cost-effectiveness, renewables still have a large role in the overall energy system, despite the removal of renewable target policies. Interestingly, large quantities of battery storage are added in this scenario to meet energy production requirements. There is no real effect on hydropower utilization, which is expected given its cost-effectiveness. Hydropower pays dividends regardless of what happens with federal policy.

Figure 7: Difference in capacity between the Policy Baseline and Federal Policy Interference Scenarios.



Discussion

Energy and water system resiliency in the context of climate change

These results underscore the interdependence of California's water and energy systems, as well as the value of water conservation in a changing climate. We found that precipitation varies greatly across a range of climate projections, affecting the quantity of freshwater sources in California. Low rainfall levels and short-term droughts affect agricultural water consumption, with farmers turning to groundwater sources to meet water needs; this can lead to groundwater abstraction at unsustainable rates (Chappelle et al. 2017). This, in turn, impacts energy demands, as abstracting groundwater requires pumping, which requires power (especially when pumping from deeper levels).

To ensure greater resiliency in a future with uncertain precipitation patterns, policy-makers could look to alternative sources of water supply. This could include water recycling and the desalination of brackish water and seawater. In this study, we found that potable reuse could save on energy production and costs, while desalination could increase them.

Despite some variability in water availability, low-cost hydropower continues to play a strong role in the electricity sector and in scenarios that meet California's 100% carbon-free targets. Distributed solar systems are also gaining traction, in response to recent wildfires; such systems, which may be disconnected from the grid, could diversify the energy system and provide greater energy system resiliency. We evaluated the increase of grid-connected battery storage systems to improve energy resiliency. One storage option with significant potential – not specifically evaluated here, but ripe for future modeling – is a zero-emission vehicle (ZEV) with a two-way charger. The planned growth in ZEVs could provide residential storage systems or greater grid stability (Coignard et al. 2018).

Potential for carbon neutrality in California

California aims to carbon-free by 2045. Meeting that target will mean changes in electricity generation, which makes up about 16% of the state's carbon emissions. Massive growth in solar, wind, and energy storage systems is key to achieving carbon neutrality in California. Regardless of targets, renewable technologies are on the rise; this study shows that their cost-effectiveness means they play a large role in California's energy future.

The growth of solar power has exploded over the last decade. Since 2013, California has added 1.5 GW of distributed solar and 1.5 GW of utility solar PV every year. To meet California's renewable and carbon-free targets, the growth rate of distributed solar could stay at about this rate (reaching 55 GW in 2050). The growth rate of utility solar PV, however, may have to increase to 4.5 GW, in order to reach the 155 GW shown under our Policy Baseline Scenario. To ensure a resilient provision of energy, policy-makers need to consider both solar PV systems packaged with storage and large-scale energy storage systems. Solar PV systems that are packaged with storage improve solar utilization, reduce curtailment (wasted energy), and provide grid stabilization. However, these packaged systems are different from large-scale energy storage systems, which can be dispatched quickly to meet varying system needs, such as to regulate frequencies or provide energy arbitrage for the grid.

The penetration of wind turbines has not increased as quickly as solar, but there is significant potential in California for its use. There has been very little offshore wind development in the past, but California is beginning to invest in this technology. Our results show that it is integral to the achievement of the carbon-free target.

In recent years, the rapid growth of variable renewable technologies has caused grid-related challenges in California. The electricity load plunges in the middle of the day when behind-the-meter distributed solar availability is high. This results in large peaks in the morning and evening to the point where the load curve looks like a duck (called the "duck curve"). Better grid integration to accommodate a greater amount of variable renewable energy will be vital for such a system to work. Smoothing out the peaks with more small or large-scale storage – or more regionally connected electricity networks – will be needed to provide the system with the flexibility it needs to operate variable renewables.

Aside from electricity generation, the transportation sector has a long way to go before it can reduce fossil fuels to achieve carbon neutrality. While the ZEV target is an important step, deeper decarbonization policies are needed, including higher ZEV targets across all vehicle types and better public transit infrastructure.

Conclusions

California's ambitious climate targets are within reach. But, as this study shows, they require policy-makers to plan for a future where water is more scarce and weather more extreme – and to understand the state's vulnerability across a range of economic, political and demographic shifts.

This study takes a first step, by developing the modeling tools to test out water and energy infrastructure options and to demonstrate how policies such as Senate Bill 350 (renewable energy and efficiency targets), SB 32 (GHG emissions targets), and Executive Order B-48-18 (zero-emission vehicle adoption) impact California's water and energy security. Under the CERC-WET partnership, we gathered information on the decisions, political shifts, and climate impacts that affect California's future. We developed baseline information – and built trust – by working with policy-makers at the highest levels of California government, including WET-CAT. The result is a peek into the actions necessary for deep decarbonization. Further efforts could test out potential policies – such as higher ZEV targets and city-specific targets – so that policy-makers can weigh trade-offs and make informed decisions that lead to a sustainable, resilient future.

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