CALPINE® NYSE CPN

A GENERATION AHEAD, today

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E3/Calpine ELCC Modeling

CLEAN MODERN EFFICIENT FLEXIBLE POWER GENERATION

Intro

- ELCC implementation is a high priority for Calpine
  - Solar over-counting is displacing other generation from the RA market and potentially undermining reliability
  - Level playing field for different renewable technologies, including geothermal
- Calpine decided to invest in modeling
  - Shadow Energy Division modeling
  - Develop simpler approaches to ELCC implementation
- Today's presentation summarizes preliminary results and thoughts on implementation
- Calpine sought E3's technical assistance in implementing RECAP. (Modeling choices are Calpine's.)

Overview

- RECAP
- Results
- Translating results to NQCs

Why RECAP?

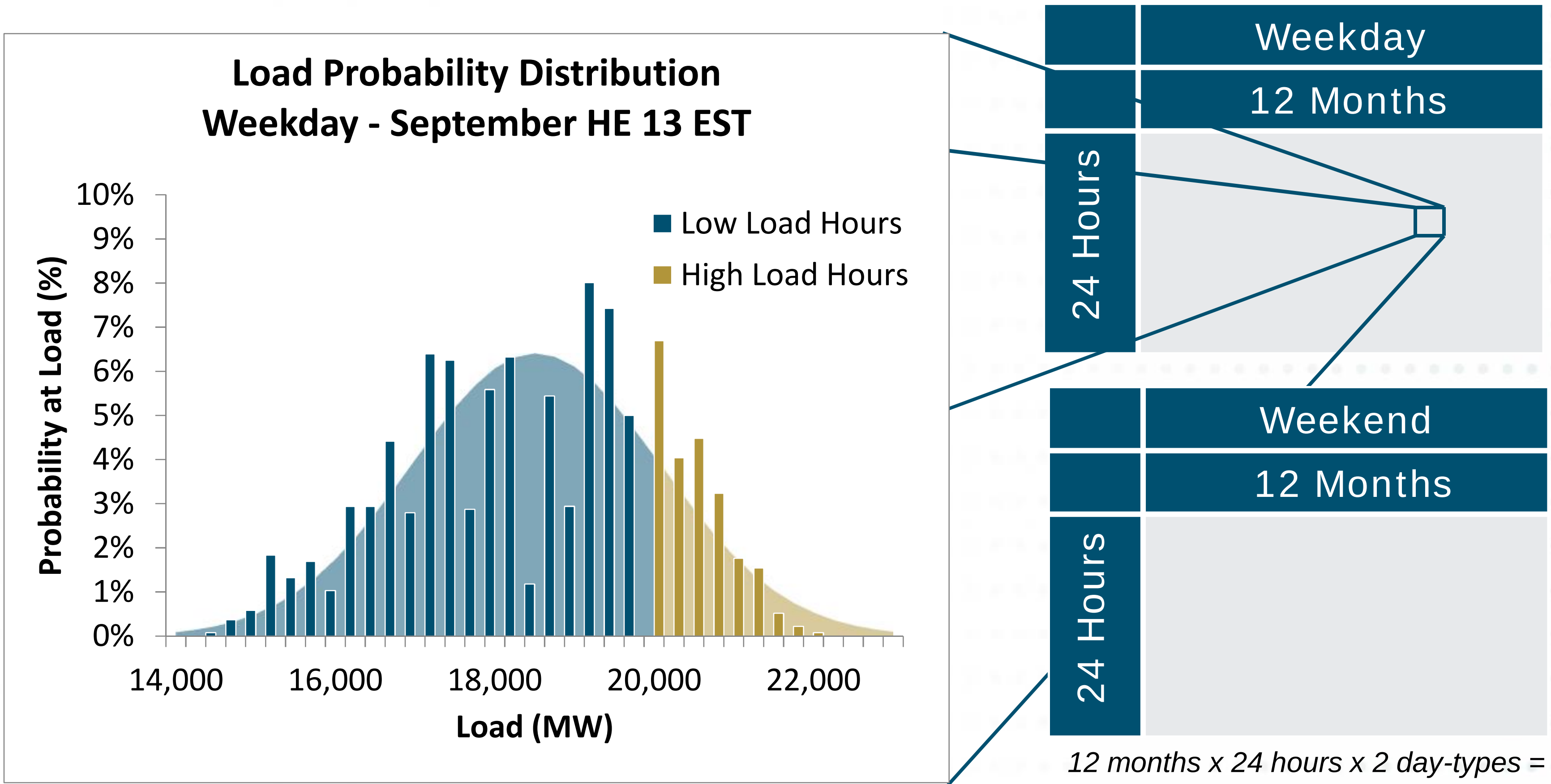
- RECAP is a publicly available ELCC model developed by E3
  - Excel interface
  - Core analytic engine written in Python
  - Download: https://ethree.com/public_projects/recap.php
- RECAP is used in numerous other CPUC proceedings and by several utilities in long-term planning
  - DR/EE cost-effectiveness
  - RPS calculator
  - SMUD IRP
- Our implementation of RECAP is significantly simpler than ED’s implementation of SERVM
  - CAISO modeled as a single area
  - No explicit chronology, i.e., each hour independent
    - 576 hour types rather than 8,760 hours
  - No explicit representation of external resources
- Ignoring topology and chronology allows RECAP to run quickly i.e. 20+ minutes depending on model settings

Energy+Environmental Economics

RECAP:
E3'S RENEWABLE ENERGY CAPACITY PLANNING MODEL

Creating Gross Load Distributions

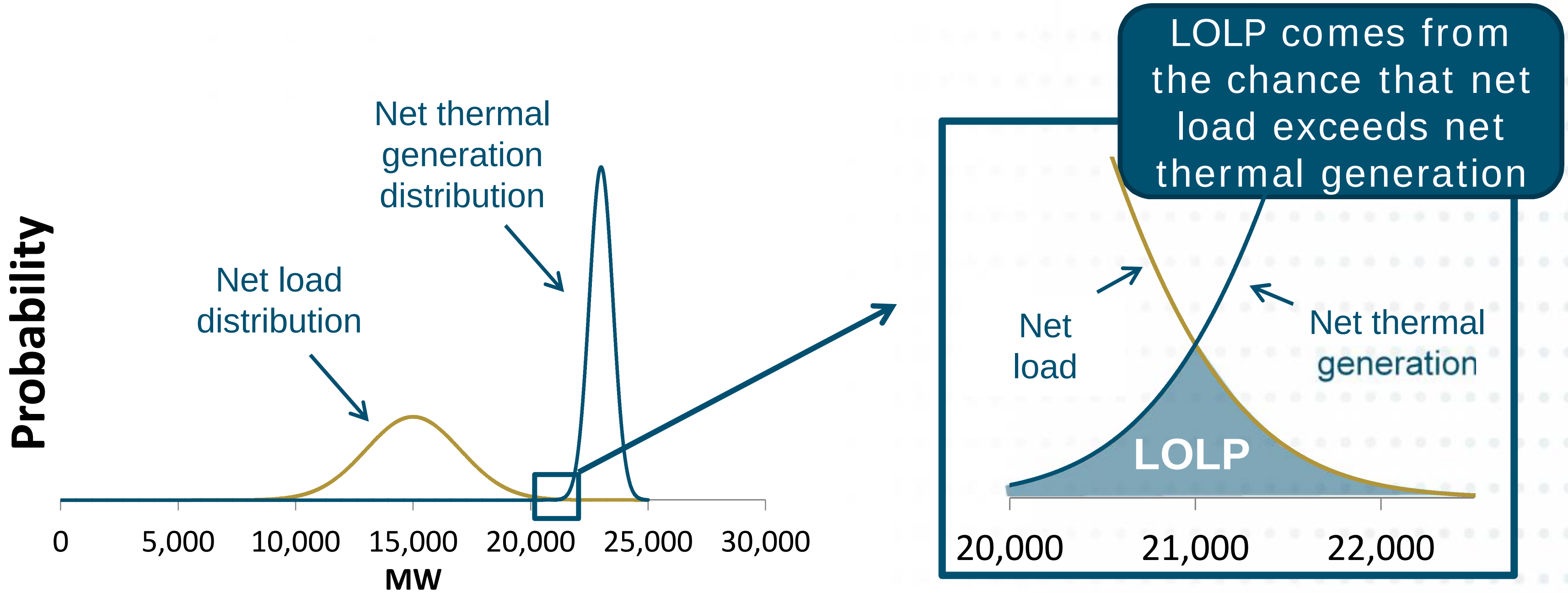
- Using a large load sample size created by a neural network, probability distributions are created for each month/hour/day-types (24*12*2 = 576 total distributions)



12 months x 24 hours x 2 day-types = 576 Total Distributions

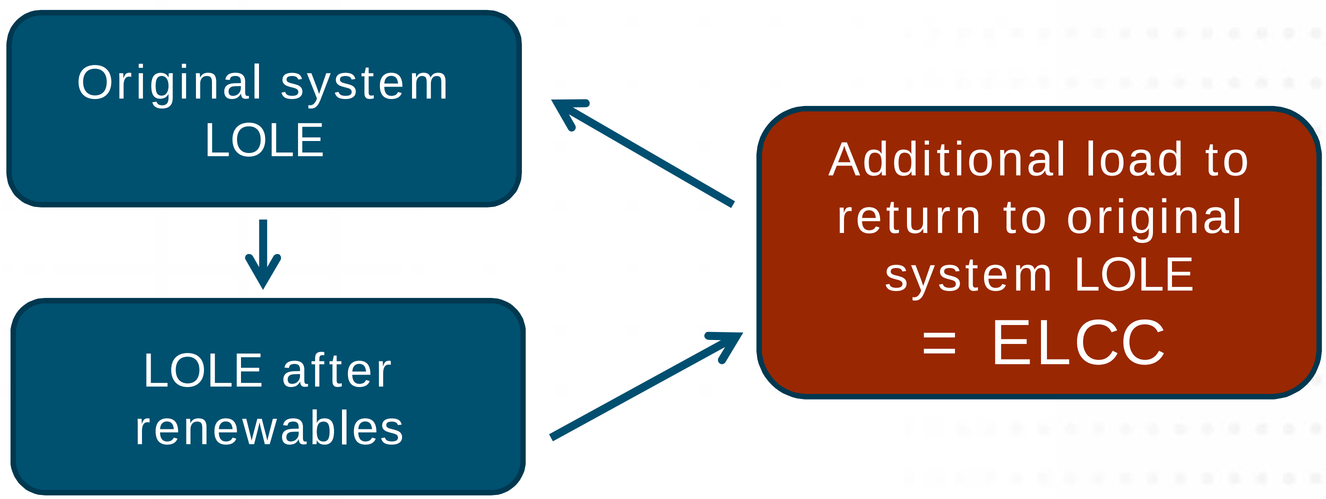
Calculating LOLP

- RECAP compares a unique pair of distributions (thermal generation and net load) for all 576 month/hour day-types
- Then it is possible to calculate the loss of load probability (LOLP) for each pair of distributions



Calculating ELCC

- Since LOLE has decreased with the addition of renewables, adding pure load will return the system to the original LOLE
- The amount of load that can be added to the system is the effective load carrying capability (ELCC)

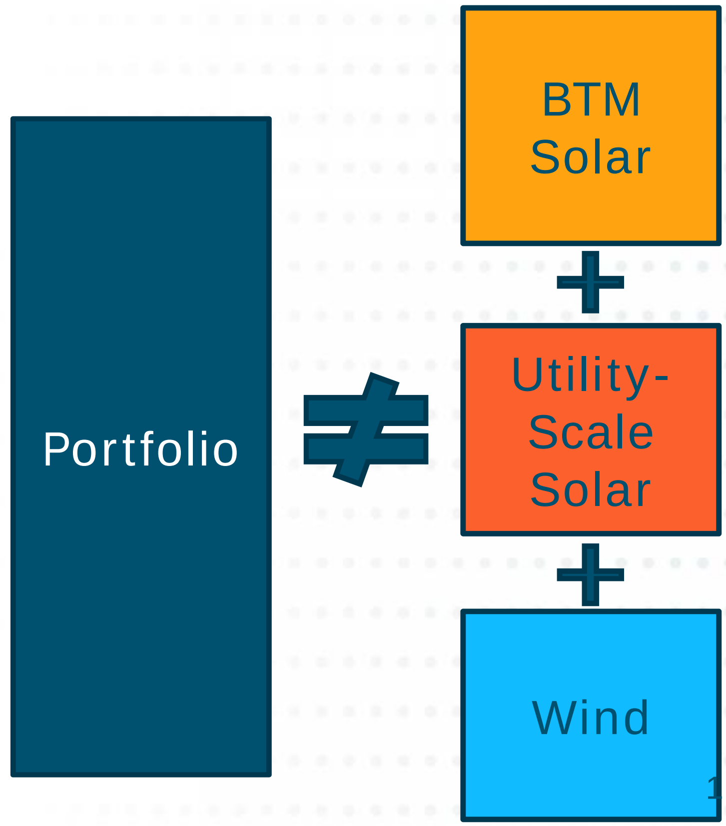


Ideal RA process for renewables

1. Calculate portfolio ELCC
2. Allocate portfolio ELCC to existing resources (NQC)
3. Given current portfolio, calculate new resources' marginal ELCC to guide procurement

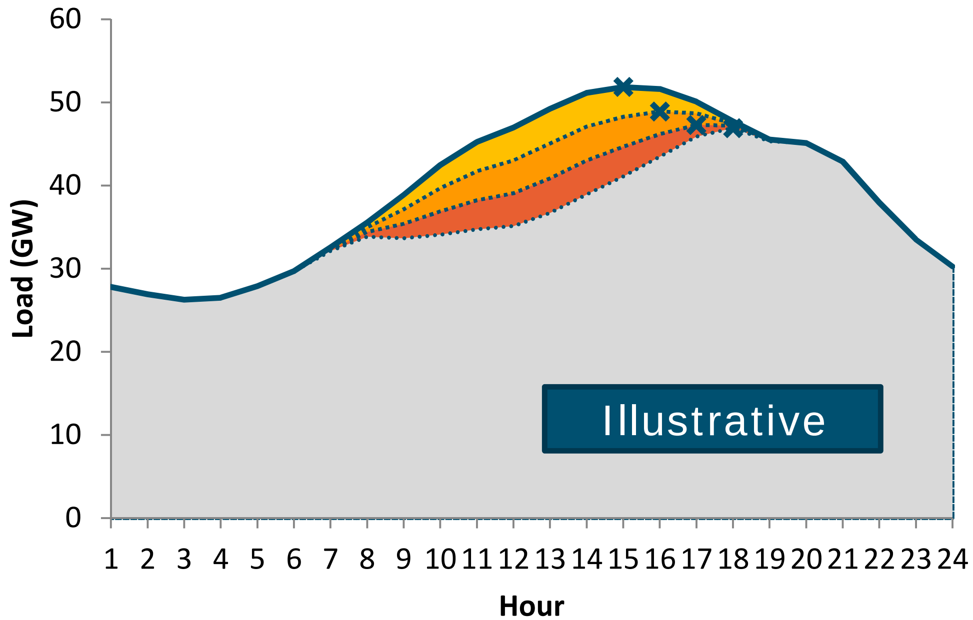
Art vs Science of Capacity Value

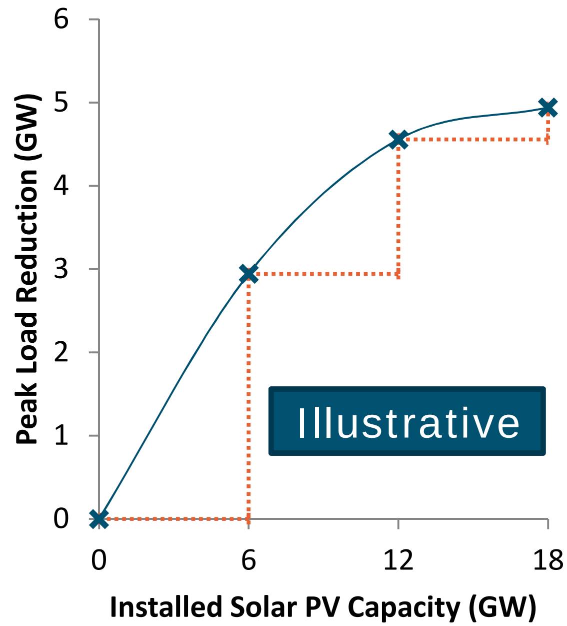
- Science: RECAP can correctly measure the capacity value contribution of the entire renewable portfolio
- Art: There is no ‘correct’ method to allocate the portfolio capacity value to all of the individual resources
  - Summing the individual capacity contribution of resources will not equal the portfolio capacity value because it does not capture interactive effects
  - However, there are several reasonable methods to allocate portfolio capacity value



Interactive effects

- A resource's contribution towards reliability depends on the other resources on the system
- The diminishing marginal peak load impact of solar PV is illustrative of this concept
  - While the first increment of solar PV has a relatively large impact on peak, it also shifts the "net peak" to a later hour in the in day
  - This shift reduces the coincidence of the solar profile and the net peak such that additional solar resources have a smaller impact on the net peak (note that the opposite happens for wind, i.e. wind's capacity value increases with increasing solar)





Ener

Load and Renewable Inputs

2018 Renewable Portfolio Assumptions, Load Levels, and Shapes*

Type	Weather Record	CF	2016 GWh	2018 GWh	2018 MW	Notes
Load	1950-2012	-	223,117	221,877	45,604	Created by neural network developed by E3. Scaled to 2018 energy and peak forecast, which is consistent with latest RPS calculator inputs (v6.2)
Wind	2007-2012	30%	13,729	14,895	5,592	Created using NREL's Wind Toolkit wind speed data and E3 algorithm that applies power curves and hub heights depending on vintage.**
Utility Scale PV	2005-2012	24%	15,199	19,775	9,257	Created by aggregating NREL generation profiles based on the System Advisor Model (PVWatts).**
BTM PV	2005-2012	19%	6,708	8,636	5,072	Created by aggregating NREL generation profiles based on the System Advisor Model (PVWatts).**
Solar Thermal	2006-2012	29%	2,736	2,746	1,077	Created using NSRDB solar data and NREL's System Advisor Model. **

** All other inputs such as thermal generation are consistent with public RECAP version. Solar shapes were updated to obtain an overlapping set of weather years (2006-2012). This was necessary because NQC calculations require a matching set of renewable profiles (same weather year) in order to capture the diversity benefits correctly.*

*** Delivered energy is consistent with latest RPS calculator results (v6.2). Capacity is derived from shape's capacity factor.*

LOLE assumptions

- We target 1 hour of expected loss-of-load in a 10 year period (1-in-10 standard)
  - 1 hour in ten years in the annual results
  - 1/12 hour in ten months (1 month x 10 years = 10 months) in the monthly results
    - In the winter/spring months with excess capacity, load is added until the reliability target is met. This normalizes all months to the same reliability and allows us to look at the capacity value in months that there isn't an actual need for capacity.

Energy+Environmental Economics

RESULTS

Misalignment of Exceedance NQC

- Current exceedance approach did a relatively good job at capturing the most important hours when there was a low penetration of renewable energy
- At high penetrations of renewables, solar has shifted the peak to later in the day and later in the year, and current approach no longer does a good job at capturing the most important hours

Gross Load LOLP

i.e. LOLP Pre-Renewables

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	7.04E-13	0	3.74E-12	0	0	0
11	0	0	0	[illegible]	[illegible]	[illegible]	4.75E-09	1.18E-08	2.64E-08	0	0	0
12	0	0	0	[illegible]	[illegible]	[illegible]	1.31E-06	5.76E-06	7.77E-06	0	0	0
13	0	0	0	0	0	2.99E-09	8.01E-05	0.00014	7.25E-05	0	0	0
14	0	0	0	0	0	2.26E-08	0.0003	0.00052	0.00025	0	0	0
15	0	0	0	0	0	1.45E-07	0.00039	0.00092	0.00045	1.87E-10	0	0
16	0	0	0	0	0	1.05E-07	0.00017	0.00038	0.00021	7.61E-10	0	0
17	0	0	0	0	0	1.43E-09	1.00E-05	1.29E-05	1.19E-05	3.73E-12	0	0
18	0	0	0	0	0	3.53E-15	2.24E-07	2.67E-08	5.27E-08	0	0	0
19	0	0	0	0	0	0	5.99E-10	8.44E-09	8.17E-10	0	0	0
20	0	0	0	0	0	0	8.42E-10	1.31E-12	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

NQC Hours

Net Load LOLP

i.e. LOLP With Renewables (2018)

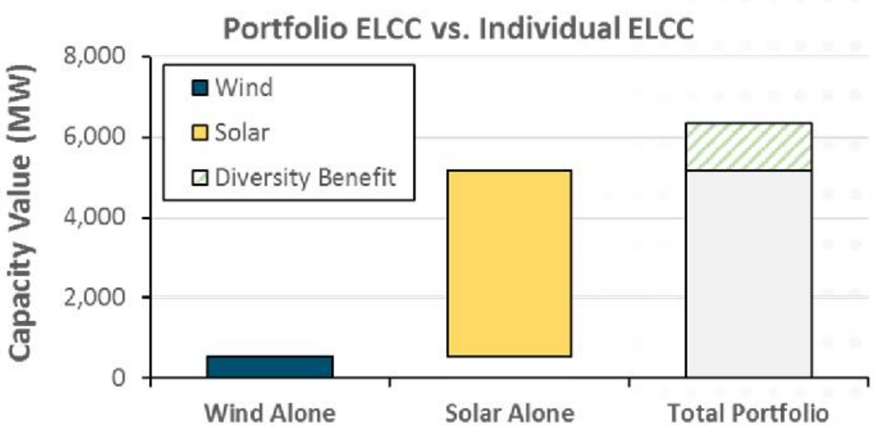
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0.00E+00	0	2.51E-16	0	0	0
11	0	0	0	[illegible]	[illegible]	[illegible]	0.00E+00	0.00E+00	6.88E-15	0	0	0
12	0	0	0	[illegible]	[illegible]	[illegible]	5.35E-16	0.00E+00	3.05E-13	0	0	0
13	0	0	0	0	0	6.53E-17	2.36E-13	9.4E-13	1.42E-12	0	0	0
14	0	0	0	0	0	2.19E-13	7.1E-11	1E-10	2.5E-10	0	0	0
15	0	0	0	0	0	1.51E-11	1.3E-08	4.3E-08	8.7E-08	2.11E-12	0	0
16	0	0	0	0	0	2.16E-10	3.4E-07	2.8E-06	1.1E-05	3.75E-09	0	0
17	0	0	0	0	5.7E-17	6.12E-10	2.88E-06	2.56E-05	2.81E-04	9.04E-07	0	0
18	0	0	0	0	1.3E-15	2.94E-09	1.71E-05	1.35E-04	1.74E-03	3.8E-06	0	0
19	0	0	0	0	0	1.5E-09	1.38E-05	5.71E-04	5.96E-04	9.6E-07	0	0
20	0	0	0	0	0	1.5E-09	2.04E-05	2.53E-05	2.6E-05	3.8E-10	0	0
21	0	0	0	0	0	0	2.3E-09	3.4E-09	4.7E-09	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

NQC Hours

All NQC hours shown in standard time (PST)
Tables show results for annual ELCC

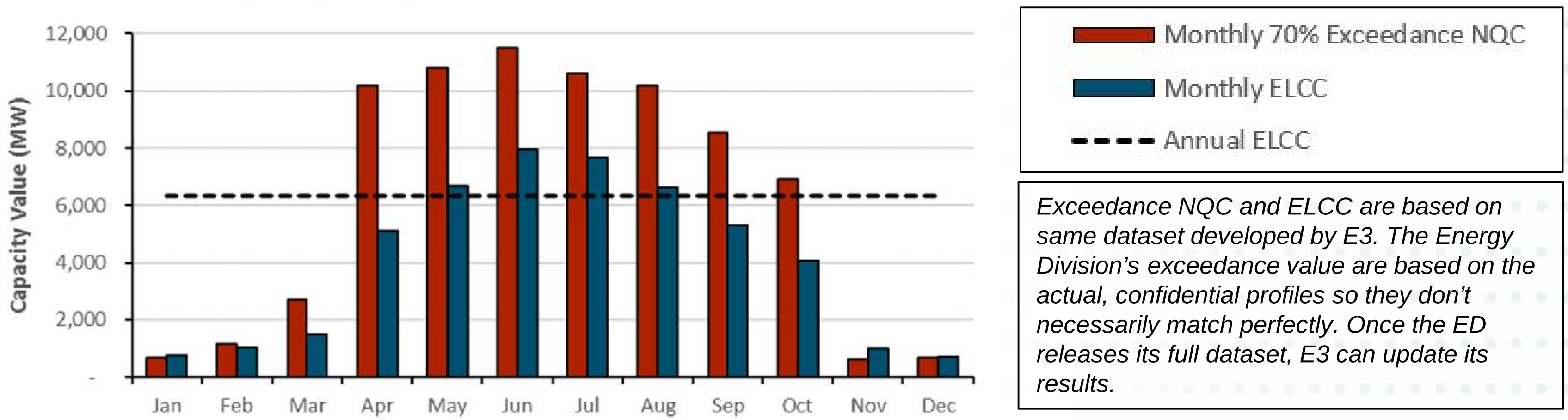
Annual Portfolio ELCC

- ELCC of the overall 2018 portfolio is 6,350 MW
  - Significant reduction of peak load due to renewables
  - 30% of the total installed capacity (5.5 GW of wind + 15.2 GW of solar)
- This is the true contribution to reliability of renewables in 2018, consistent with reliability standards and PRM
- Allocations by resource must be consistent with this result
- Separate ELCC analysis of each of the individual resources will not sum up to the portfolio value due to interactive effects



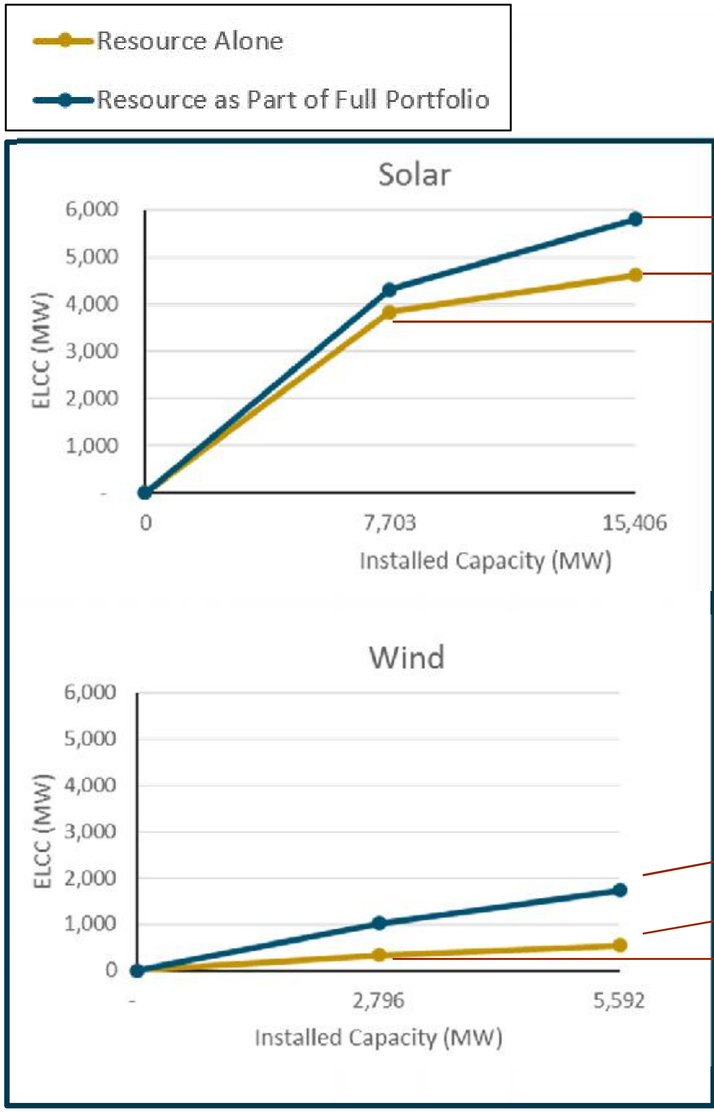
Monthly ELCC vs. Exceedance NQC

- Monthly ELCC values range from < 1,000 MW in winter to almost 8,000 MW in summer. Peak summer months (Jul, Aug, Sep) weigh most heavily in annual ELCC and therefore have monthly ELCC values close to annual ELCC
- Monthly 70% Exceedance NQC is significantly higher than monthly ELCC in the summer
  - Average NQC based on exceedance in the peak summer months (Jul, Aug, Sep) is 9,786 MW
  - Average monthly ELCC in the peak summer months (Jul, Aug, Sep) is 6,540 MW
  - Both numbers include 5,072 MW of BTM PV
- Difference is due to diminishing returns as solar shifts the peak to night-time



Exceedance NQC and ELCC are based on same dataset developed by E3. The Energy Division's exceedance value are based on the actual, confidential profiles so they don't necessarily match perfectly. Once the ED releases its full dataset, E3 can update its results.

Diminishing Returns and Portfolio Diversity Benefits



Presence of 5.6 GW of wind boosts capacity value of solar*
~15.4 GW of solar adds ~4.5 GW of capacity (30%)
~7.7 GW of solar adds ~4 GW of capacity (50%)

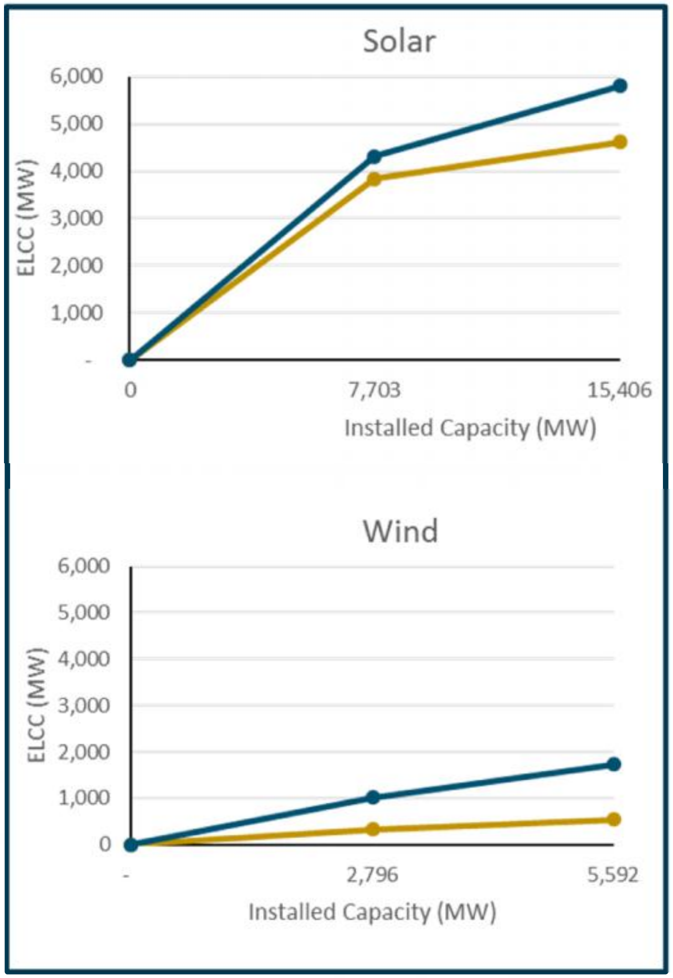
+ **Solar initially has higher capacity value but shows stronger diminishing returns**
+ **Wind boosts capacity value of solar and vice versa.**

Presence of 15.4 GW of solar boosts capacity value of wind*
~5.6 GW of wind adds ~0.5 GW of capacity (10%)
~2.8 GW of wind adds ~0.3 GW of capacity (12%)

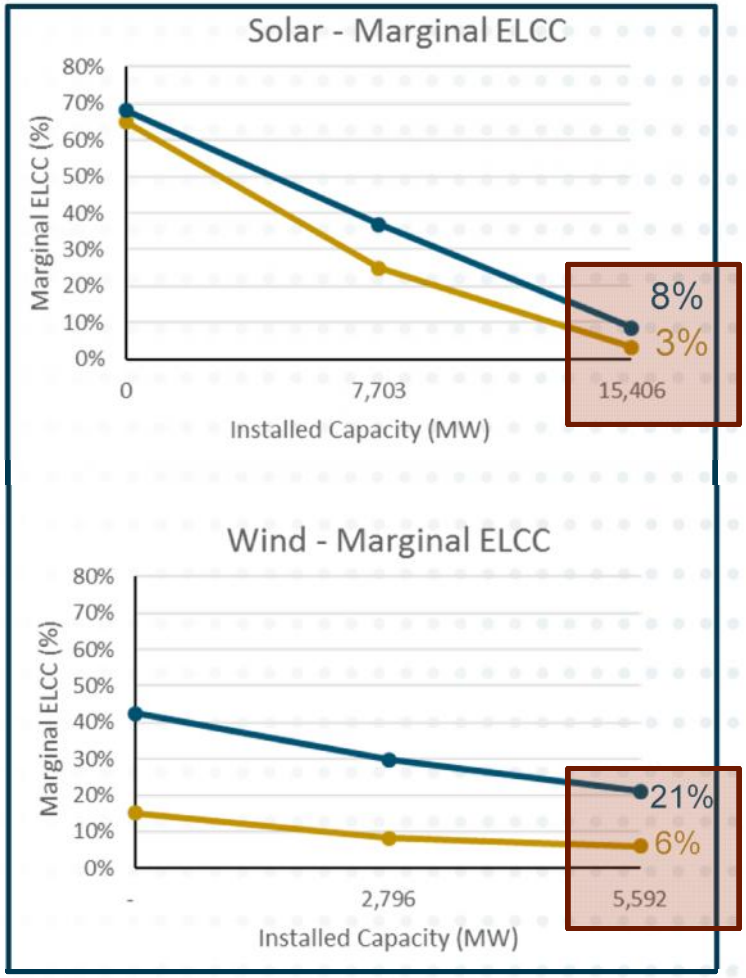
**Note: Can't sum up the capacity values of both resources as part of the full portfolio as this will "double count" the interactive effect*

Marginal ELCC

- By 2018, additional solar will have very limited additional capacity value as the net peak has almost fully shifted to night-time, boosting ELCC of wind.



Marginal ELCC represents the capacity value of the next increment of installed capacity. It represents the slope of the ELCC curve on the left

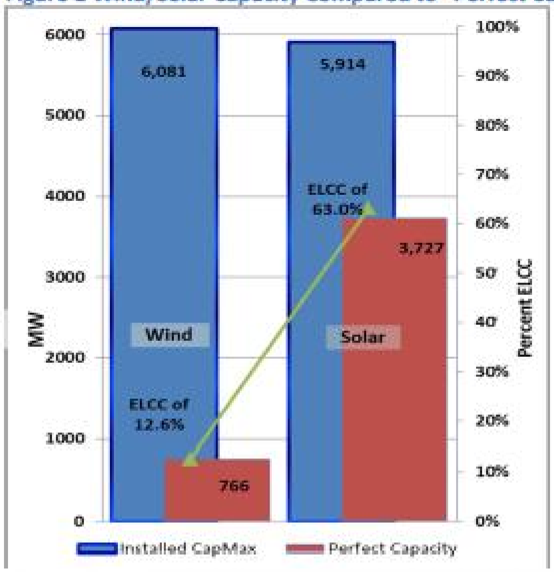


Comparison with 2016 ED ELCC Results

- ED in-out results:
  - 63% ELCC for solar (3,727 MW / 5,914 MW)
  - 12.6% ELCC for wind (766 MW / 6,081 MW)
- E3 in-out results (ED analysis mirroring):
  - 57% ELCC for solar (3,482 MW / 5,914 MW)
  - 14.2 % ELCC for wind (863 MW / 6,081 MW)
- E3 Recap results are consistent with ED SERVM results
  - Slight differences likely due to different renewable and load shape inputs
- These in-out results do not sum up to the portfolio ELCC as they double count the diversity benefits

ED results (2016 study year)

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



E3 RECAP Results (2016)	Utility PV Capacity (MW)	Wind Capacity (MW)	Portfolio ELCC (MW)	Difference in ELCC vs. All Resources (MW)	Marginal Capacity Value of in-out Resource (%)
All Resources	5,914	6,018	4,051	N/A	N/A
No Utility PV	-	6,018	569	3,482	57% (3,482 / 5,914)
No Wind	5,914	-	3,188	863	14% (863 / 6,081)

Compare with CPUC results

Conclusion

+ At high penetrations of renewables, currently implemented exceedance approach no longer captures the most important hours
  - Solar generation shifts the peak into night-time, lowering capacity value of solar and increasing capacity value of wind
  - By 2018, current approach could overvalue RA contribution of renewables by over 3 GW in the summer months
+ Annual ELCC of renewable portfolio is the true contribution to reliability
  - Renewable portfolio ELCC in 2018 is 6,350 MW (incl. BTM PV)
  - Any allocations by resource should sum up to this value
+ E3's RECAP results are consistent with the Energy Division's ELCC modeling results. E3's 2018 update adds the following:
  - Updated 2018 renewable portfolio
  - Accounts for BTM PV
  - Allows monthly calculations of ELCC

TRANSLATING RESULTS TO NQCs

Translating results to NQCs

- ELCC of the entire intermittent portfolio *is* its reliability contribution
- How to allocate portfolio ELCC to existing resources?
  - Allocate to technologies based on in-out results?
  - Allocate based on exceedance?
    - Old exceedance hours give solar too much credit
    - New exceedance focused on hours later in the day?
  - Vintaging
    - Calculate ELCCs that vary by technology and COD year
      - Alternatively, estimate resource-specific ELCCs as resources come on-line
    - Each vintage treated as preexisting for the purpose of calculating ELCCs for subsequent vintages
    - Resources with earlier CODs get higher ELCCs
    - ELCCs static once established?
    - Even with vintaging, a significant adjustment to NQCs of existing resources will be necessary to make aggregate NQC consistent with aggregate ELCC
- How to send accurate signals for future procurement?
  - Vintaging may be needed for future acquisitions

Example

Allocation of ELCC based on monthly individual ELCC

Month	Wind Alone ELCC		Solar Alone ELCC		Portfolio ELCC		Diversity Benefit	ELCC allocation wind		ELCC allocation solar	
Calc.	[1]		[2]		[3]		[4] = [3]-[2]-[1]	[5] = [1] + [1]/([1]+[2]) * [4]		[5] = [2] + [2]/([1]+[2]) * [4]	
Jan	746	*13%*	0	*0%*	746	*4%*	0	746	*13%*	0	*0%*
Feb	837	*15%*	144	*1%*	1,043	*5%*	62	890	*16%*	153	*1%*
Mar	345	*6%*	854	*6%*	1,511	*7%*	311	435	*8%*	1,076	*7%*
Apr	439	*8%*	3,920	*25%*	5,087	*24%*	729	512	*9%*	4,575	*30%*
May	734	*13%*	4,948	*32%*	6,695	*32%*	1,013	865	*15%*	5,830	*38%*
Jun	877	*16%*	5,592	*36%*	7,970	*38%*	1,501	1,081	*19%*	6,889	*45%*
Jul	765	*14%*	4,708	*31%*	7,660	*36%*	2,187	1,071	*19%*	6,589	*43%*
Aug	536	*10%*	4,535	*29%*	6,640	*32%*	1,568	702	*13%*	5,937	*39%*
Sep	344	*6%*	3,933	*26%*	5,321	*25%*	1,044	427	*8%*	4,894	*32%*
Oct	389	*7%*	3,356	*22%*	4,046	*19%*	302	420	*8%*	3,626	*24%*
Nov	359	*6%*	550	*4%*	1,016	*5%*	107	401	*7%*	615	*4%*
Dec	710	*13%*	0	*0%*	710	*3%*	0	710	*13%*	0	*0%*

Total solar installed capacity: 15,406 MW
Total wind installed capacity: 5,592 MW

How to address BTM PV?

- BTM currently counts differently than comparable IFOM resources
  - BTM reduces load and hence reduces RA obligations
  - IFOM treated as a resource
- How accurate is the current "counting" of BTM?
- Will changes to load forecasting methodologies improve the accuracy of the counting of BTM?
- For purposes of RA, should BTM be treated as a resource:
  - RA requirements based on gross load
  - RA credit for BTM ELCC?

Next Steps

- Use ED profiles and capacity assumptions in our model
- Investigate heuristics that approximate ELCC
  - Performance of resource or class of resource in top net load hours (Similar to SCE proposal)
- Explore implications of different allocation approaches

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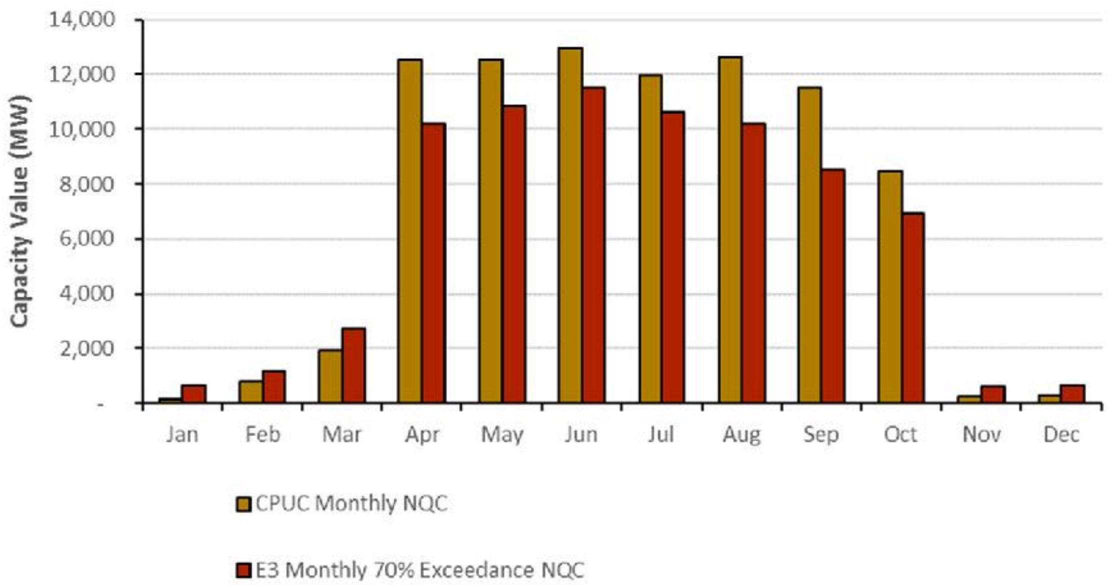
APPENDIX

E3 NQC vs. ED NQC

- Exceedance NQC based on E3's data differs from ED's exceedance NQC due to different inputs
- Once ED releases renewable profiles E3 can work with the same dataset to show results consistent with ED data



Note: CPUC NQC is product of 2018 installed capacity and technology factors from CPUC's draft 2017 NQC list. Assumed rooftop PV has 78% of the NQC of utility-scale PV (rooftop PV is not included in CPUC NQC calculations)