Impacts of California's Ongoing Drought: HYDROELECTRICITY GENERATION

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Peter H. Gleick is co-founder and president of the Pacific Institute. He works on the hydrologic impacts of climate change; sustainable water use, planning, and policy; and international conflicts over water resources. Dr. Gleick received a B.S. from Yale University and an M.S. and a Ph.D. from the University of California at Berkeley. He is a MacArthur Fellow, an academician of the International Water Academy, a member of the U.S. National Academy of Sciences, and the author of many scientific papers and books, including the biennial water report *The World's Water* and *Bottled and Sold: The Story Behind Our Obsession with Bottled Water*.

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Introduction

From 2012 through 2014, the State of California experienced one of the worst droughts in recorded history. This three-year period is both the driest and the hottest in the instrumental record, and there is evidence of growing adverse impacts for communities, ecosystems, and the economy.

Drought consequences are widespread, but unevenly distributed. They include impacts on all water users, including farmers, industry, cities, and natural ecosystems that depend on water quantity, timing of flows, or waters of particular quality. This paper examines the impacts of drought on the production of hydropower, which is directly dependent on quantities of water available at specific times to flow through turbines that generate electricity.

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) and most recently with an analysis of the 2007-2009 drought (Christian-Smith et al. 2011). Here, we examine one aspect of the current drought: the impacts to hydropower generation and the cost of those impacts. Future studies over the coming months will examine other drought-related consequences.

Our analysis find that during the three years ending in October 2014 (the end of the 2014 "water year"), the "cost" to California ratepayers of reduced hydroelectricity production and the use of additional natural gas was approximately $1.4 billion dollars. The additional combustion of fossil fuels for electric generation caused an eight percent increase in

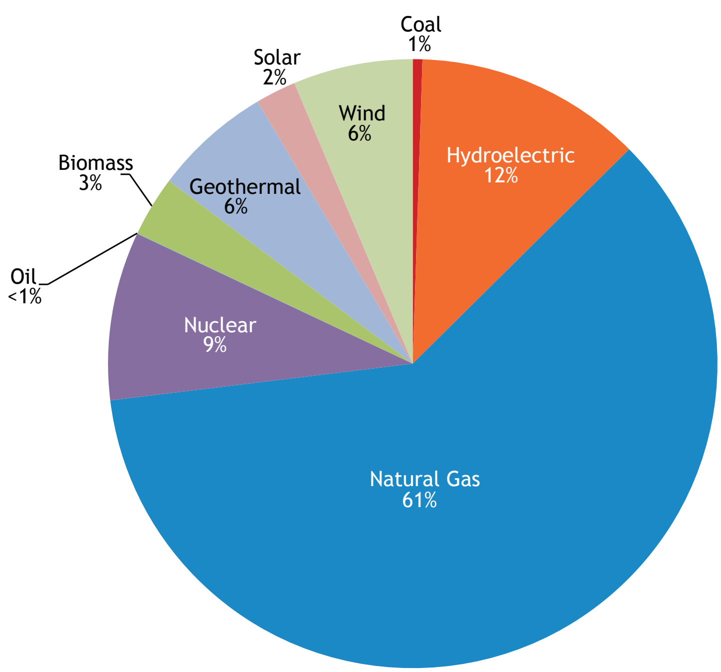

Figure 1. California In-State Electricity Generation by Source, 2013

Notes: 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)

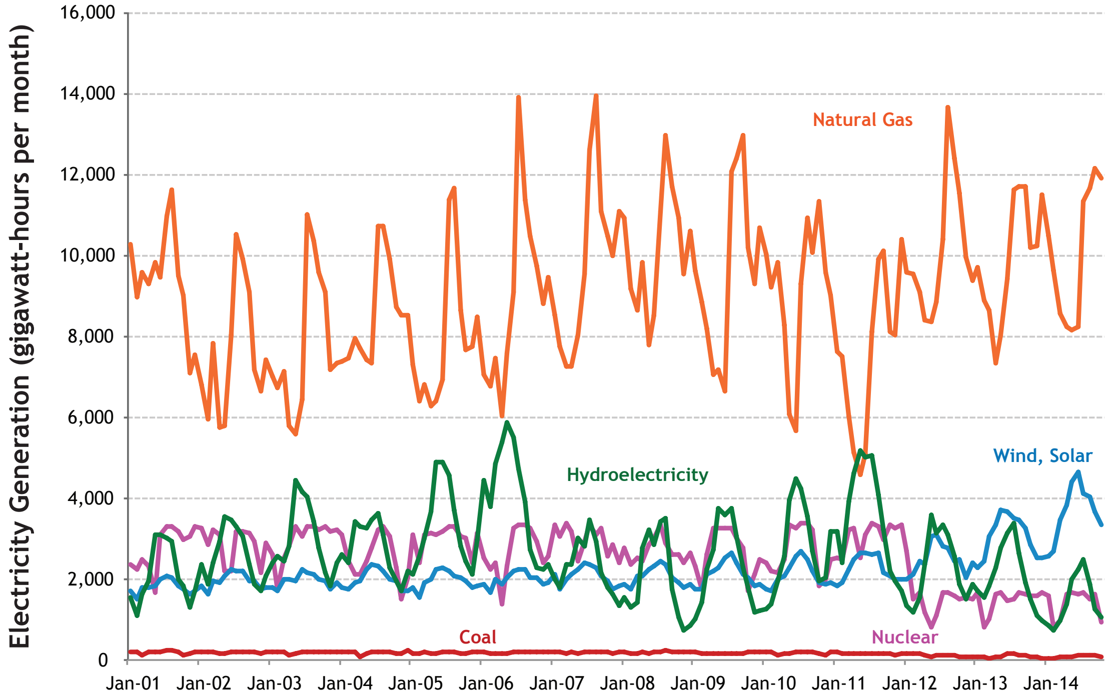

Figure 2. Monthly Electricity Generation in California by Source, 2001-2014

Source: Data from the US Energy Information Administration (2014)

the release of carbon dioxide from California power plants (CARB 2015). As of the publication of this analysis in March 2015, that drought has not yet ended and we expect these costs to rise further.

Background: California's Electrical Generating System

The State of California benefits from a diverse electricity generation system. More than 60 percent of in-state electricity in 2013 came from fossil fuels, largely natural gas. Other sources, such as solar, wind, biomass, geothermal, and nuclear, made up 26 percent of the state's electricity. Hydroelectricity provided approximately 12 percent of in-state electricity that year (Figure 1).

The amount of electricity generated from each source varies with availability, cost, the form and location of consumer demand, and other factors. Figure 2 shows monthly electricity produced in California from January 2001 to the end of the 2014 water year by major generating source.[1] As this figure illustrates, 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.

In California – and elsewhere – there are strong links between water use and energy production – sometimes referred to as the water-energy

[1] A gigawatt-hour is a million kilowatt-hours.

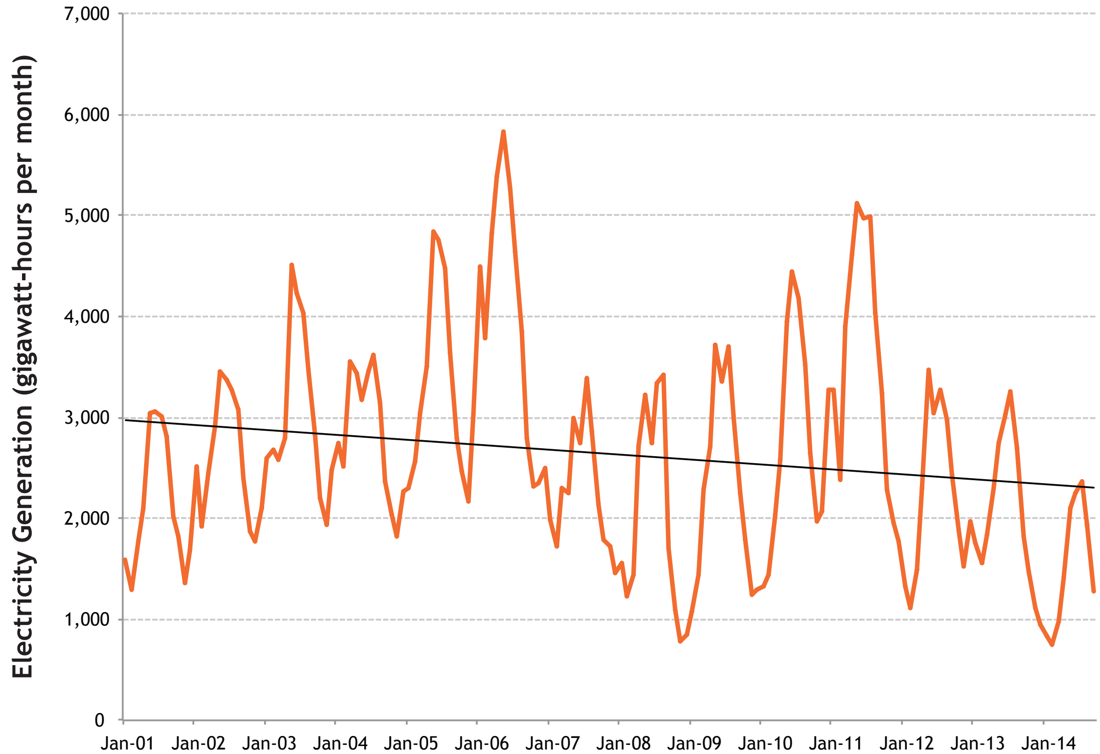

Figure 3. Total Hydroelectricity Generation in California, 2001-2014

Note: A linear trend is plotted over the period 2001-2014.
Source: US EIA 2014

nexus.[2] In particular, substantial amounts of water are required to cool thermal power plants (typically coal, oil, natural gas, nuclear, and geothermal), and water is used directly 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 generation; it produces few or no greenhouse gases; and it is extremely valuable for 'load-following' and satisfying peak electricity demands, which are often the most difficult and costly forms of electricity to provide.

The amount and value of hydroelectricity that can be generated in any given year is a function of water flows in California's rivers, the amount of water stored in reservoirs, and the way those reservoirs are operated. In wet years, hydroelectricity generation increases; during dry years, and especially during droughts, total hydroelectricity generation drops. Figure 3 shows monthly hydroelectricity generation from 2001 through the end of the water year in 2014, along with the linear trend over this period.

These data correlate directly with actual runoff in California rivers. Figure 4 shows total hydroelectricity generation in California from 1983 to 2014, plotted against the unimpaired natural water flows in the Sacramento and

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

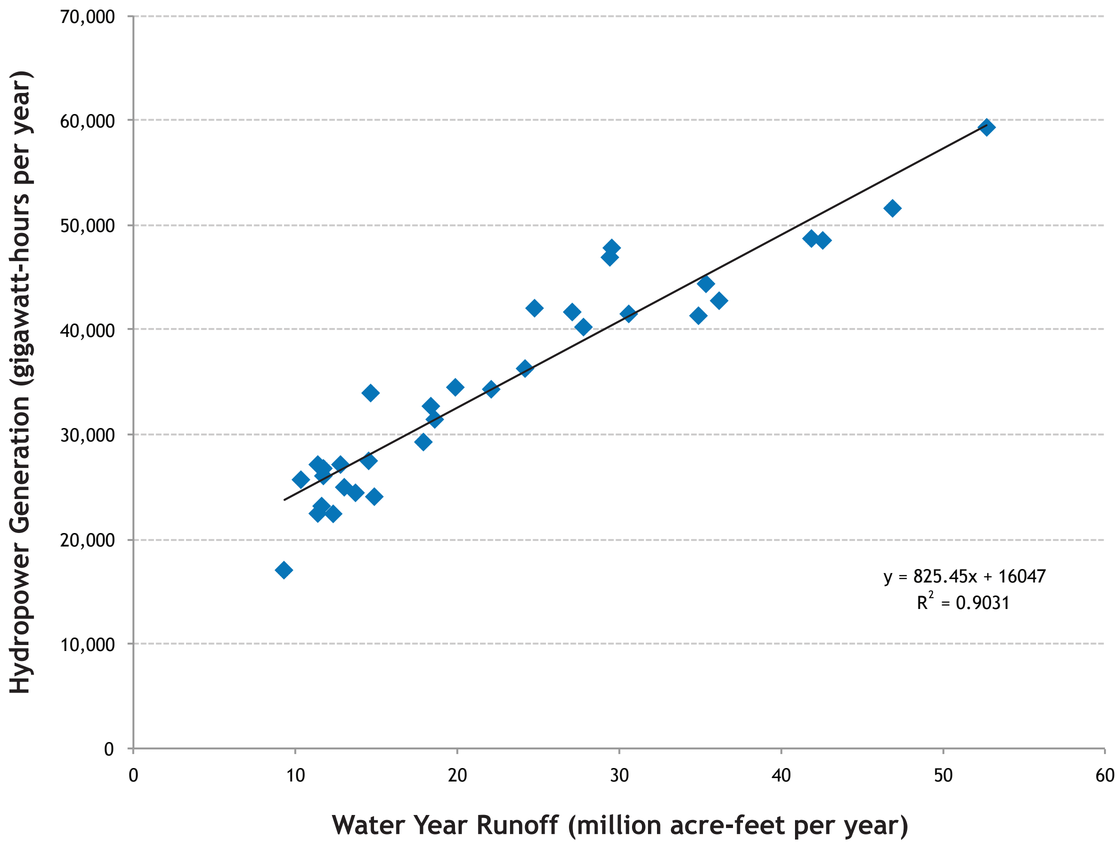

Figure 4. California Hydroelectricity Generation versus Water-Year Runoff in the Sacramento/ San Joaquin Rivers, 1983 to 2014.

Source: Data on hydroelectricity production from the US Energy Information Agency; data for unimpaired runoff from the Department of Water Resources. (US EIA 2014, CDWR 2014)

San Joaquin Rivers by water year (October 1 to September 30).[3] 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 percent from 1983 to 2013. The percentage has diminished as demand for electricity has continued to grow (Figure 3), but total installed hydroelectricity capacity has remained relatively constant (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.

[3] 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.

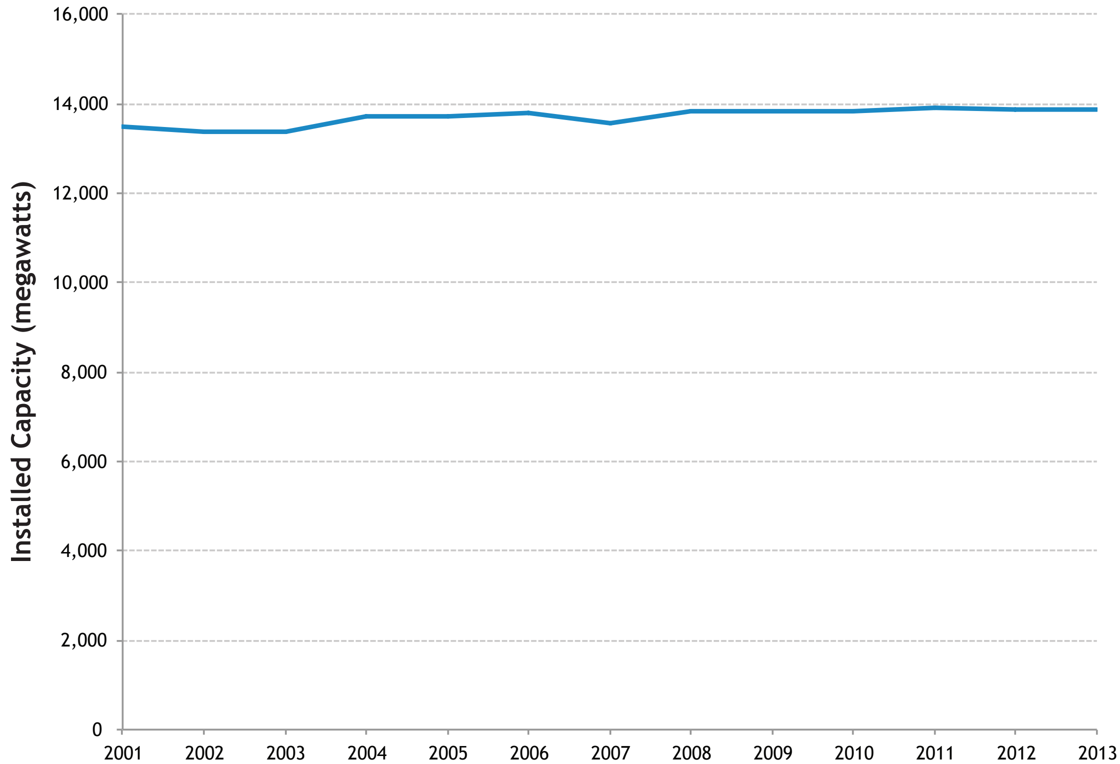

Figure 5. Total Installed Capacity of California Hydroelectricity, 2001-2013

Notes: Includes both large and small hydroelectricity.
Source: CEC (2015)

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 only around 13 percent of the state's overall electricity generation (Christian-Smith et al. 2011), down from an average of 18 percent.[4] In the current drought period, extending from October 2011 through September 2014, hydroelectricity made up less than 12 percent of total electricity generation. 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 Impacts and Environmental Costs 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 from the California Energy Commission and the U.S. Energy Information Administration (U.S. EIA) of hydroelectricity generation, we calculate that, during the most recent three-year drought

[4] Assumed here to be an average of two relatively normal hydrologic years 2003 and 2010, based on unimpaired flow data from the Sacramento and San Joaquin River Basins.

(2012-2014), hydroelectricity generation was approximately 34,000 gigawatt hours (GWh) lower than the long-term average. During that period, 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; Klein 2010).[5] In order to calculate the impact on electricity costs, we averaged the hourly marginal cost data over each month from 2012 to 2014 to compute an average monthly marginal electricity cost. Using the monthly hydropower anomalies in Figure 6, we then estimated that the total reductions in hydropower generation during the 2012-2014 drought increased statewide electricity costs by approximately $1.4 billion.[6]

There is growing concern by climatologists that the current drought may be part of a longer trend (see, for example, Swain et al. 2014). Indeed, when the past 15 years are viewed (in Figure 3), 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 precipitation during 2010 and 2011. When these longer-term water shortfalls over the past seven years 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 2014 water years, the full additional costs to California electricity customers of six years of drought were a reduction of 62,000 GWh of hydroelectricity and an increased cost of approximately $2.4 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

Box 1. The Water Year versus the Calendar Year

The calendar year runs January 1 to December 31. The "water year" in California, however, 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 year 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 three drought years of 2012 through 2014 are from October 1, 2011 through September 30, 2014. The same definition of "water year" is also used by the U.S. Geological Survey.

[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. http://oasis.caiso.com/. Personal communication, Eric Cutter 2015; 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.

[6] Hourly marginal costs of electricity in California from 2012 through 2014 were provided by E. Cutter from the hourly "Day Ahead CAISO price data for NP15" (Personal communication, E. Cutter, 2015). 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.

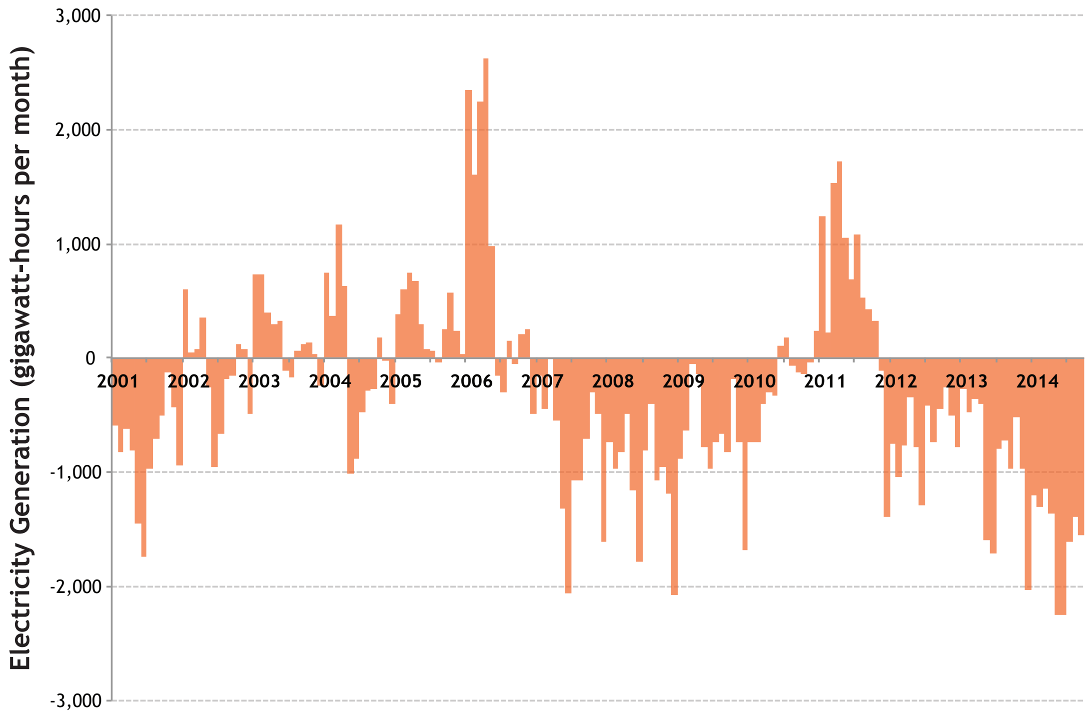

Figure 6. Monthly Anomalies in Hydroelectricity Generation Due to California Drought, 2001 through September 2014

Source: Computed here from USEIA (2014) electricity data to the end of September 2014 compared to generation during average hydrologic years.

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 (see, for example, Vine 2012, Madani et al. 2014).

Other Environmental Costs Associated with Reduced Hydroelectricity Generation

In addition to the direct economic costs of replacing lost 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 (PM2.5), 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, the 2012-2014 drought led to the emissions of substantial quantities of additional pollutants (Table 1). We estimate that these emissions included nearly 14 million tons of additional carbon dioxide, or about an eight percent increase in CO_2-equivalent emissions from California power plants over the same three-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. An evaluation of the actual health impacts of these increased emissions is complex and beyond the scope of this study.

Table 1. Criteria Air Pollutant Emissions Factors and Total Additional Emissions for Natural Gas Generation During the 2012-2014 Drought

	NO_x	CO	SO_x	PM2.5	CO_2
Emissions factors (pounds per MWh)	*0.07*	*0.1*	*0.01*	*0.03*	*810*
Additional emissions from natural gas use (tons)	1,000	2,000	200	500	14,000,000

Note: Numbers rounded to one or two significant figures, as appropriate. NO_x stands for nitrous oxides; CO for carbon monoxide; SO_x for sulfur oxide; PM2.5 for particulate matter with a diameter of 2.5 micrometers; and CO_2 for carbon dioxide. Some of these are greenhouse gases that contribute to climate change. Additional volatile organic compounds are emitted and contribute to air pollution, at rates depending on the technologies used. We do not compute VOC emissions here.

Source: Emissions factors are for conventional combined cycle natural gas generation based on Loyer and Alvarado (2012) and Christian-Smith et al. (2011).

We note that these estimates are conservative, 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.

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 made up with other energy sources. In California, the marginal source of electricity is natural gas, which is both more costly and more polluting than hydroelectricity. For the three years from October 2011 through the end of the 2014 water year, California experienced a reduction of around 34,000 GWh of hydroelectricity compared to average water years, at a cost to ratepayers of approximately $1.4 billion. In addition, the combustion of replacement natural gas led to an eight percent increase in emissions of carbon dioxide and other pollutants from California power plants during this period. As of March 2015, the drought continues: reservoir levels remain abnormally low, precipitation and especially Sierra Nevada snowpack are far below normal, and hydrogeneration is expected to continue to be below average. Thus, we expect the costs to California ratepayers and the environment to continue to mount.

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