Impacts of California's Ongoing Drought:

Hydroelectricity Generation

2015 Update

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INTRODUCTION

Drought continued to afflict California through 2015, making the last four years the driest and the hottest in the instrumental record and one of the worst droughts in memory. Impacts on local communities, ecosystems, and the economy have continued to grow. These consequences are widespread but unevenly distributed and include impacts on all water users, including farmers, industry, cities, and natural ecosystems that depend on water quantity, timing of flows, and waters of particular quality. This analysis examines the impacts of drought on hydropower production, which depends on water available at specific times to flow through turbines that generate electricity. It provides an update of a report released last year (Gleick 2015) that evaluated these impacts during the first three years of the drought.

The Pacific Institute has regularly analyzed the consequences of California droughts, beginning with comprehensive assessments of the serious 1987-1992 drought (Gleick and Nash 1991; Nash 1993), the 2007-2009 drought (Christian-Smith et al. 2011), and the current 2012-2015 drought (Cooley et al. 2015; Gleick 2015). This analysis finds that during the four years ending September 30, 2015 (the end of the 2015 "water year"), hydropower generation was substantially below average, and the added economic cost to California ratepayers of reduced hydroelectricity production was approximately $2.0 billion.[1] The additional combustion of fossil fuels for electric generation also led to a 10% increase in the release of carbon dioxide from California power plants (CARB 2015). As of the publication of this analysis in early 2016, the drought has not yet ended.

1 All cost estimates have been adjusted for inflated and are reported in year 2015 dollars.

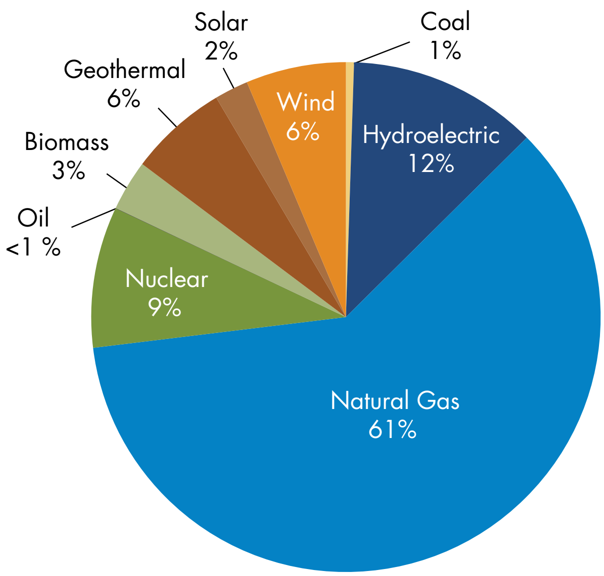
BACKGROUND: CALIFORNIA'S ELECTRICAL GENERATING SYSTEM

In California – and elsewhere – there are strong links between water use and energy production – sometimes referred to as the water-energy nexus.[2] In particular, water is used to cool thermal power plants (typically coal, oil, natural gas, nuclear, and geothermal) and to drive hydroelectric turbines. Electricity generated at the hundreds of major hydropower stations in California is relatively inexpensive compared to almost every other form of electricity generated, produces few or no greenhouse gases, and is extremely valuable for 'load-following' and satisfying peak energy demands, often the most difficult and costly forms of electricity to provide. In 2013, hydropower represented 12% of in-state electricity generation (Figure 1), while more than 60% of in-state electricity was from fossil fuels, largely natural gas. Other non-carbon emitting sources, such as solar, wind, biomass, geothermal, and nuclear, made up 26% of the state's electricity.

2 For more detail and references on this issue, see "Water-Energy Nexus," http://pacinst.org/issues/water-energy-nexus/.

Figure 1.

California in-state electricity generation by source, 2013.



Note: Additional electricity is generated in other states and sent to California, but details on the sources and variations due to drought are not available. This graph shows in-state generation by source.

Source: CEC 2015

The amount and value of hydroelectricity generated is a function of water flows in California's rivers, the amount of water stored in reservoirs, and the way those reservoirs are operated. Hydroelectricity production rises in winter and spring months with increased runoff and drops during late summer, fall, and early winter when natural runoff is low. Figure 2 shows monthly electricity produced in California from January 2001 to the end of the 2015 water year by major generating source.[3] In wet years, hydroelectricity generation increases; during dry years, and especially during droughts, total hydroelectricity generation drops (Figure 3). Moreover, a linear trend fitted to the data shows that hydroelectricity generation has been declining over the past 15 years, largely due to drought conditions.

Not surprisingly, hydroelectricity generation correlates directly with actual runoff in California rivers. Figure 4 shows total hydroelectricity

3 A gigawatt-hour is a thousand megawatt hours or a million kilowatt-hours.

Figure 2.

Monthly electricity generation, in thousand megawatt-hours per month, in California by source, 2001-2015.

Natural gas
Wind, Solar
Hydroelectricity
Nuclear

Source: US EIA 2015

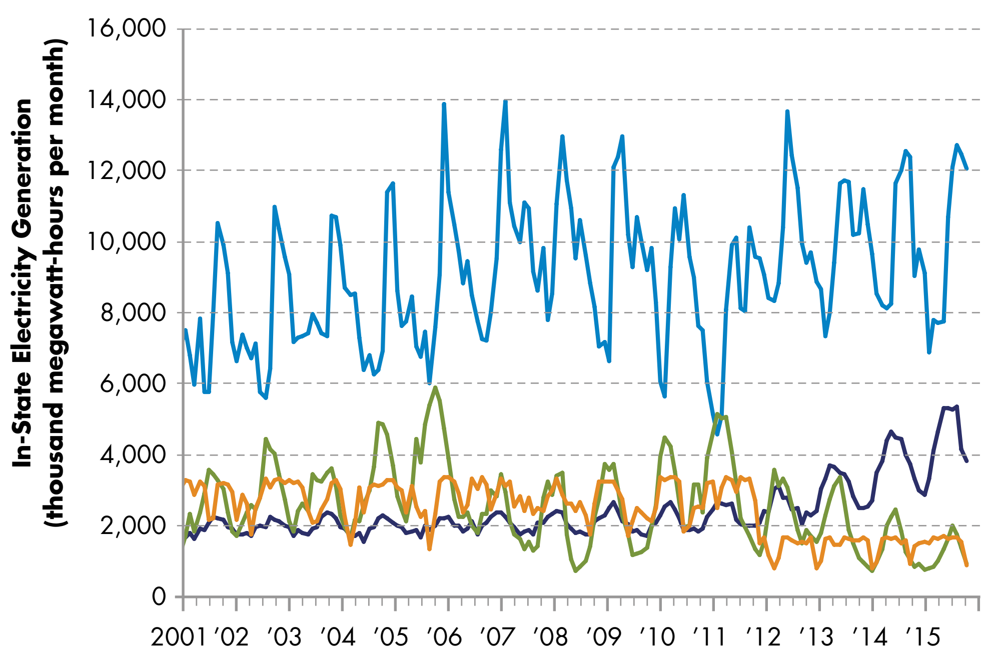


Figure 3.

Total hydroelectricity generation, in thousand megawatt-hours per month, in California, Water Years 2001-2015.

Note: A linear trend is plotted over the period 2001-2015

Source: US EIA 2015

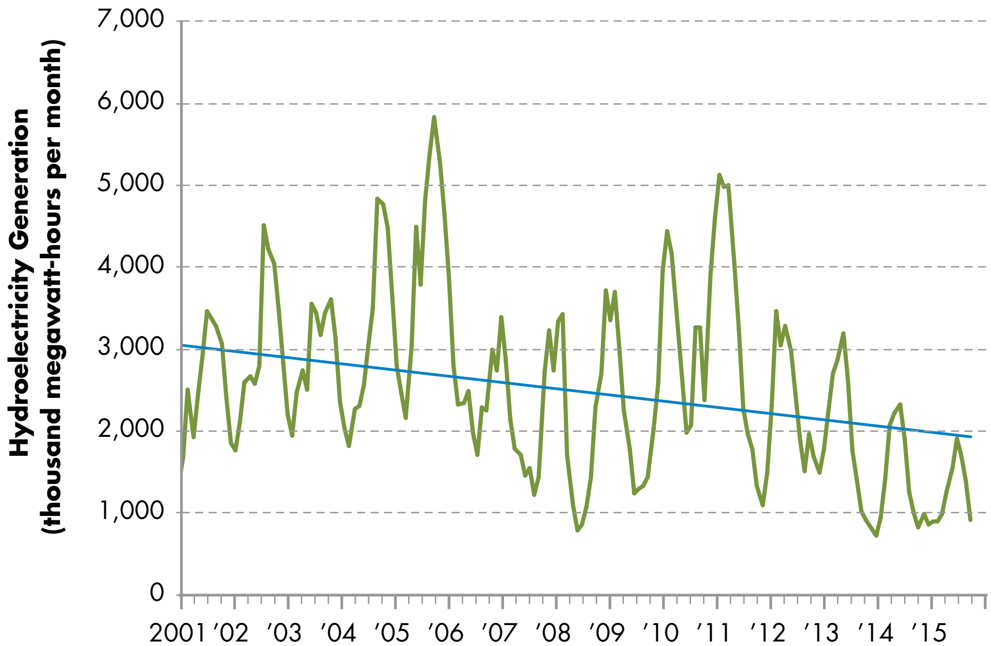


Figure 4.

California hydroelectricity generation versus water-year runoff, 1983-2014.

Note: Plotted using a linear regression.

Source: US EIA 2014; CDWR 2014

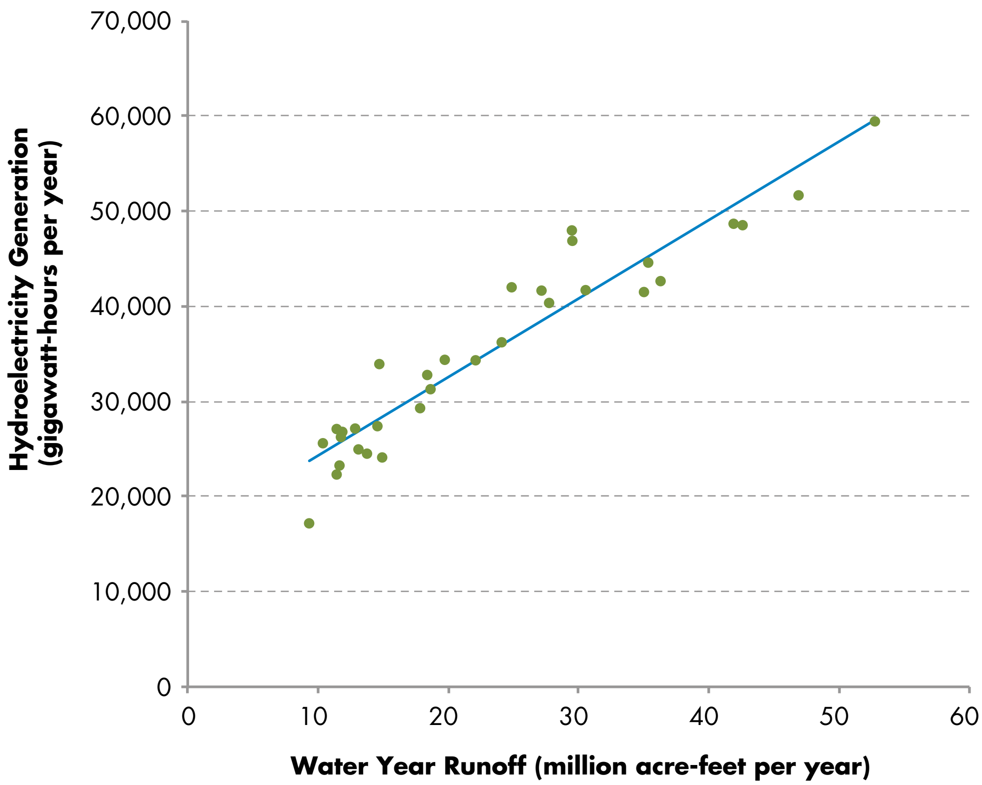
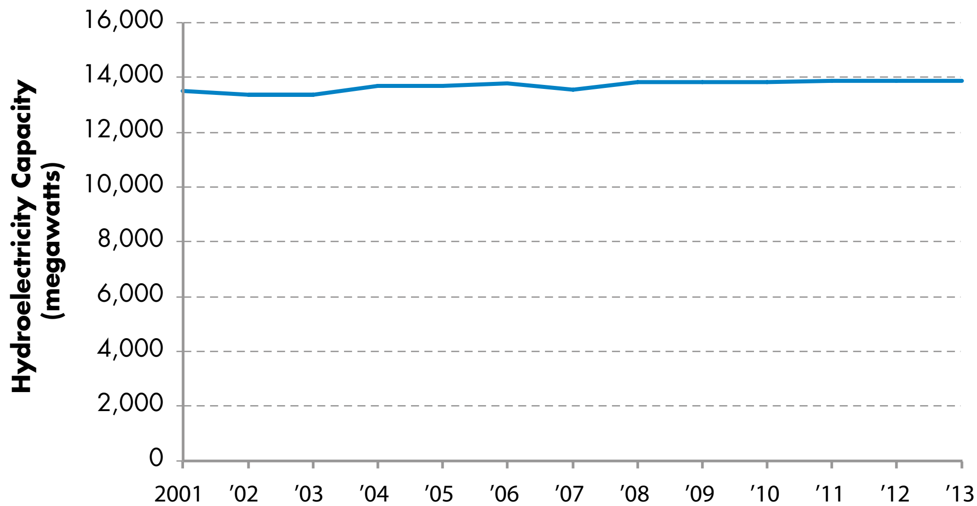


Figure 5.

Total installed capacity, in megawatts, of California hydroelectricity, 2001-2013.

Note: Includes both large and small hydrological plants. No significant additions occurred in 2014 or 2015.

Source: CEC 2015



generation in California from 1983 to 2014 (2015 unimpaired runoff data were not available at the time of this analysis), plotted against the unimpaired natural water flows in the Sacramento and San Joaquin Rivers by water year (October 1 to September 30).[4] The correlation between the two curves is strong: when runoff falls, hydroelectricity production falls, and when runoff is high, hydroelectricity production increases.

While it is increasingly difficult to find a "normal" water year in California, in-state electricity generation (excluding power imported from outside the state) from hydropower facilities averaged 18% from 1983 to 2013. The percentage has diminished as demand for electricity has continued to grow, but total installed hydroelectricity capacity has remained relatively constant at around 14,000 megawatts (MW) (Figure 5). Indeed, the ability to expand California's hydroelectric capacity is limited, as there are few undammed rivers, little unallocated water, and growing environmental, economic, and political constraints to adding new hydropower capacity.

4 Unimpaired runoff refers to the amount of runoff that would be available in a system without human consumptive uses. Because almost all hydroelectricity production occurs in upstream reaches of California rivers, before withdrawals for cities and farms, this is an appropriate dataset to apply.

Box 1.

The Water Year versus the Calendar Year

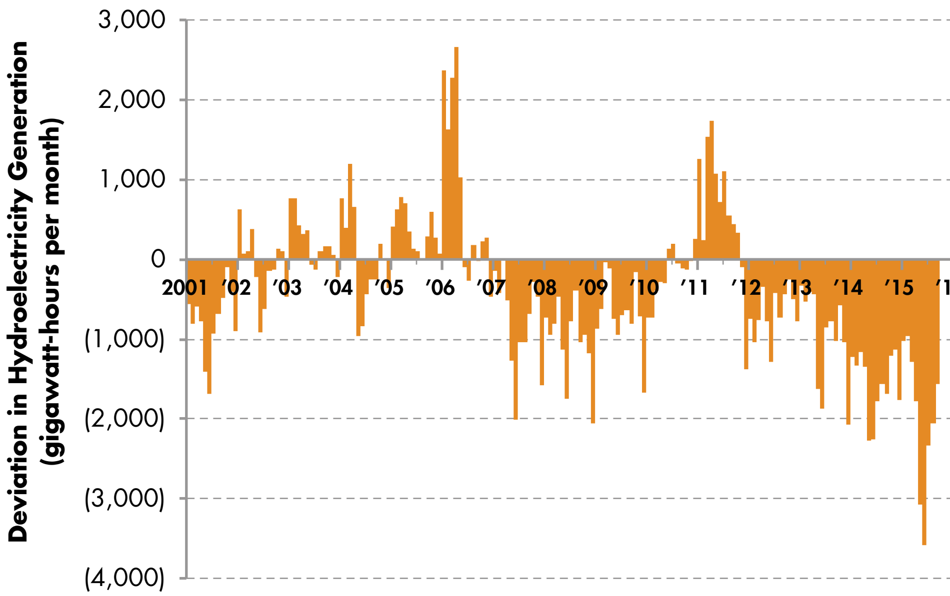
While the calendar year runs January 1 to December 31, the "water year" in California runs from October 1st to September 30th of the following year. Water managers and hydrologists evaluate moisture records over the water year rather than the traditional calendar year. The water year is defined this way because California has a Mediterranean-type climate with a distinct wet and dry season. The wet season begins October 1st and ends in spring, around mid-April, followed by a period with effectively no precipitation, from April through September.

The water years is designated by the calendar year in which it ends: thus the period October 1, 2013 to September 30, 2014 is called the 2014 water year. Unless otherwise explicitly mentioned, the results presented here for the four drought years of 2012 through 2015 are from October 1, 2011 through September 30, 2015. The same definition of "water year" is also used by the U.S. Geological Survey.

Figure 6.

Deviations in hydroelectricity generation, in gigawatt-hours per month, 2001 through September 2015.

Source: Computed here from US EIA (2015) electricity data to the end of September 2015 compared to generation during average hydrologic years.



THE EFFECTS OF DROUGHT ON CALIFORNIA HYDROELECTRICITY GENERATION

As noted above, when less water is available in rivers or stored in reservoirs, less hydroelectricity is generated. During the 2007-2009 drought in California, hydroelectricity production accounted for around 13% of the state's overall electricity generation (Christian-Smith et al. 2011), down from an average of 18%. The current drought is more severe, and hydropower generation is even lower, at 10.5% of total electricity generation during the four-year period from October 2011 through September 2015. For the 2015 water year overall, hydropower was especially low, providing less than 7% of total electricity generated in-state. Figure 6 shows the drop in hydroelectricity generation by month from average monthly generation levels during typical water years. In these periods, reductions in hydropower were made up primarily by burning more natural gas, increasing purchases from out-of-state sources, and expanding wind and solar generation.

ECONOMIC AND ENVIRONMENTAL IMPACTS OF REDUCED HYDROELECTRICITY

Hydropower, including both fixed and variable costs, is considerably less expensive than other forms of electricity. As a result, the drought has led to a direct increase in electricity costs to California ratepayers. Using estimates of hydroelectricity generation from the California Energy Commission and the U.S. Energy Information Administration (U.S. EIA), we estimate that during the four-year drought (2012-2015) hydroelectricity generation was reduced by approximately 57,000 gigawatt hours (GWh) compared to the long-term average and replaced by a mix of energy sources, at the variable marginal cost. During that period, the average monthly marginal cost of California's electrical system varied between two and just over six cents per kilowatt-hour (CAISO 2015; personal communication, Eric Cutter 2015, 2016; Klein 2010).[5] To calculate the impact on electricity costs, we averaged the hourly marginal cost data over each month from 2012 to 2015 to compute

5 Computed by the author from the Locational Marginal Price (LMP) for Day Ahead energy for the NP15 APNode (NP15_GEN-APND) downloaded on January 19, 2015 (for 2012-2014) and January 5, 2016 (for 2015) http://oasis.caiso.com/. Personal communication, Eric Cutter 2015, 2016; Klein 2010. This represents the specified price per MWh of electricity for delivery on a specified date, stated in U.S. dollars, published by the California ISO.

an average monthly marginal electricity cost. Using the monthly hydropower anomalies in Figure 6, we estimate that the total reductions in hydroelectricity generation during the 2012-2015 drought increased statewide electricity costs[6] by approximately $2.0 billion.

There is growing concern by climatologists that the current drought may be part of a longer trend (Swain et al. 2014; Mann and Gleick 2015). Indeed, when the past 15 years are viewed (in Figure 6), it is apparent that the shortfall in hydroelectricity includes the three-year drought period beginning in 2007, with a brief respite of average or slightly above average hydroelectricity generation during 2010 and 2011. When these longer-term water shortfalls over the past decade are taken into account, California's electricity is becoming more expensive on average. Assuming the marginal costs for electricity during the 2007-2009 drought were approximately the same as between the 2012 and 2015 water years, the full additional costs to California electricity customers of seven years of drought were a reduction of 85,000 GWh of hydroelectricity and an increased cost exceeding $3 billion.

On average, however, we note that under stable climate conditions ("hydrologic stationarity"), decreases in hydrogeneration in dry years should be balanced with increases in generation during wet years. As shown in Figures 3 and 5, however, there appears to be a downward trend in hydroelectric generation unrelated to changes in installed generation capacity. This raises the question of the role of climate change in affecting long-term hydrologic conditions in the state – a question beyond the scope of this analysis, but one that researchers are actively pursuing (Vine 2012; Madani et al. 2014; Diffenbaugh et al. 2015; Mann and Gleick 2015).

In addition to the direct economic costs of replacing hydroelectricity generation, there are environmental costs associated with the additional combustion of natural gas, including increased air pollution in the form of nitrous oxides (NO_x), volatile organic compounds (VOCs), sulfur oxides (SO_x), particulates (PM), carbon monoxide (CO), and carbon dioxide (CO_2) – the principal greenhouse gas responsible for climatic change. Using standard emissions factors from the California Air Resources Board and the California Energy Commission for combined cycle natural gas systems (Table 1), the 2012-2015 drought led to the emissions of substantial quantities of additional pollutants (Table 2). These emissions included up to 23 million tons of additional carbon dioxide, or about a 10% increase in CO_2 from California power plants over the same four-year period, along with substantial quantities of nitrous oxides, volatile organic chemicals, particulates, and other pollutants (CARB 2015).

Many of these pollutants are known contributors to the formation of smog and triggers for asthma. No estimates of the health impacts or the economic costs of these increased emissions are included here. This also excludes unintentional emissions of greenhouse gases that may occur throughout the natural gas fuel cycle, such as the massive methane emissions associated with the Porter Ranch leak in California, which as of early 2016 remains uncapped (Walton and Myers 2016).

6 Hourly marginal costs of electricity in California from 2012 through 2015 were provided by E. Cutter from the hourly "Day Ahead CAISO price data for NP15" (Personal communication, E. Cutter, 2015, 2016). Klein (2010) includes detailed and careful descriptions of the advantages and limitations of using single-point levelized costs. For the purposes of this assessment, we use the actual monthly marginal costs of electricity over the drought period calculated from the hourly data.

We note that these estimates are somewhat uncertain, assuming that all additional natural-gas combustion came from efficient combined cycle systems rather than conventional or advanced simple cycle natural gas systems, where emissions are higher due to lower efficiencies of combustion. They also assume that natural gas made up the entire shortfall in hydroelectricity, though recent rapid expansion of renewable energy sources has caused some load management complications that make it difficult to precisely identify which energy sources displace lost hydroelectricity on an hour-to-hour basis.[7]

Table 1.

Criteria air pollutant emissions factors, in pounds per megawatt-hour, for conventional combined cycle natural gas generation.

NO_x	VOC	CO	SO_x	PM2.5	CO_2
0.07	0.21	0.1	0.01	0.03	810

Note: Criteria air emissions factors from stationary source natural gas power plants. Numbers rounded to one or two significant figures, as appropriate. NO_x stands for nitrous oxides, VOC for volatile organic compounds, CO for carbon monoxide, SO_x for sulfur oxides, PM2.5 for particulate matter (with a diameter of 2.5 micrometers), and CO_2 for carbon dioxide.

Source: Loyer and Alvarado 2012; Christian-Smith et al. 2011.

Table 2.

Total additional emissions, in tons, from natural gas use during the 2012-2015 drought.

NO_x	VOC	CO	SO_x	PM2.5	CO_2
2,000	6,000	3,000	300	900	23,000,000

Note: Numbers rounded to one or two significant figures, as appropriate. NO_x stands for nitrous oxides, VOC for volatile organic compounds, CO for carbon monoxide, SO_x for sulfur oxides, PM2.5 for particulate matter (with a diameter of 2.5 micrometers), and CO_2 for carbon dioxide. Several of these are greenhouse gases (GHGs) that contribute to climate change.

Source: Loyer and Alvarado 2012; Christian-Smith et al. 2011.

SUMMARY

Droughts have a wide range of economic, social, and environmental costs. Among these costs are reductions in river flows and the generation of hydroelectricity, which must be replaced by other energy sources. Hydroelectricity is less expensive and, in most cases, less polluting than other electricity sources. In California, the marginal source of electricity is typically natural gas, which is both more costly (based on real time purchase prices from the grid) and more polluting than hydroelectricity. For the four years from October 2011 through the end of the 2015 water year, California experienced a reduction of around 57,000 GWh of hydroelectricity compared to average water years, at a cost to ratepayers of approximately $2.0 billion. In addition, the combustion of replacement natural gas led to a 10% increase in emissions of carbon dioxide, as well as added emissions of other pollutants from California power plants during this period. As of early 2016, the drought continues: reservoir levels remain abnormally low, precipitation and especially Sierra Nevada snowpack are marginally above normal, and hydrogeneration is expected to continue to be below average until reservoirs refill. Thus, we expect costs to California ratepayers and to the environment will continue to mount.

7 With only rare exceptions, 100% of electricity from renewables is fed into the grid, while natural gas generation is the marginal source.

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