SCHOOL OF SUSTAINABLE ENGINEERING AND THE BUILT ENVIRONMENT

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Future Electricity Supply Vulnerability and Climate Change:
A Case Study of Maricopa and Los Angeles Counties

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Abstract

Climatic changes have the potential to impact electricity generation in the U.S. Southwest and methods are needed for estimating how cities will be impacted. This study builds an electricity vulnerability risk index for two Southwest cities (Phoenix and Los Angeles) based on climate-related changes in electricity generation capacity. Planning reserve margins (PRM) are used to estimate the potential for blackouts and brownouts under future climate scenarios. Reductions in PRM occur in both cities in 2016 with the most significant reductions occurring in regions relying more heavily on hydropower.

1. Methods

1.1 The Role of a Balancing Authority:

The North American Electric Reliability Corporation (NERC) defines a Balancing Authority as the specific entity responsible for integrating resource plans ahead of time and maintaining in real time, the balance of electricity loads and resources. Essentially, a balancing authority is responsible for balancing supply and demand, and maintaining the interconnection frequency (60 Hertz) in real time. [1] We explore the influence of variability in water levels on power generation at a '*Balancing Authority*' (BA) scale. Electricity generation can be studied at different geographical resolutions, and the resolution scale we use for each case is contingent on the research question. The geographical resolution can range from highly aggregated scales such as national, regional, and state, to more disaggregated scales such as independent system operators (commonly called, balancing authorities or power control areas), and individual power plants. In this case we wanted to analyze the variability in water levels on power generation, and hence we predicate our analysis at a balancing authority scale. Reporting potential power losses at a balancing authority scale lends more meaning to the analysis because it is indeed the balancing authority who balances loads and resources throughout the year. It is also the balancing authority's responsibility to respond to such potential power losses, moving forward. This type of analysis can be expanded to a regional scale in the future, but the first step would be to analyze power losses at a balancing authority scale.

Los Angeles County: Los Angeles Department of Water and Power (LADWP), and California Independent System Operator (CAISO) are the two balancing authorities serving LA County. The utility service territories in LA County are Southern California Edison (territory), Los Angeles city, Burbank, Pasadena, Vernon, Glendale, AZUSA, Cerritos, and Industry.[2] More than 97% of electricity supply and number of accounts for LA county is included in this analysis (electricity supply data for Cerritos and Industry were not available). We include power plants outside California that serve LA County (LADWP owned plants in states such as Utah and Nevada). Additionally, certain plants are owned by more than one entity, and in that case, ownership percentage was used to estimate electricity output accordingly.

Maricopa County: Maricopa County is served by a combination of two balancing authorities: Arizona Public Service Company (APS) and Salt River Project (SRP). All of the power plants inside and outside the state (i.e. Arizona, and New Mexico) serving the County was included in the analysis. Four out of the 29 plants had multiple ownerships, and we estimated corresponding output managed by APS and SRP using those ownership percentages.

1.2 Physical Basis Model

Power generation can be affected by several hydrological and meteorological conditions depending on the generation technology and facility location. Thermoelectric power, which provides roughly 91% of generation in the U.S., is vulnerable to periods of low streamflow and high water temperature – conditions which may occur during a drought. The physical basis for changes in power generation in future climate change scenarios are developed by Bartos and Chester (2014)[3].

1.3 Power Plants Characteristics and Integration with Hydrological Model

There is evidence that the temperature of cooling water influences thermo-electric power production, however there is no direct evidence that thermo-electric power production is affected by varying stream flows.[4] Hence we focus exclusively on hydropower, evaluating the influence of varying water levels on hydroelectric output in both counties. Using the US EPA's e-GRID (The Emissions and Generation Resource Integrated Database), we obtain an extensive list of power plants serving both counties (most recent data available for the year 2009).[5] We obtain characteristics of each power plant such as name plate capacity, capacity factor, primary fuel, annual net output, plant ID, plant name and ownership, balancing authority, and utility service territory. The baseline output would be the cumulative output from all power plants in 2009, for each county.

The results from the hydrology model provide monthly stream flow as a function of historical average (1949 – 2010) of stream flow from each water source. For instance, a 0.16 cubic feet per second (CFS) in January 2010 indicates the stream flow to be 16% of the historical average of stream flow (in January) between 1949 and 2010. The hydrology model also specifically identifies the power plants served by each stream flow. e-Grid reports net output on an annual time scale, and hence, to successfully integrate the hydrology model with e-Grid, we estimated annual stream flow by estimating the median of a twelve month stream flow. Subsequently, the hydrology model was integrated with the power plant component to estimate reduction in hydropower production in the future.

1.4 Metrics for Analysis

1.4.1 Reduced Hydroelectric and Overall Net Output

The baseline output was for the year 2009, and we analyzed variation in annual hydropower output and overall output until 2016. The output remained constant (same as 2009) for the power plants that were not influenced due to varying stream flows, and the total reduction in annual output (in succeeding years) was estimated by a summation of output from both hydro and non-hydro plants. The reduction in hydroelectric and overall output is the metric that directly captures the influence of varying water levels on electricity generation.

1.4.2 Planning Reserve Margin

Planning Reserve Margin (PRM) is a capacity based metric that indicates the additional capacity available to meet sudden increases in demand (possibly due to unforeseen events). PRM is the difference between available capacity and peak demand, normalized to peak demand in a year (Equation 1). PRM values can vary widely depending on the location, ambient weather conditions, interconnectivity, and import and export flows. All other parameters being equal, it is very important for an electrical system with lower import/export capacity to comply with the recommended PRM (e.g. ERCOT), when compared to other regions with increased inter-connectivity. Figure 1 presents the current reserve margin estimate, and NERC recommended target for different regions in the US. Once the PRM decreases below the recommended threshold the balancing authorities issue emergency warnings at different levels (e.g. level 1, 2, and 3).[6] The different levels tend to be,

Level 1: Conservation Needed
Level 2: Conservation Critical: Risk of Rotating Outages
Level 3: Conservation Critical: Rotating Outages in Progress

There is not an exact value (of PRM) below which balancing authorities issue each warning. This is predominantly due the diverse import and export flow capacity, anticipated increase in resources, and number of enforceable demand response programs each power control area has under its jurisdiction. However, it is certain that once the PRM reduces below the recommended threshold, it will eventually lead to brownouts (first), and subsequently, blackouts.
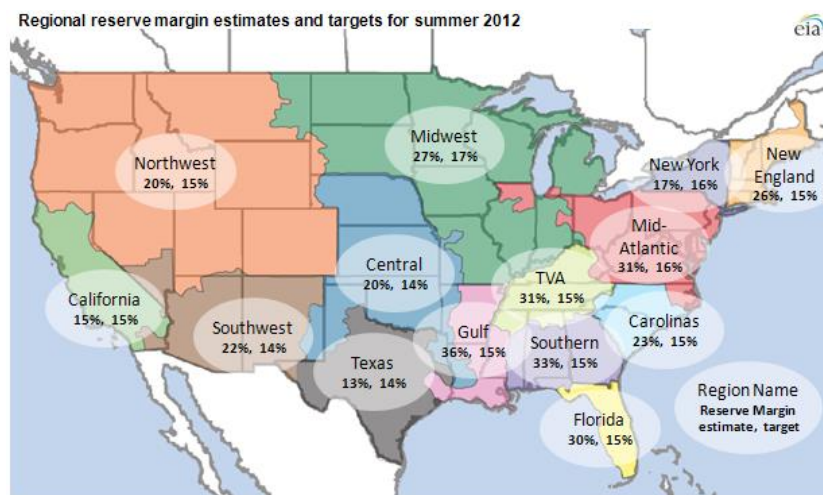

Figure 1: Reserve Margin Estimate and Target for different Regions in the US (Link: http://www.eia.gov/todayinenergy/detail.cfm?id=6510)

Also, PRM is usually estimated for balancing authorities, and not for individual counties (such as LA and Maricopa counties, in our case). Each balancing authority has extensive information on its load (peak, for calculating PRM) and available resources, and can coordinate supply and demand accordingly. Since the balancing authorities serving LA County include both LADWP and

CAISO, we theoretically estimate the influence of varying water levels on the PRM for the county. In this case, we estimate PRM for both counties as a function of variation in annual net output between 2009 and 2016.

$$Planning\ Reserve\ Margin\ (PRM) = \frac{Available\ Capacity - Peak\ Demand}{Peak\ Demand}\ \text{(Equation 1)}$$

1.4.3 Blackouts and Brownouts

For the purpose of this study, we define Blackout as complete interruption of power. Brownout tends to happen before Blackout, and brownout is essentially an intentional drop in voltage (below 90% of nominal voltage) by the balancing authority to manage increasing loads successfully (during times of peak demand). We represent blackout and brownout in our model by considering blackouts to occur when the PRM drops 60% below the recommended threshold, and brownouts to occur when the PRM drops 30% below the recommended threshold. We additionally conduct sensitivity analyses to evaluate the influence of the above mentioned percentages on the final results.

2. Results and Discussion

Los Angeles County: Figure 2 presents the cumulative capacity and annual net output for the power plants (under both balancing authorities, inside and outside the state) serving LA County, categorized by fuel type. This also includes power plants outside the state in which LADWP has a shared ownership (indicated by the keyword "OutState" in the figure). LADWP has a 21.2% and 5.7% ownership of Navajo coal plant and Palo Verde nuclear plant – both located outside the state. Hence, based on ownership percentages, output from those plants were also modeled as electricity inflows serving LA County. The cumulative capacity and output from hydropower for LA County is 11.3% (of total, 29.4 GW) and 7.7% (of total, 73,365 GWh) respectively. Given the Mohave plant shutdown recently, while a total of 29.5 GW capacity is available for generation, in reality, only 27.7 GW is available for generation (reflected in Figure 4). Electricity from power plants outside the state contributed to 3.6% of the total demand. The total annual net output from the power plants is validated using other databases: the annual output is consistent with reported electricity demand for LA County in 2009 (approx. 70,000 GWh).[7]

Figure 3 presents the annual net output from each power plant serving LA County between 2009 and 2016. The total output for 2009 was 73,365 GWh; the hydroelectric output (and hence, the total output) in succeeding years varied as a function of varying stream flows. Due to the varying stream flows each year, the total output increased by as much as 3.1% (in 2013), and decreased by as much as 6.6% (in 2010). The output for other years remained within this range. Figure 3 presents the cumulative net output from power plants in their decreasing order of capacity factor i.e. base load plants on the left (of x-axis), intermediate load plants in the middle, and peak load plants on the right. Using the various utility service territories in LA County, the approximate peak demand for the county was determined to be 21.3 GW. The dichotomy between areas served by balancing authorities and estimating power consumption at the county level poses a limitation at this point. While peak demand in various service areas within LA County can be obtained, obtaining peak demand for the area within LA County served by Southern California Edison (SCE) is not easy. Since only 42% (31,877 GWh out of 81,027 GWh) of total

electricity output from SCE is used by LA County, it is impossible to determine the relevant peak demand in LA County (specifically for SCE). Hence we assumed the peak demand in LA County was 75% of the peak demand reported by SCE (18,515 MW).[8]
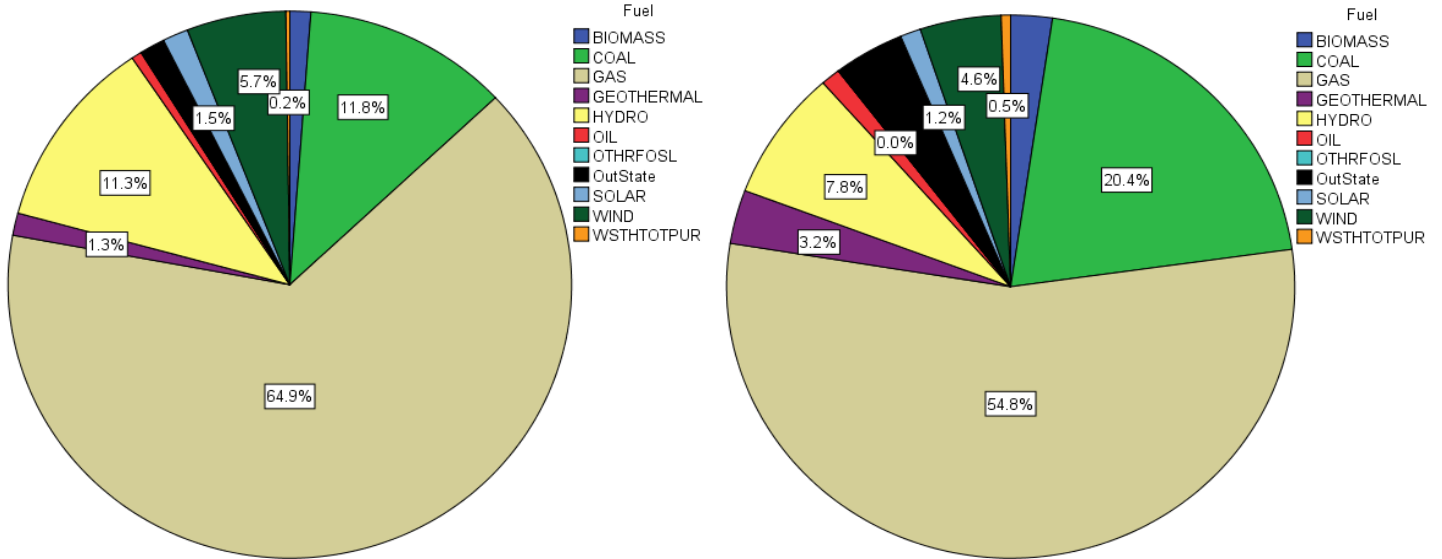
Figure 2: Cumulative Nameplate Capacity (Total 29.4 GW) (Left), and Cumulative Annual Net Output (Total 73,365 GWh) (Right) of Power Plants Serving LA County, Categorized by Fuel Type (OutState indicated plants located outside California)
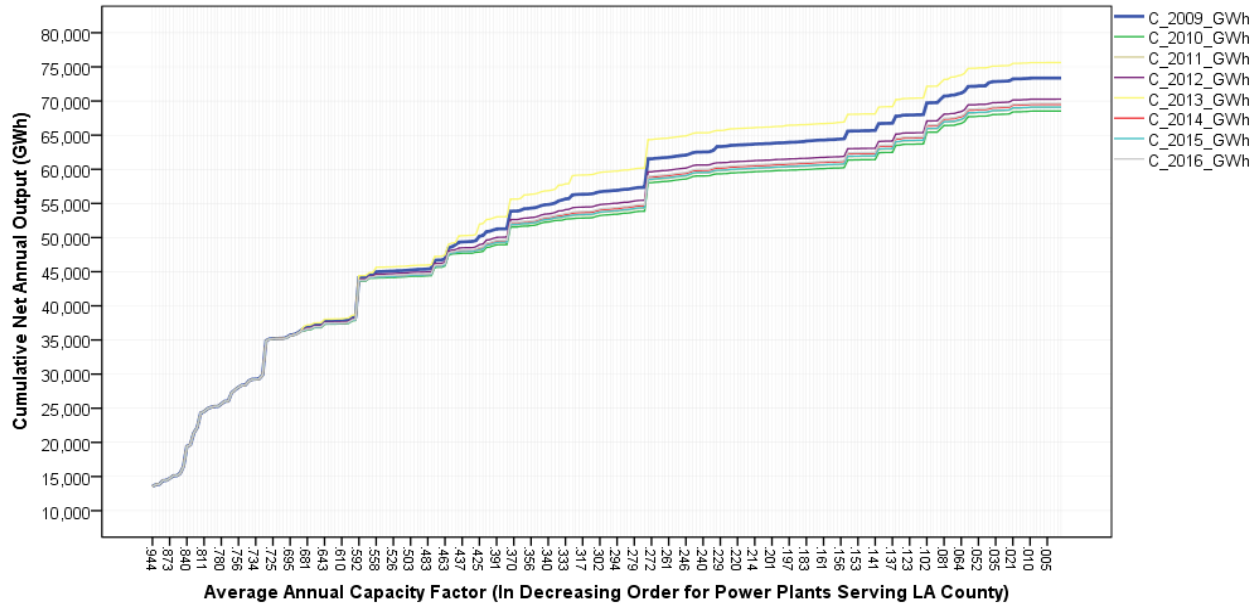

Figure 3: Cumulative Net Annual Output from Power Plants (In Decreasing Order of Capacity Factor) Serving LA County, between 2009 and 2016

Variation in hydroelectric output due to fluctuating water levels changes the capacity factor for each hydroelectric power plant. Technically, reduced electricity output can also be translated into "reduced available capacity", by holding the initial capacity factor constant. This implies that due to reduced stream flows, a decreased hydroelectric capacity is available for deployment in the future years. Hence, varying generation was translated into varying nameplate capacity for hydroelectric plants, holding the 2009 capacity factor constant throughout the analysis. Eventually, by comparing the cumulative capacity available for generation each year with peak demand (in LA County), we analyze the Planning Reserve Margin each year (Figure 4). Subsequently, as the PRM reduces to levels below the recommended threshold, brownouts and blackouts ensue accordingly. Figure 4 also presents the variation in PRM as a function of total available capacity for generation each year.
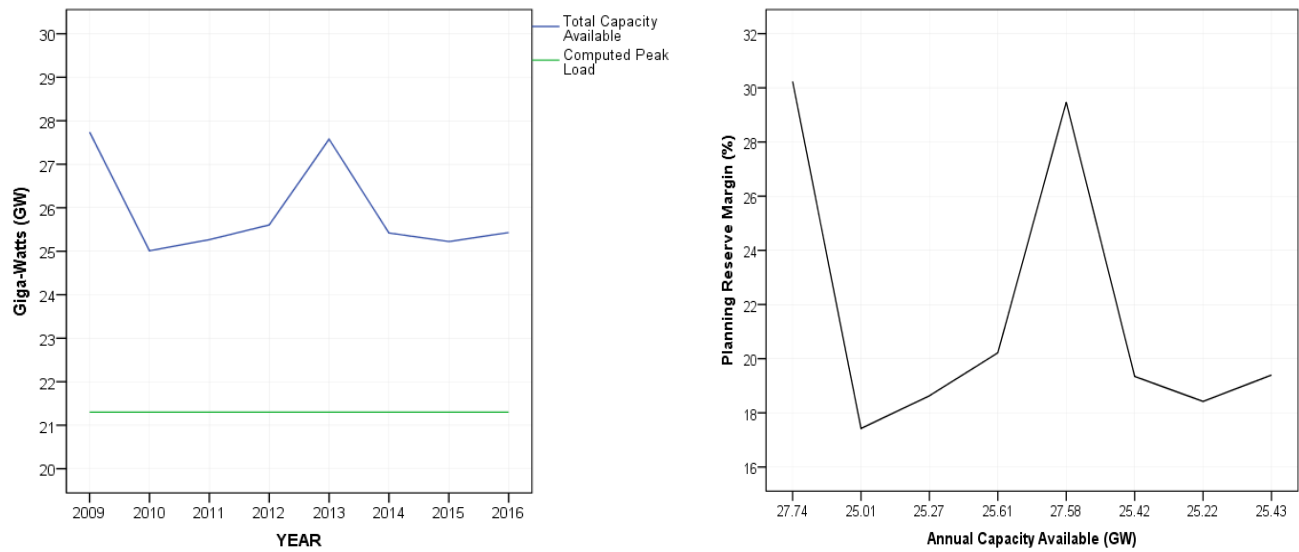
Figure 4: Total Available Capacity and Peak Demand (Left), and PRM as a Function of Total Available Capacity (Right)

Maricopa County: Figure 5 presents the cumulative capacity and net annual output for power plants under both balancing authorities of APS and SRP. Maricopa County utilizes lower amounts of hydropower in comparison to LA County: the total amount of hydropower was 1.9% of total capacity (14,415 MW), and 0.65% of total generation (58,000 GWh). Out of state generation (Four Corners coal plant from New Mexico) contributed to one eighth of total supply. Figure 6 presents the net annual output from each power plant in APS and SRP. Since, only 0.65% of total generation was generated from hydropower, the varying water levels did not significantly influence power generation. From a baseline (2009) generation of 58,000 GWh, electricity generation reduced between 0.22% (in 2016) and 0.47 (in 2010). Not being reliant on hydropower leads to the power generation for Maricopa County being less vulnerable to varying water levels.
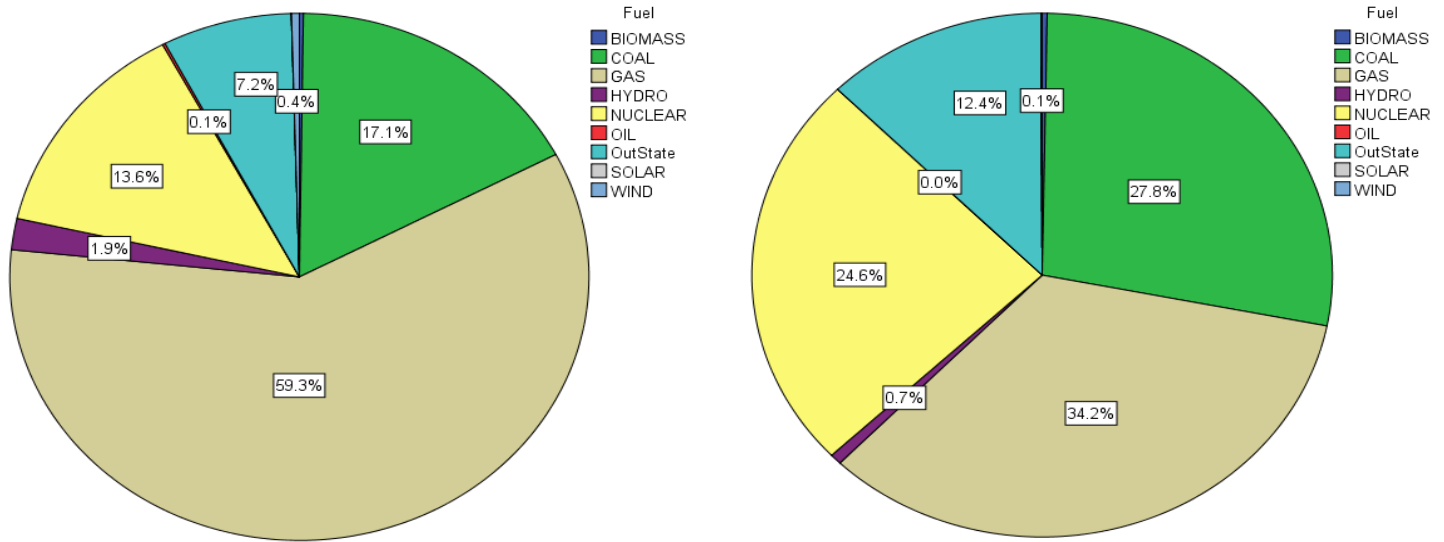
Figure 5: Cumulative Nameplate Capacity (Total 14.4 GW) (Left), and Cumulative Annual Net Output (Total 57,998 GWh) (Right) of Power Plants Serving Maricopa County, Categorized by Fuel Type (OutState indicated plants located outside Arizona)
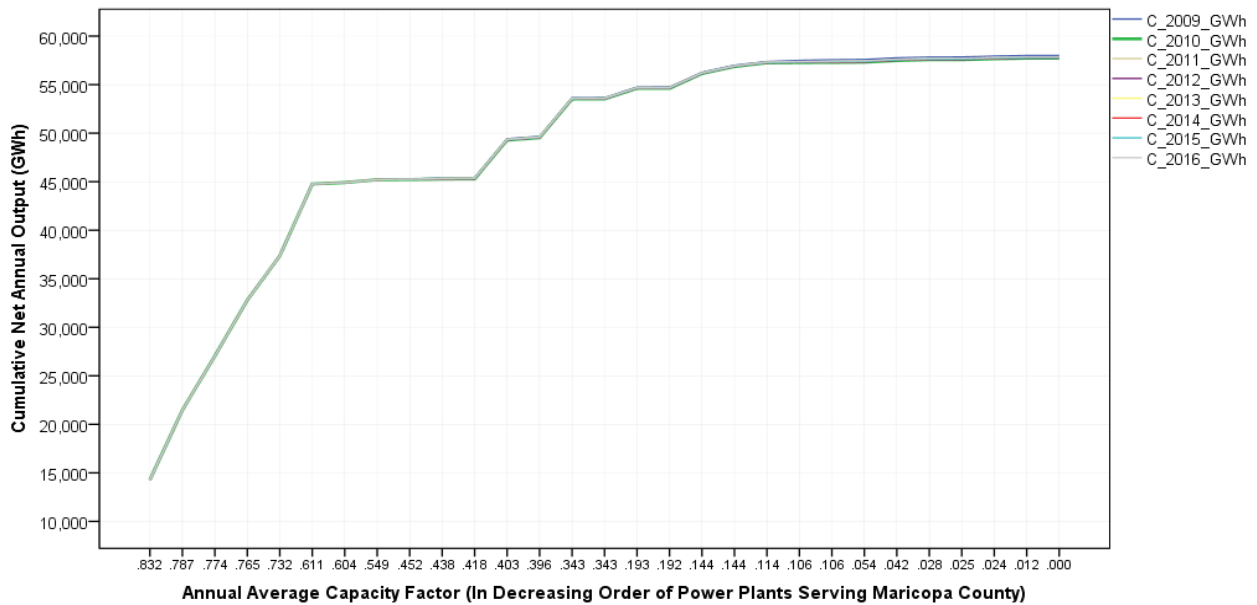

Figure 6: Cumulative Net Annual Output from Power Plants (In Decreasing Order of Capacity Factor) Serving Maricopa County, between 2009 and 2016

The peak load for Maricopa County was computed to be 13,590 MW (using individual APS and SRP estimates). APS and SRP reported 7,000 MW and 6,590 MW to be their individual peak

load annual forecasts.[9,10] Figure 7 presents the difference between computed peak load and combined total resources available for Maricopa County, and also the planning reserve margin with reduced capacity available due to varying water levels. *Very interestingly,* the difference between total available resources and peak demand dropped to as low as 4.64% in 2010 (the PRM is much lower when compared to LA County). Even though Maricopa County is much less dependent on hydropower, the PRM reduces to very low values (simply due to less total capacity available for generation). To validate these results, moving forward, we will conduct a sensitivity analysis by using a different modeling approach to represent combined ownership (of plants). It is also very important to mention that import and export flows are also not captured by our entire analyses.
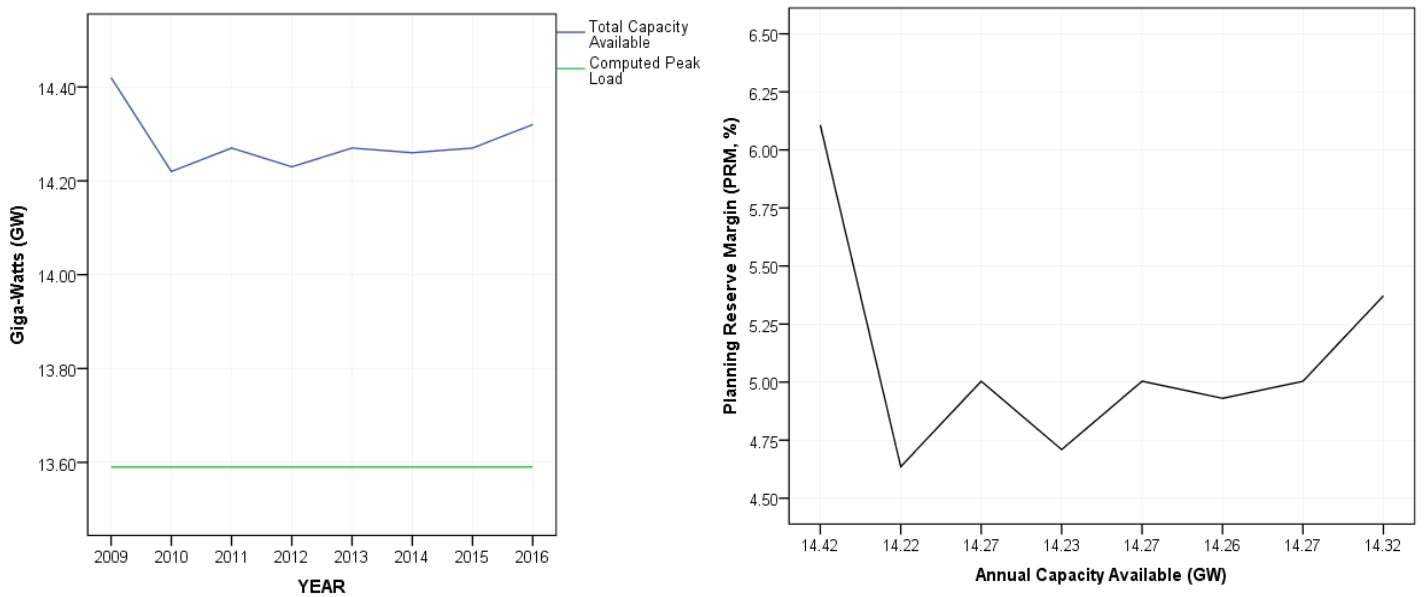

Figure 7: Total Available Capacity and Peak Demand (Left), and PRM as a Function of Total Available Capacity (Right)

Reference:

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