California Public Utilities Commission

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Energy Division Draft Staff Paper

Effective Load Carrying Capability of Wind and Solar Resources in the CAISO Balancing Authority

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Acknowledgements

Several people have contributed to preparing the data for this model, as well as reviewing outputs to ensure that the results are appropriate. In particular, ED staff would like to acknowledge the work of Donald Brooks and Joanna Gubman from Energy Division, who worked to prepare and document the input assumptions, run the model, and prepare output reports. Kevin Carden from Astrape Consulting provided expert support in preparing the inputs, as well as reviewing all documentation and providing crucial editorial assistance to several versions of this draft study results report. This draft report was also reviewed by Michele Kito and Judith Ikle in Energy Division. Their help is much appreciated.

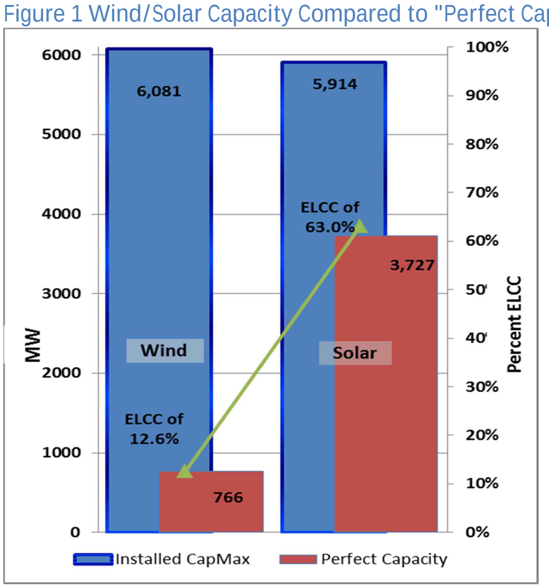
Executive Summary

As part of fulfilling the mandate of Senate Bill X1 2 (2011) to assess the Effective Load Carrying Capability (ELCC) of wind and solar facilities as part of the Resource Adequacy (RA) program, Energy Division (ED) staff has studied the reliability impact of wind and solar facilities for the past year using a vendor provided software called Strategic Energy Risk Valuation Model (SERVM). ED staff has issued reports describing the proposed methods and data inputs for the model, and provide an updated version of the inputs and assumptions document along with this report.[1]

A portion of the ELCC work has been completed, and is presented in this paper. Staff calculated the "average ELCC" of solar and wind generators in the CAISO in 2016, although the values are not yet specific to location or individual technologies within the solar or wind types. These values also do not represent the value these facilities have in each individual month of the year.

Average ELCC for solar resources in 2016 equaled approximately 63%; exchanging 5,914 MW of solar capacity for 3,727 MW of "Perfect Capacity" resulted in a probability weighted Loss of Load Expectation (LOLE)[2] of approximately 0.1 over all 165 cases run. When wind facilities were removed and "Perfect Capacity" was added as substitution, reliability was measured at approximately 0.1 at an Average ELCC of 12.6%. Figure 1 illustrates the magnitude of wind capacity versus "Perfect Capacity" and solar capacity versus "Perfect Capacity".

Figure 1 Wind/Solar Capacity Compared to "Perfect Capacity" (MW)



ED staff does not yet have confidence in the application of these results to set the overall capacity target for reliability procurement, such as setting the RA obligation or the LTPP procurement authorizations. Staff has identified a number of next steps to accomplish those tasks, and is preparing to undertake

[1] For more information on SERVM please consult Inputs and Assumptions for ELCC modeling published to the CPUC website here: http://www.cpuc.ca.gov/PUC/energy/Procurement/RA/Probabilistic+Modeling.htm#Documents

[2] LOLE values indicate the expectation of loss of firm load as an indicator of service reliability across a large electric system. High LOLE values indicate higher expectation of a loss of firm load. Traditionally 0.1 (i.e. one loss of load event in ten years) has been the established metric.

those steps. At this time these study results are not ready to determine the effective planning reserve margin or RA obligation for the next RA compliance year although staff is confident in the application of these results to Annual Average ELCC values for wind and solar resources.

Analytical Methods of Study

ELCC and LOLE studies are performed in a sequence of steps. There are two main parts. The first part is a convergence study, to establish the optimal number of iterations to study for each case. Once it is determined how many iterations are best to produce stable LOLE results, the results of the study can be trusted on as stable and consistent. Initial studies are performed to calibrate the California Independent System Operator (CAISO) system to a LOLE result of 0.1 or one event in ten years. If there is less than 0.1 LOLE observed, the system is more reliable than intended; higher LOLE means a less reliable than intended system. LOLE studies are iterative; generators are added or subtracted to raise or lower the resulting LOLE level to 0.1.

Once the CAISO system is calibrated to the right LOLE levels, staff modeled the ELCC of wind and solar facilities for the study year of 2016[3]. Once the overall electric system is set to 0.1 LOLE, then the ELCC study is performed. Solar capacity (or wind capacity) is removed and replaced with a quantity of "Perfect Capacity" and the simulation is repeated. More "Perfect Capacity" [4] is added or subtracted until again the resulting LOLE equals 0.1. "Perfect Capacity" is taken away to lower reliability and the system is modeled again.

The CAISO system is simulated via 165 separate cases. Each case is a unique combination of load shape year (load shapes from 1980 to 2012) and wind/solar/hydro weather influenced generation shape years corresponding to load years. Each year is modeled hourly. Each of the 33 years is modeled at five different load forecast uncertainty levels; 33 load years times 5 forecast levels equals 165 individual cases. Each case is run over and over iteratively, to measure a pattern of reliability given the random variables that influence overall reliability such as generator outages. Each case results in an average reliability value over all the iterations of that particular case. Thus a single study is made up of a number of cases (i.e. 165 cases), with multiple iterations (random draws of variables such as generator outages) for each case. The overall CAISO system is modeled over all 165 cases (with all 33 weather years, at five load forecast uncertainty points) and calibrated to an expected LOLE of 0.1.

Solar facilities in CAISO are removed and the system is recalibrated by the addition or subtraction of "perfect capacity" in CAISO proportionate to where the facilities were removed. If 70% of the solar capacity is removed in SCE's territory, then 70% of the "Perfect Capacity" is replaced in SCE's territory. The CAISO system is modeled repetitively until the desired 0.1 LOLE result across CAISO is again achieved. The process is repeated for wind resources. Wind facilities in CAISO are removed and the system is recalibrated by addition and subtraction of "Perfect Capacity" proportionate to where the facilities are removed, until the 0.1 LOLE result across CAISO is achieved.

[3] ELCC values represent the ratio of existing electric capacity in reality compared to idealized "Perfect Capacity" to measure the quantity of reliability benefit provided by the existing electric capacity in reality. Reliability benefit is measured as ability to offset LOLE events.

[4] "Perfect Capacity" is defined for this paper as a dispatchable resource with zero maintenance events, forced outages, or derates.

Convergence Analysis

In order to ensure stability and consistency of LOLE and ELCC results, ED staff began by performing a convergence analysis on eight of the total 165 cases. These eight cases were chosen as they represented the cases that produced the largest LOLE levels. ED staff modeled each of the eight cases with 500 iterations and kept each iteration's reliability results. ED staff combined each iteration's results and tracked the change in average LOLE as each incremental iteration's results are added to the pool of results. ED staff observed a pattern of convergence where the average change in LOLE became very small and continued to decrease; LOLE became more stable as more iterations were averaged together. ED staff performed a similar analysis looking at percent change in standard deviation of LOLE and looked at patterns of convergence.

Analysis of the percent change in standard deviation resulted in the most conservative estimate, meaning the highest number of iterations before converging. Although the patterns of convergence are slightly different for each case modeled, ED staff observed a similar pattern in each and chose a threshold where it can be expected that all cases would have converged around a satisfactorily stable result.

ED staff selected a threshold number of iterations that converged each of the eight cases to within a range between -2% and 2% change in standard deviation; the same 120 iterations appears to converge the average change in LOLE to within a range of plus or minus 1%. ED staff will reassess patterns of convergence as the study variables change or as desired to converge to a narrower range. Adding wind and solar uncertainty parameters, for example, would alter the pattern of convergence and may require more iterations to converge. For the ELCC study, ED staff conducted all the LOLE modeling to the level of 120 iterations.

Convergence Results

ED staff sought the optimal number of iterations to ensure replicability and stability of the results, but run times place a constraint on the number of iterations that can realistically be accomplished. A balance between precision and confidence on the one hand and run time on the other necessitates compromise.

ED staff modeled the eight selected cases at 500 iterations, intending to "overshoot" the pattern of convergence and identify it within the sample. Each case produced a unique pattern of LOLE and a pattern of convergence that was unique from the other cases; nevertheless a clear pattern of convergence emerged in all eight cases between 100 and 200 iterations.

Three sample cases are shown below, each combination of load and weather dependent generation (wind, solar, and hydro). The charts below illustrate the pattern of convergence as measured by percent change in LOLE and percent change in standard deviation when incrementally larger number of iterations are averaged together. Results begin by fluctuating wildly around the mean, but as more iterations are performed, the percent change begins to decrease, and the results of the study become more stable. As the percent change in LOLE and the percent change in standard deviation begin to be confined to a narrower and narrower range, ED staff is confident that a correct LOLE level illustrative of the study case has been identified.

Figure 2 Convergence in % Change in LOLE with Greater Iterations – case 148 (2009 load year)

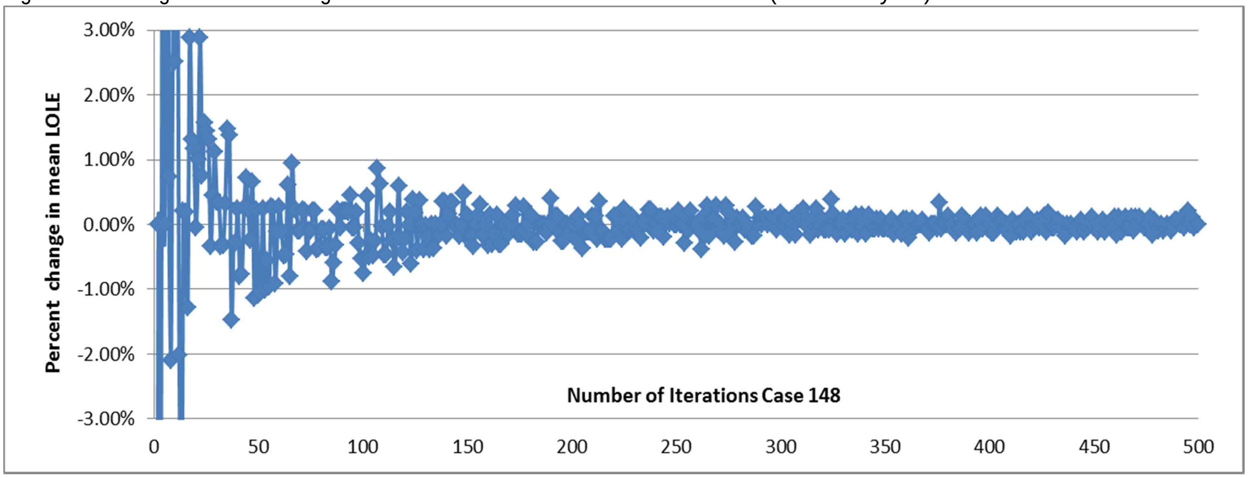


Figure 3 Convergence in % Change in STDev with Greater Iterations – case 148 (2009 load year)

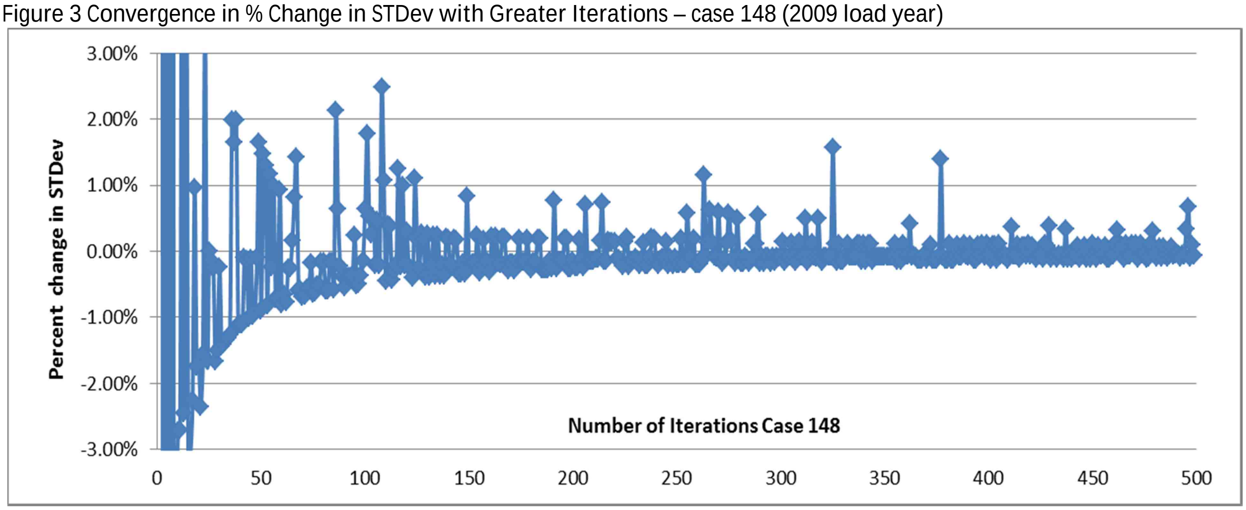


Figure 4 Convergence in % Change in LOLE with Greater Iterations – case 135 (2006 load year)

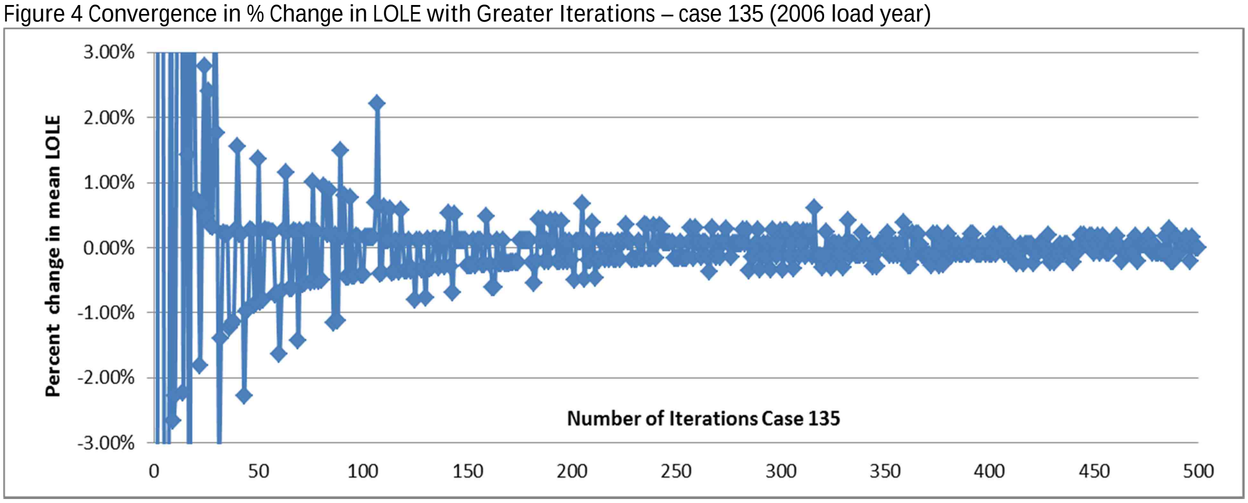


Figure 5 Convergence in % Change in STDev with Greater Iterations – case 135 (2006 load year)

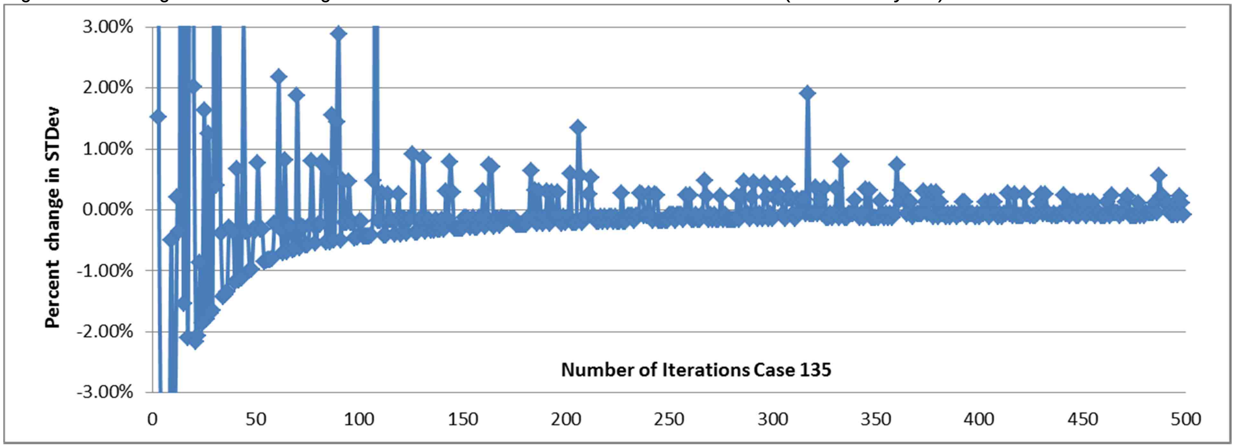


Figure 6 Convergence in % Change in LOLE with Greater Iterations – case 75 (1994 load year)

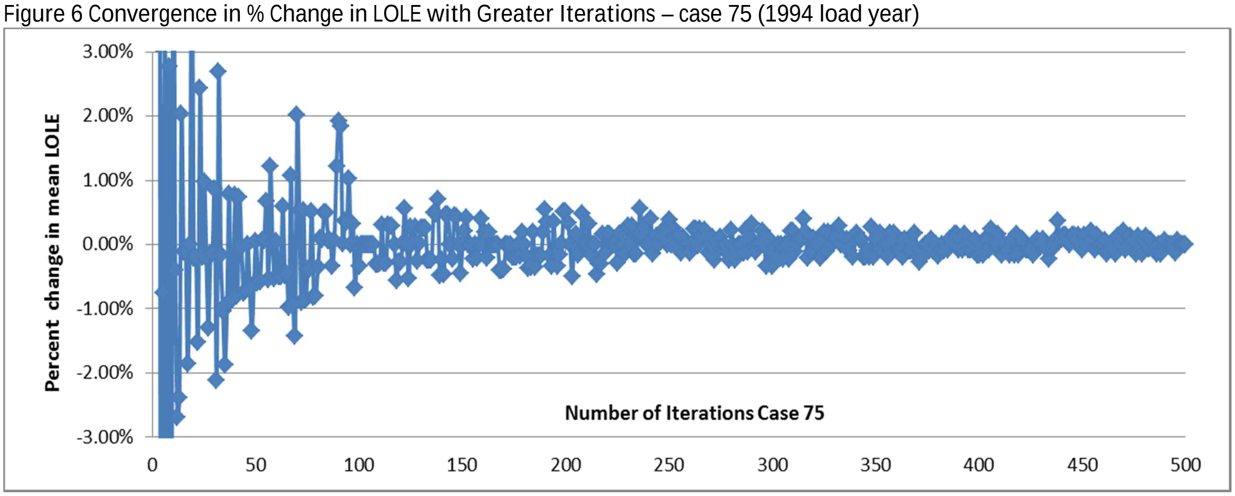
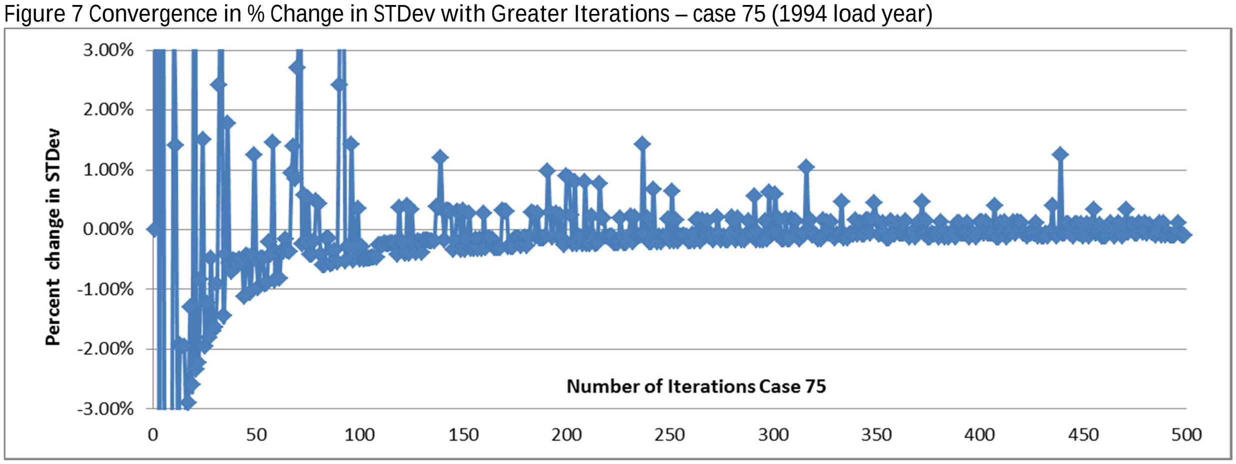


Figure 7 Convergence in % Change in STDev with Greater Iterations – case 75 (1994 load year)



ELCC Study Process

Once convergence and the number of iterations have been determined, the overall CAISO system is calibrated to result in a probability weighted LOLE result of 0.1[5] across all 165 cases modeled, taking away capacity or adding capacity in specific increments, then remodeling the CAISO system. This process is repeated, removing increments of perfect capacity or adding increments of perfect capacity, until the probability weighted LOLE observed over the 165 cases again equals 0.1. With the current system, actual existing power plants were removed or added to calibrate.

Once the overall system was calibrated, a similar process was repeated to gauge the ELCC of wind and solar facilities. For purposes of this first ELCC study, all wind facilities were tested together, and all solar facilities were tested together, although there are multiple technology groups with different performance profiles, in each area of the model. With ELCC studies, the entire wind (or solar) group in CAISO was removed, and the system was recalibrated to produce a 0.1 LOLE over the 165 cases by addition or subtraction of chunks of "Perfect Capacity". The attributes of "Perfect Capacity" are provided in Table 1 below.

Table 1 Resource Characteristics of Perfect Capacity

Variable description	Description	Value of Variable
Capmax	Maximum generation level	204.2
CapMin	Minimum capacity level (PMin)	1 MW
Availability	Percentage factor (1- percent of time unit is unavailable)	0.999 (indicating perfect availability)
Time to fail	User can specify a distribution of values for how long a resource will run before it fails. Outage events are randomly drawn from this distribution. High values mean greater reliability and low values the opposite.	90000 (never fail)
Time to repair	Given in hours, this variable is how long a resource is out when it is on outage. Users can specify a number of hours for planned and forced outages separately.	0 (Repairs instantly)
Startminutes	How long in minutes for the plant to start up	2 minutes
Ramp Rate	MW per minute	24 MW/min
Maintenance periods	Unit specific variable users can use to specify more than one maintenance period for each year	None
Startup probability	Users can specify what the probability is for resources to successfully start up	1 (Never fails on startup)

An ELCC study requires several steps. The entire process required a series of iterative studies, each calibrating capacity margins around the target LOLE level. First, ED staff added or subtracted capacity

[5] Actual LOLE results are often dependent on the error in the data inputs and convergence. Staff attempted to calibrate to a LOLE of 0.1 exactly, but accepted LOLE between 0.09 and 0.11.

until the CAISO system resulted in a LOLE of 0.1 modeling at 120 iterations.[6] Less attention was paid to areas outside of CAISO, but transfers between external regions and CAISO regions were monitored, and effective reserve margins of those external regions were increased or decreased (by addition of load to those regions) until transfers between regions fit within historical patterns.

With the CAISO system calibrated to 0.1 LOLE, ED staff removed all the wind facilities from the studies, including all facilities that are linked to CAISO. ED staff then iteratively added more "Perfect Capacity" to each region in proportion to the wind facilities removed from those regions until LOLE again equaled 0.1 LOLE for the CAISO region.

In summary average annual portfolio ELCC for all solar or wind facilities in CAISO can be calculated following these steps:

1. Create the capacity portfolio that brings the CAISO area as a whole to a LOLE of 0.1 given the loads and resources that are expected to exist in the 2016 study year.
2. Perform a study and save all required output reports.
3. Remove all facilities of interest (either wind or solar depending on the ELCC study) in CAISO, but not those outside of CAISO.
4. Perform a study and save all required output reports.
5. Make an estimate of the amount of "Perfect Capacity" needed to replace the removed facilities distributed proportionately among regions where the facilities were removed.
6. Perform a study and save all required output reports. If the LOLE of the new system is not yet equal to 0.1, repeat steps 3 and 4 until LOLE equals 0.1 either by adding a little more (if LOLE is greater than 0.1) or removing (if LOLE is less than 0.1) MW of "Perfect Capacity".
7. Once LOLE equals 0.1, find the ELCC by calculating a ratio of nameplate MW removed to "Perfect Capacity" nameplate MW added. The result is the average ELCC of the CAISO portfolio of all the studied facilities. The resulting annual ELCC value will be a percentage less than 1.
8. Energy Division staff is currently unable to create "monthly" ELCC values, as the methodology is unestablished.

Calibration

ED staff first ran hourly simulations to become familiar with the dynamics of the model and the patterns of dispatch, load, generation, and other important variables. ED staff worked to calibrate the hourly simulation to actual historical patterns, and located several key patterns that would indicate more or less realistic simulation results.

ED staff evaluated initial calibration studies and tracked the levels of transfers between regions; transfers between PGE_Valley and SCE area in particular were reviewed to ensure that the representation of Path 26 was maintained. In addition, the link between SCE and Arizona was analyzed.

[6] Staff conducted a convergence analysis to determine the appropriate number of iterations. For more description of convergence analysis and calibration of results, please refer to the companion report published on the CPUC website, entitled Part 2- Probabilistic Reliability Modeling Inputs and Assumptions.

Once ED staff became confident that the simulation was realistic, ED staff began to study the correct level of capacity margin to produce a weighted average LOLE of 0.1 across all 165 cases. ED staff began by selecting five load shapes (1992, 1994, 1998, 2007, and 2009) and modeled each load shape at each of the five points of economic and demographic forecast error levels; this translated to a bracketing study of 25 cases instead of the full 165 cases. ED staff studied the same 25 cases at different levels of capacity margin in order to arrive at the level of capacity margin that would produce a weighted average LOLE of 0.1.

Once ED staff determined they had calibrated the smaller set of cases to the appropriate level of LOLE, then a full study was performed on all cases; staff performed a full study at 60 iterations to test whether with all cases run, the LOLE remained at 0.1. If, with all cases modeled, the LOLE was either higher or lower than 0.1, ED staff recalibrated and performed "bracketing" again to fine tune the LOLE more precisely. ED staff completed a full study with all cases at 60 iterations to achieve a LOLE of 0.1. Once that was completed, ED staff performed the full study with 165 cases at 120 iterations and documented the results. ED Staff performed the solar ELCC first, and this experience led to more precise initial assumptions of Perfect Capacity levels when wind resources were studied.

Results

The CAISO system was calibrated by adding or subtracting existing resources until the simulation resulted in a LOLE of 0.1. Table 2 lists the capacity that was included in the study in each of the study areas in the "Calibrated CAISO LOLE Case". Northern California had a higher margin of capacity over load than Southern California, hence capacity that was taken away in Northern California did not result in deficits, while solar or wind capacity removed, particularly in SCE area, resulted in capacity deficit. Transfers across Path 26 were critical in maintaining reliability, and were generally very close to maximum in the north to south direction, which means the capacity excess in Northern California was unable to transfer to Southern California, or else the average ELCC between the two areas would have been more equal.

Table 2 Resource Breakdown – Calibrated CAISO LOLE Case

Region	SDGE	PGE_Bay	PGE_Valley	SCE	CAISO
Study Year	2016	2016	2016	2016	2016
Peak Load (all figures in MW)	4,421	8,233	13,408	22,789	47,038
Total Nameplate Resources	6,015	8,979	24,195	26,045	65,235
Nuclear Resources	0	0	2,300	0	2,300
Fossil Resources	4,030	5,617	9,600	13,523	32,770
Peaking Resources	600	1,621	2,438	2,808	7,467
Run of River Hydro Resources	0	0	374	132	505
Scheduled Hydro Resources	0	0	5,586	972	6,558
Emergency Hydro Resources	0	0	0	200	200
Pumped Storage Resources	40	0	1,218	200	1,458
Demand Response Resources	43	169	703	1,268	2,182
Total Wind and Solar Resources	1,302	1,572	1,976	6,943	11,794

When the Calibrated LOLE Case was modeled, there were 16 of the 33 weather shapes that produced deminimus LOLE (0.00 when rounded to the second decimal place); seven of the 33 load shapes produced LOLE greater than 0.1, and the rest produced LOLE in between. Peak loads in each load shape were very similar; the peak load of each weather year was scaled up to match the peak load forecast for 2016, and the rest of the overall load shape for that year was scaled by the same ratio.

Scaling the entire year's weather shape by the same factor preserves the shape of the load relative to each hour of the year, but weather years may be scaled asymmetrically to reliability risk. Mild weather periods are made more extreme, potentially distorting the reliability risk that the historical year corresponding to that weather year actually presented. Extreme weather years are made more extreme, but not as much since the peak in an extreme weather year will be more anomalous to the rest of the year than the peak in a normal year relative to the rest of a normal year. It is unclear how much this affect impacted the relative weighting of each weather year's LOLE results. There was considerable variability between weather years and their effect on system reliability. High and low LOLE load shapes are listed below.

Load Years with High LOLE	Load Years with Low LOLE
1992	1982
2009	1984
1994	1991
2006	1997
1985	1999
2007	2002
1998	2004

Table 3 illustrates the distribution of LOLE events across the 12 months of each year and across the areas in the study. The CAISO row serves as the aggregate of the other areas, and each row sums to the total LOLE observed in that area. The total of the CAISO row sums to approximately 0.1 LOLE. LOLE is concentrated in SCE area, and in the third quarter of the year. All of the LOLE events are attributable to Southern California, and none to Northern California.

Table 3 Calibrated CAISO LOLE Case LOLE Values by Month and Region

Month	1	2	3	4	5	6	7	8	9	10	11	12
CAISO	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.073	0.003	0.000	0.000	0.000
SCE	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.072	0.003	0.000	0.000	0.000
SDGE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PGE_Bay	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PGE_Valley	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4 illustrates both the distribution of LOLE in the CPUC Calibrated LOLE Case (today's default system calibrated to LOLE of 0.1) and the disproportionate impact of a small number of load shapes on the outcome. In this table, each column lists the LOLE observed for that weather year, and the columns total the LOLE events observed in each area of the model. The CAISO column totals to 0.1 LOLE. The seven load shapes with the highest amount of LOLE account for 91% of total LOLE observed in the entire study. LOLE is concentrated in a few years of extreme risk and many others of negligible risk.

Table 4 Calibrated CAISO LOLE Case LOLE Ranked by Load Year and Region

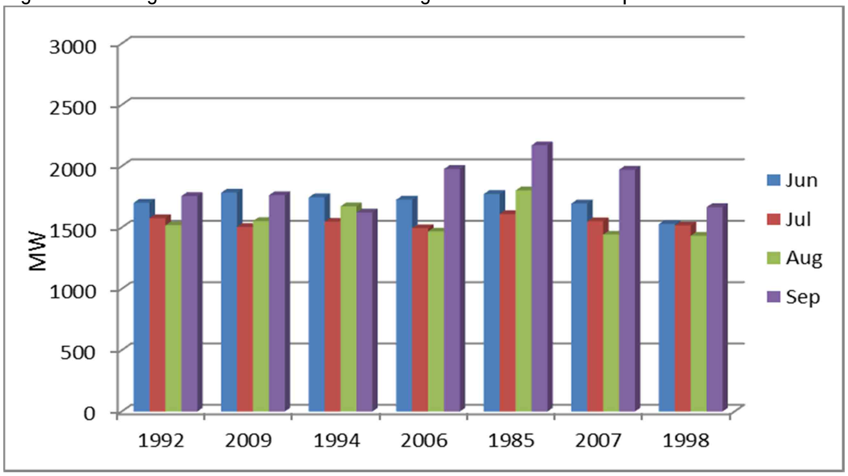
Load Year	CAISO	SCE	SDGE	PGE_Bay	PGE_Valley
1992	0.027	0.027	0.000	0.000	0.000
2009	0.022	0.022	0.000	0.000	0.000
1994	0.014	0.014	0.000	0.000	0.000
2006	0.013	0.013	0.000	0.000	0.000
1985	0.007	0.007	0.000	0.000	0.000
2007	0.005	0.005	0.000	0.000	0.000
1998	0.004	0.004	0.000	0.000	0.000
2012	0.002	0.002	0.000	0.000	0.000
2011	0.002	0.002	0.000	0.000	0.000
1990	0.002	0.002	0.000	0.000	0.000
1980	0.001	0.001	0.000	0.000	0.000
2010	0.001	0.001	0.000	0.000	0.000
1996	0.001	0.001	0.000	0.000	0.000
2001	0.001	0.001	0.000	0.000	0.000
1981	0.000	0.000	0.000	0.000	0.000
2003	0.000	0.000	0.000	0.000	0.000
1988	0.000	0.000	0.000	0.000	0.000
1983	0.000	0.000	0.000	0.000	0.000
1987	0.000	0.000	0.000	0.000	0.000
1995	0.000	0.000	0.000	0.000	0.000
1986	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.000	0.000	0.000	0.000
2005	0.000	0.000	0.000	0.000	0.000
1993	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.000
2008	0.000	0.000	0.000	0.000	0.000
1982	0.000	0.000	0.000	0.000	0.000
1984	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.000	0.000	0.000	0.000
2002	0.000	0.000	0.000	0.000	0.000
2004	0.000	0.000	0.000	0.000	0.000

ED staff more closely examined the seven load shapes that tended to produce the highest LOLE values, and the seven load shapes that produced the lowest LOLE values to determine the extent to which load shapes might reveal insight into potential reasons for greater or lesser reliability risk. ED staff made a spreadsheet of hourly loads, hourly renewable resource generation, and the LOLE associated with the load shapes. ED staff analyzed the "high load forecast uncertainty" set of hourly load shapes for each of the 14 load shapes that produced the highest and lowest LOLE events.[7] ED staff calculated the monthly average difference between daily peak load and daily median load for each load shape, and focused on the months of June through September where most of the LOLE events were observed. Months with low average MW differences between median and peak loads are months where load is close to peak load for the greatest period of time, and months with high average MW differences between daily

[7] For more information on ED staff modeling of load forecast uncertainty, please reference Section VB in Part Two – Probability Modeling Inputs and Assumptions posted to the CPUC website here: http://www.cpuc.ca.gov/PUC/energy/Procurement/RA/Probabilistic+Modeling.htm

median load and daily peak load are months where the majority of the time load is much lower than peak. System risk is highest when loads are closer to peak for longer periods of time. Figure 8 reflects the relatively lower values for load years that produce highest LOLE and Figure 9 illustrates the opposite, where the MW difference is great and the load shape produces the lowest LOLE values.

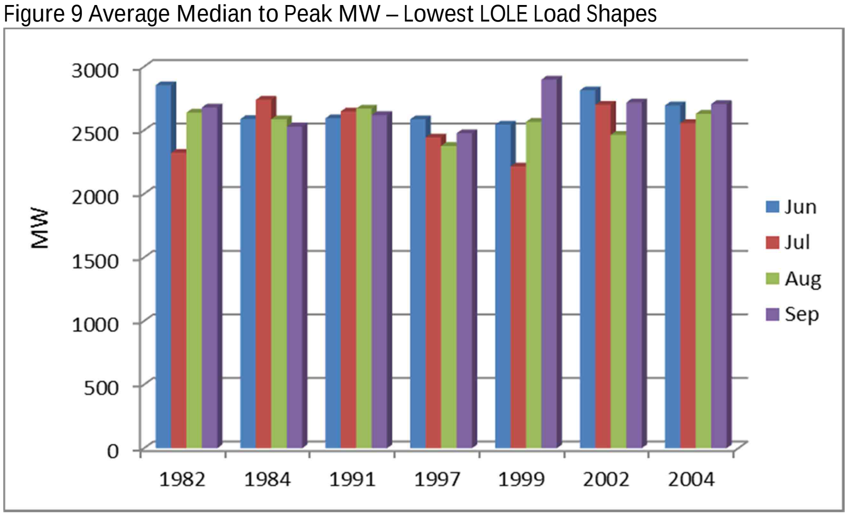
Figure 8 Average Median to Peak MW - Highest LOLE Load Shapes



The range of values differ significantly; the average monthly MW differences range from about 1400 MW to 1970 MW, except for one value over 2100 MW in Figure 8 and the average monthly MW differences range much higher, from about 2200 MW to over 2900 MW in Figure 9.

These figures illustrate the systematic difference in load shapes between the conditions that lead to high LOLE and those that lead to low LOLE. This presents insight into analysis of load shapes for a variety of purposes.

Figure 9 Average Median to Peak MW – Lowest LOLE Load Shapes



Solar ELCC

Staff conducted multiple rounds of studies to determine the ELCC of solar facilities within the CAISO. When solar facilities were removed and "Perfect Capacity" was added as substitution, LOLE results were calibrated to within the acceptable range of 0.1(LOLE of 0.101) at an ELCC of 63% with 120 iterations. Figure 10 illustrates the quantity and location of the 5,914.39 MW of solar facilities removed as well as the 3,726.55 MW of "Perfect Capacity" added to CAISO to calculate the ELCC.

Figure 10 Solar Capmax versus Perfect Capacity in CAISO

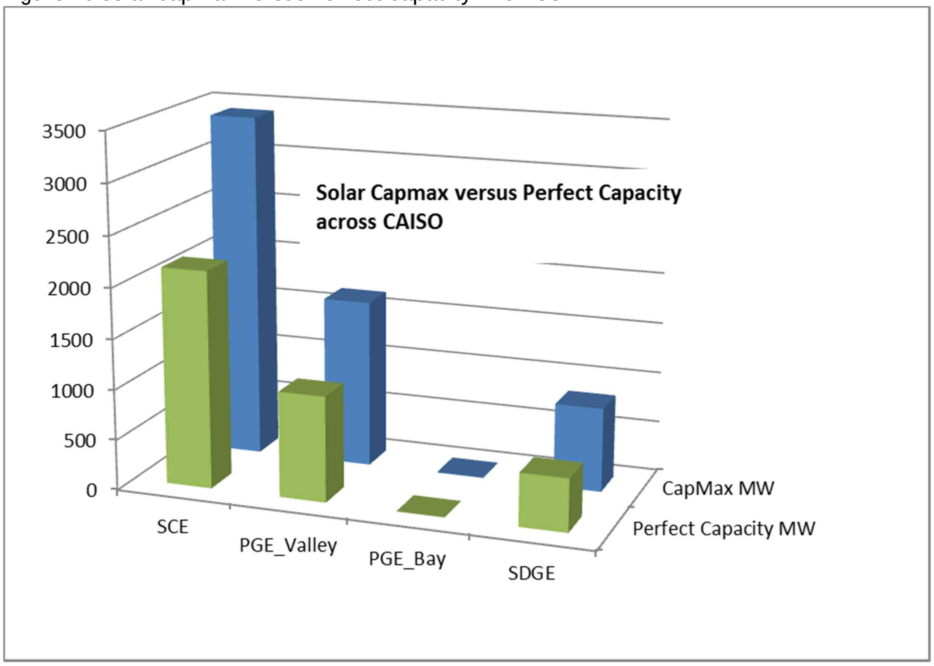


Table 5 reflects the remaining resources once solar facilities are removed, and reflects the addition of 3726.55 MW of "Perfect Capacity" added to recalibrate the LOLE in CAISO to 0.1. Figures are in MW and are nameplate (capmax) values, not adjusted for ELCC.

Table 5 Resource Breakdown - Solar ELCC Case

Region	SDGE	PGE_Bay	PGE_Valley	SCE	CAISO
Study Year	2016	2016	2016	2016	2016
Peak Load (All figures in MW)	4,421	8,233	13,408	22,789	47,038
Total Nameplate Resources	5,707	8,977	23,581	24,983	63,248
Nuclear Resources	0	0	2,300	0	2,300
Fossil Resources	4,030	5,617	9,600	13,523	32,770
Peaking Resources	1,124	1,625	3,485	4,961	11,194
Run of River Hydro Resources	0	0	374	132	505
Scheduled Hydro Resources	0	0	5,586	972	6,558
Emergency Hydro Resources	0	0	0	200	200
Pumped Storage Resources	40	0	1,218	200	1,458
Demand Response Resources	43	169	703	1,268	2,182
Wind Resources (no solar)	470	1,566	316	3,729	6,081

Table 6 below illustrates the distribution of LOLE events across the 12 months of each year and across the areas in the study. The CAISO row serves as the aggregate of the other areas, and each row sums to the total LOLE observed in that area. The total of the CAISO row sums to approximately 0.1 LOLE. Solar facilities are all removed, and Perfect Capacity is added back until the CAISO area us recalibrated to a LOLE of 0.1. ED staff found that the preponderance of LOLE events is attributable to the SCE area, and that PG&E areas are responsible for near zero of the LOLE events. Each row totals to the total LOLE observed in that area over the whole study.

Table 6 Solar ELCC LOLE values by month and region

	1	2	3	4	5	6	7	8	9	10	11	12
CAISO	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.068	0.005	0.000	0.000	0.000
SCE	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.067	0.004	0.000	0.000	0.000
SDGE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PGE_Bay	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PGE_Valley	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 7 breaks down LOLE by load year and ranks each load year for the Solar ELCC study. In this table, each column lists the LOLE observed for that weather year, and the columns total the LOLE events observed in each area of the model. The CAISO column totals to 0.1 LOLE. LOLE values are spread out across load years more widely than in the Calibrated LOLE Case results in Table 4, with the seven most unreliable load years responsible for only 84.7% of total LOLE as opposed to 91% of total LOLE.

Table 7 LOLE ranked by Load Year and Region - Solar ELCC

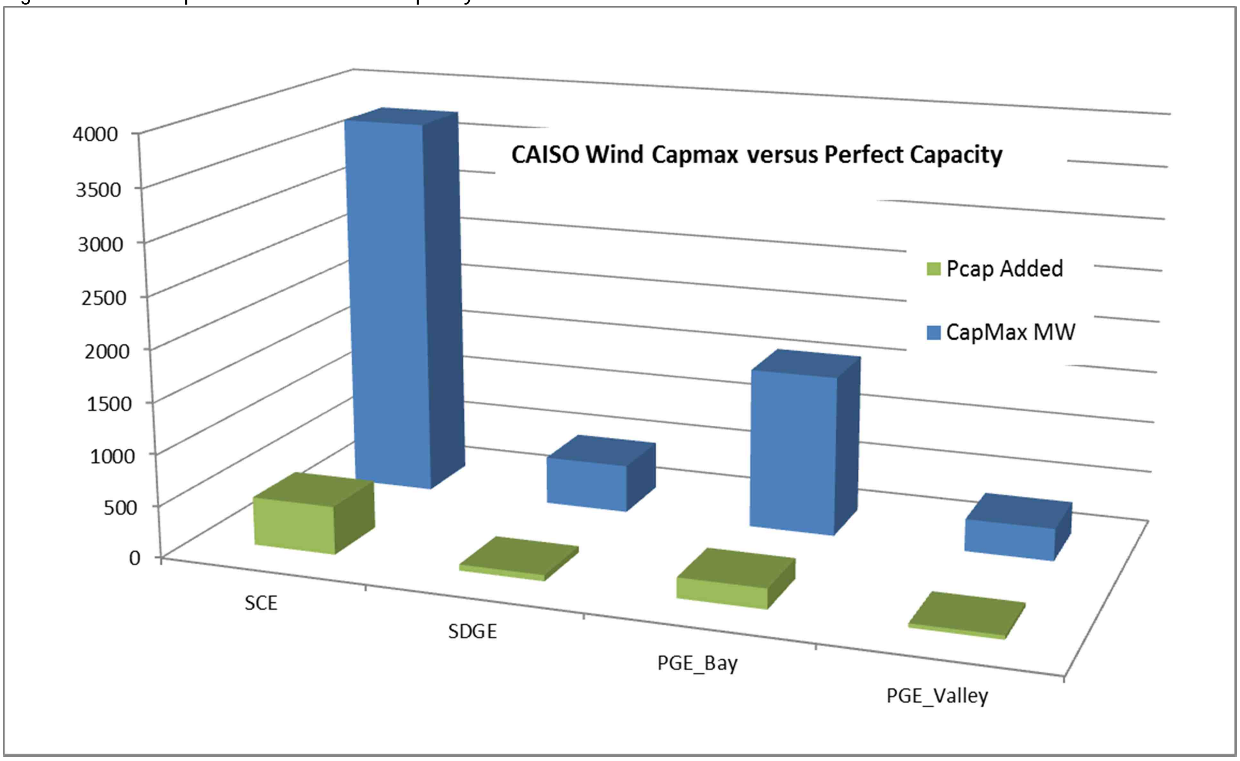
Load Year	CAISO	SCE	SDGE	PGE_Bay	PGE_Valley
1992	0.019	0.019	0.000	0.000	0.000
2009	0.018	0.018	0.000	0.000	0.000
1994	0.018	0.018	0.000	0.000	0.000
2006	0.011	0.011	0.000	0.000	0.000
1985	0.010	0.010	0.000	0.000	0.000
2007	0.008	0.008	0.000	0.000	0.000
1998	0.005	0.005	0.000	0.000	0.000
1990	0.001	0.001	0.000	0.000	0.000
1981	0.002	0.002	0.000	0.000	0.000
1980	0.001	0.001	0.000	0.000	0.000
2012	0.001	0.001	0.000	0.000	0.000
1996	0.001	0.001	0.000	0.000	0.000
2011	0.001	0.001	0.000	0.000	0.000
2010	0.001	0.001	0.000	0.000	0.000
1995	0.000	0.000	0.000	0.000	0.000
2001	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.000	0.000	0.000	0.000
1987	0.000	0.000	0.000	0.000	0.000
1988	0.000	0.000	0.000	0.000	0.000
2005	0.000	0.000	0.000	0.000	0.000
1983	0.000	0.000	0.000	0.000	0.000
1982	0.000	0.000	0.000	0.000	0.000
1993	0.000	0.000	0.000	0.000	0.000
2003	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.000
1986	0.000	0.000	0.000	0.000	0.000
2008	0.000	0.000	0.000	0.000	0.000
1984	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.000	0.000	0.000	0.000
2002	0.000	0.000	0.000	0.000	0.000
2004	0.000	0.000	0.000	0.000	0.000

Wind ELCC

Staff conducted multiple rounds of studies to determine the ELCC of wind facilities within the CAISO. When wind facilities were removed and "Perfect Capacity" was added as substitution, LOLE results were calibrated to within the acceptable range of 0.1 (LOLE of 0.092) at an ELCC of 12.6% with 120 iterations.

Figure 11 illustrates the distribution of wind capacity in CAISO, as well as the distribution of "Perfect Capacity" added to CAISO to recalibrate the LOLE back to the acceptable range.

Figure 11 Wind Capmax versus Perfect Capacity in CAISO



Results are provided for the "Perfect Capacity" level in the middle of the range, equivalent to an ELCC of 12.6% of "Perfect Capacity". Table 8 reflects the load and resource balance once wind facilities are removed, and reflects the addition of "Perfect Capacity" added to recalibrate to LOLE of 0.1. Figures are in MW and are nameplate (capmax) values, not adjusted for ELCC.

Table 8 Resource Breakdown - Wind ELCC Case

Region	SDGE	PGE_Bay	PGE_Valley	SCE	CAISO
Study Year	2016	2016	2016	2016	2016
Peak Load (all figures in MW)	4,421	8,233	13,408	22,789	47,038
Total Nameplate Resources	5,537	7,608	24,375	22,780	60,301
Nuclear Resources	0	0	2,300	0	2,300
Fossil Resources	3,960	5,611	9,599	13,517	32,687
Peaking Resources	662	1,822	2,474	3,278	8,236
Run of River Hydro Resources	0	0	374	132	505
Scheduled Hydro Resources	0	0	5,586	972	6,558
Emergency Hydro Resources	0	0	461	200	661
Pumped Storage Resources	40	0	1,218	200	1,458
Demand Response Resources	43	169	703	1,268	2,182
Solar Resources (no wind)	832	6	1,661	3,214	5,914

Table 9 below illustrates the distribution of LOLE events across the 12 months of each year and across the areas in the study resulting from ELCC of 12.6%. The CAISO row serves as the aggregate of the other areas, and each row sums to the total LOLE observed in that area. The total of the CAISO row sums to approximately 0.092 LOLE. Results highlight the preponderance of LOLE events attributable to the SCE area, although some LOLE is now observed in PGE's areas.

Table 9 Wind ELCC LOLE Values by Month and Region

	1	2	3	4	5	6	7	8	9	10	11	12
CAISO	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.061	0.006	0.000	0.000	0.000
SCE	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.061	0.006	0.000	0.000	0.000
SDGE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000
PGE_Bay	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
PGE_Valley	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 10 breaks down LOLE by load year and ranks each load year resulting from "Perfect Capacity" levels equal to the midpoint of the ELCC range specified above. At an ELCC level of 12.6%, LOLE is equal to approximately 0.092. In this table, each column lists the LOLE observed for that weather year, and the columns total the LOLE events observed in each area of the model. The CAISO column totals to 0.92 LOLE.

Table 10 LOLE Ranked by Load Year and Region - Wind ELCC

Load Year	CAISO	SCE	SDGE	PGE_Bay	PGE_Valley
2009	0.022	0.022	0.001	0.000	0.000
1992	0.016	0.016	0.000	0.000	0.000
1985	0.011	0.011	0.000	0.000	0.000
2007	0.011	0.010	0.001	0.000	0.000
2006	0.010	0.010	0.000	0.000	0.000
1994	0.007	0.007	0.000	0.000	0.000
1998	0.003	0.003	0.000	0.000	0.000
2011	0.003	0.003	0.000	0.000	0.000
2010	0.002	0.002	0.000	0.000	0.000
1990	0.001	0.001	0.000	0.000	0.000
2012	0.001	0.001	0.000	0.000	0.000
1980	0.001	0.001	0.000	0.000	0.000
1981	0.001	0.001	0.000	0.000	0.000
2001	0.000	0.000	0.000	0.000	0.000
1996	0.000	0.000	0.000	0.000	0.000
1983	0.000	0.000	0.000	0.000	0.000
2003	0.000	0.000	0.000	0.000	0.000
1989	0.000	0.000	0.000	0.000	0.000
1995	0.000	0.000	0.000	0.000	0.000
1988	0.000	0.000	0.000	0.000	0.000
1987	0.000	0.000	0.000	0.000	0.000
1982	0.000	0.000	0.000	0.000	0.000
2005	0.000	0.000	0.000	0.000	0.000
2008	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.000
2004	0.000	0.000	0.000	0.000	0.000
1993	0.000	0.000	0.000	0.000	0.000
1986	0.000	0.000	0.000	0.000	0.000
1984	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.000	0.000	0.000	0.000
2002	0.000	0.000	0.000	0.000	0.000

Next Steps and Implementation in the RA Proceeding

ED staff has identified several important next steps that will enable further calibration to historical patterns, and create further confidence in the application of study results to broader purposes in the RA and LTPP proceedings. ED staff are in the process of updating to the final version of the TEPPC 2024 Common Case (v1.5) and that update will yield more exact and precise identification of generation and load forecasts for areas external to California, and ED staff is updating to a newer version of the CAISO MasterFile data than was available when ED staff began the ELCC modeling. Over the course of this summer, ED staff will repeat some of this modeling to further validate results. Primarily updates to the TEPPC case and MasterFile information are expected to improve the economic dispatch of thermal generators, and to calibrate import and export flows between study areas. Other updates are planned as well.

In addition to updated data and more realistic economic dispatch patterns, this proposal also would benefit from more stakeholder input. This proposal represents a significant departure from previous methods of determining QC for wind and solar generators; the annual value that is held flat across all months of the year is not compatible with the current monthly nature of the RA program. ED staff will need to determine how best to apply this value to month specific RA obligations. Attempting to use the values calculated by ED staff would result in capacity shortfall in the peak months and significant capacity surplus in the offpeak months. This is likely not realistic, and would otherwise reduce the amount of dispatchable thermal capacity made available to the CAISO in the offpeak months. In addition, the ELCC values presented here differentiate neither between different classes of generators nor their location. More work is needed to roll out additional ELCC values to apply more specifically based on generation type and location.