Using Energy Efficiency To Meet Flexible Resource Needs And Integrate High Levels Of Renewables Into The Grid

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ABSTRACT

Electric system planners and grid operators in California increasingly focus on meeting "net load" – total load minus the amount of load met by two types of renewable, energy: wind and solar. California's net load curve is a new challenge for grid operators and makes flexible resources much more valuable to the system: resources that can respond quickly to shifts in net load, like demand response, storage, dispatchable renewables, and gas generators. On the other hand, energy efficiency can help obviate the need for flexible resources by reshaping the net load curve to decrease net load maxima and increase the duration between net load minima and maxima. We review and compare the ability of various energy saving measures to reduce the amount of flexible resources that California's future electric grid will need. Energy efficiency measures can help maintain grid reliability as the electric grid begins to integrate significant amounts of non-dispatchable, variable, renewable energy. Consequently, we recommend that California's energy efficiency policy framework examine more closely the value of reducing flexible capacity when performing cost-effectiveness analysis, program design and implementation, measurement and verification of savings, and resource planning.

New Strategies Must be Deployed to Maintain Grid Reliability as Variable Renewable Resources Grow

In a carbon-constrained world, the electric grid will need to incorporate significantly higher penetrations of renewable energy resources (Greenblatt 2012). Some renewable energy resources, like solar and wind, produce energy at varying times of a day. Also, absent any form of integrated storage they produce energy independent of when called upon – or dispatched – by a grid operator, which makes them non-dispatchable. California and its independent system operator are on the cutting edge of identifying the mechanisms by which significant quantities of renewable resources can be integrated into the electric grid.

To describe these future operational challenges, the California Independent System Operator (CalISO) developed the "Duck Chart" (Figure 1) (CalISO 2013), which depicts the worst-case scenario of net load over a spring day in 2020, after California has integrated renewable energy such that it composes 33% of retail energy sales. The gross load curve would be higher than this net load curve at every hour of the day, but particularly when the sun is shining. Figure 1 assumes no new policy actions will be taken to manage ramping requirements from variable renewable resources.

Figure 1 displays nine different net load curves, one for each year. As more renewable energy is added to the grid, the net load shapes change over time. Driven by energy from solar, net load declines during the daylight hours, reaches its nadir at around hour 14 (forming the "belly" of the duck, then steeply rises as the sun sets and families return home (forming the "neck"), reaching its zenith at hour 20. To assess flexibility needs, CalISO has defined the critical time period as the three hour continuous window in which net load shows the greatest change. In this most recent CalISO Duck Chart, that delta net load is greatest from hour 16 to hour 19 on this critical spring day in 2020. An analysis of what the greatest contributor to this maximum three-hour net load ramp has been conducted out through 2016 (but not 2020). It shows that gross demand is responsible for about 2/3 of the total net load ramp, and solar only contributes about 1/4 (in the month of March) (CalISO 2014). This highlights the great potential to reduce the need for flexible resources through demand reduction provided by energy efficiency programs.

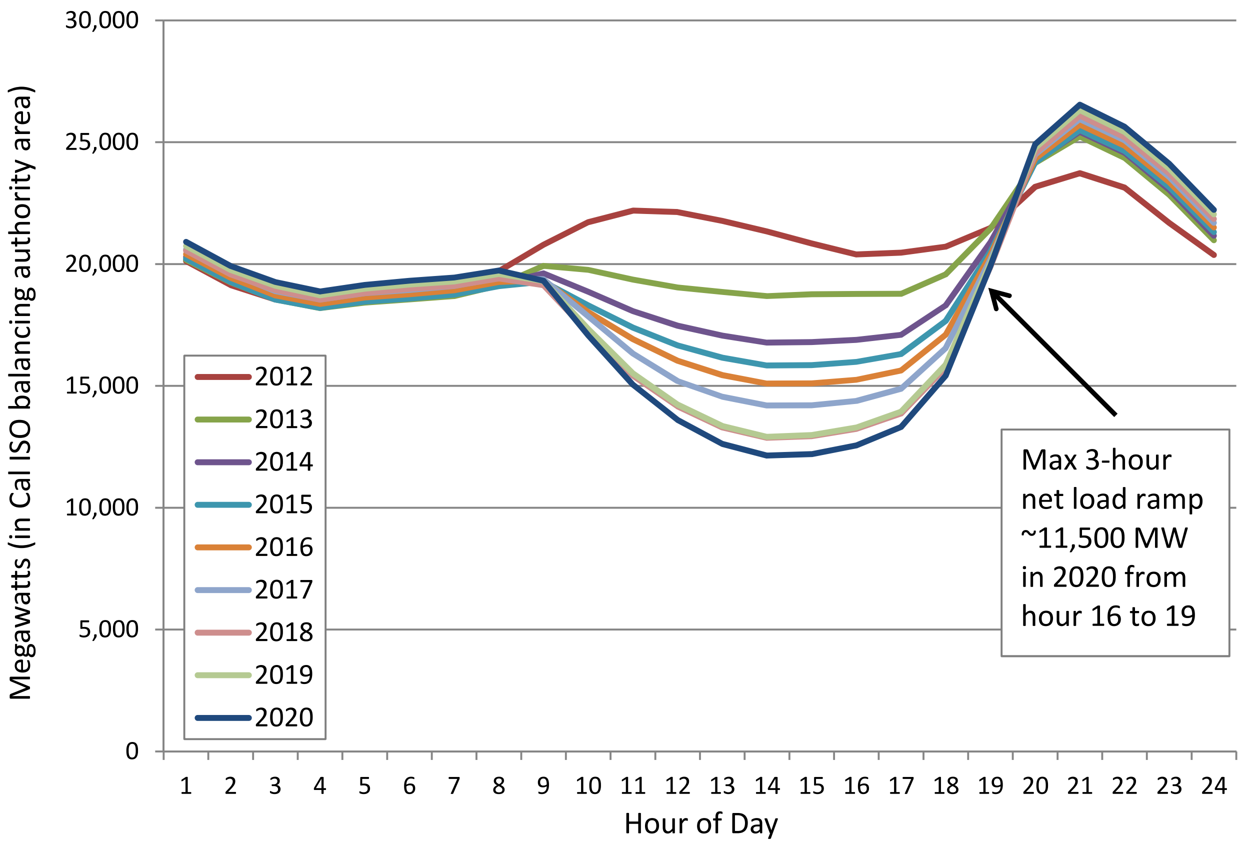

Figure 1. "The Duck Chart" – California expected net peak spring loads 2012-2020. In particular, net load for critical spring day (March 31) of various years. *Source*: CPUC/CEC 2013.

The reason to subtract the non-dispatchable renewable resources, like wind and solar, from power demand is to identify the amount of power that the grid operator must supply. So long as renewable resources are not curtailed, Figure 1 is a useful depiction of effects of integrating large volumes of renewable resources, absent any impacts from future energy efficiency initiatives, storage targets, the deployment of smart charging electric vehicles, or any other policy adaptations to the Duck Chart.

Figure 1 illustrates two major operational problems of integrating renewable energy resources, especially in 2020. First, there is a possibility of excess generation in the middle of the day due to the large amount of solar generation pushing the net load curve to extremely low levels. When the net load level is this low, baseload generation (e.g., nuclear, run-of-river hydro, fossil steam) may not be able to ramp down further, resulting in overgeneration (E3 2014). Shutting down a steam unit for the mid-day period may result in its being unavailable for the rest of the day or longer. Depending on transmission constraints and load and supply in adjacent regions, California may be able to export the excess, but over time, other regions may face similar overgeneration problems. At this stage of modeling (absent a large fleet of energy storage devices, or other possible solutions), the abundance of solar energy during mid-day suggests that this may not be the most cost-effective or grid-stabilizing time for energy efficiency measures to save energy. However, we must caveat these and other findings as results of the current models. The actual net load curve in 2020 could look incredibly different depending on the success of other clean energy policies. Second, there is a need for resources that can ramp up quickly enough to meet the evening net peak. The 2020 evening ramp is steeper than those that grid operators have previously encountered. The difference between minimum and maximum net load levels would be greater than past differences, and the ramp rate (in MW-per-hour, between hour 16 and hour 19) would be higher than current ramp rates.

Energy Efficiency Can Help Integrate Renewables

Both demand and supply resources will be deployed to meet the needs of an electricity system with high penetration of non-dispatchable renewables (RAP 2014, E3 2014). The supply-related solutions will shut down, reduce output, or store energy during the mid-day hours and then ramp up in the afternoon to produce energy for the evening net peak. These supply-side resources include storage technologies (including solar thermal), some hydro, combustion turbines, and to a lesser extent combined-cycle plants. Demand-related solutions, like demand response and energy efficiency, reduce the loads that would otherwise increase during the key evening ramping hours.

Some assessments of the solutions to integrate high penetrations of renewable resources have omitted energy efficiency a solution, resulting in higher estimates of need for flexible resources. (E3 2014) More thorough assessments that include consideration of energy efficiency show much smaller needs for flexible generation (RAP 2014), or none at all (ORA 2013). These assessments identify many resource and planning options such as, such as: temporally-targeted energy efficiency, demand response, managed electric water heating, westward orientation of fixed axis solar panels, conventional storage, thermal storage in air conditioners, electric vehicle storage, inter-regional coordination of diverse resources and loads, demand charges during ramping hours, retirement of old inflexible generators, and substitution of solar thermal for some solar PV (RAP 2014). Of these solutions, this paper focuses on energy efficiency. It explores how certain energy efficiency measures can reduce needs for flexible generation.

Methodology

We focus on efficiency measures that mitigate the steep ramp between hours 16 and 19 on a spring day, when CalISO project ramping needs will be high: more than 11,000 MW over three hours (CalISO 2013). Energy efficiency measures that save energy during this period will reduce the operational challenge of ramping up resources to meet peak net load. We developed a metric to quantitatively describe the degree to which an energy efficiency measure saves energy during this period. Qualitatively, we are interested in whether a measure's savings are concentrated in the hour 16 to 19 time period. We determine this metric for only one day in March and for only these hours, but it could be applied to longer time spans, such as the entire month of March. The formula is:

$$\textit{Ramp Period Concentration} = \frac{Sum_{xHours\ 16\ through\ 19,\ March\ 31}(SavingsFraction)}{3 \times (AverageSavingsFraction)}$$

Where *SavingsFraction* = for each hour, the portion of annual savings that occur in that hour, and where *AverageSavingsFraction* = the portion of savings (over a year, month, or day) that on average occur in an hour.

A measure with a Ramp Period Concentration (RPC) greater than 1 will help address the evening ramp, and higher RPC numbers mean that the measure's savings are more weighted to the ramp period. A measure with a RPC less than 1 will not help address the evening ramp, and will save less energy during this period than it saves typically. Changing which savings fractions are summed to create the Average Savings Fraction changes the perspective of the RPC. By averaging hourly savings over the year, for example, we can understand how a measure's savings over a year are concentrated into the hours of concern. By averaging savings over March 31, in contrast, we can understand how a measure's March 31 savings are concentrated into the hours of concern. The former tells us about the magnitude of a measure's impact on ramp period flexibility needs; the latter tells us about whether a measure savings shape is helpful during the ramp period on the day of concern.

Saving energy during the ramp period does not directly address potential overgeneration during mid-day. It would be possible for an energy efficiency measure to both save less energy than average during the spring mid-day and save more energy than average during the spring afternoon-evening ramp period. The RPC described above could be modified to take into account the degree to which a measure saves energy during the overgeneration period, but that is beyond the scope of this paper.

To determine RPCs for groups of measures, we use measure group savings profiles from the 2011 DEER Database for Energy-Efficient Resources version 4.01, which was used in California investor-owned utilities' 2013-2014 energy efficiency plans. (CPUC 2011) We used this same data to generate savings profile graphs for each measure group we examine: the y-axis is the fraction of annual energy savings that occur in each hour. The y-axis units are fractions of annual savings, such that the sum of the fractions over a year equals 1.0.

We first present the RPC score for each measure group we analyzed (residential lighting, residential white goods, residential air conditioning, residential heat pumps, residential building shell, commercial lighting, and commercial air conditioning efficiency measures), then describe each group's savings profile.

Results

Ramp Period Concentration of Measure Groups

Ramp Period Concentration measures the extent to which a measure or group of measures savings are concentrated into the ramp period, here defined as the three hours between hours 16 and 19. In Table 1 below are RPCs for measure groups. In RPC_{Annual}, a measure's savings from hour 16 to 19 on March 31 is compared to three hours of annual average hourly savings for the measure. In $RPC_{March\ 31}$, a measure's savings from hour 16 to 19 on March 31 are compared to three hours of March 31 average hourly savings for the measure. The measure group savings shapes are from DEER, and while available for each California Investor Owned Utility, are here only presented for Pacific Gas & Electric. The table is organized by declining RPC.

Table 1. Ramp period concentrations for DEER 2011 measure groups

Sector	Measure Group	$RPC_{March\ 31}$	RPC_{Annual}
Residential	Clothes Washer	1.26	1.26
Residential	Clothes & Dishwasher	1.16	1.19
Residential	Dishwasher	1.06	1.11
Residential	Refrigerator/Freezer High Efficiency	1.06	1.18
Residential	Refrigerator/Freezer Recycling	1.03	1.19
Residential	Indoor CFL Lighting	0.96	0.97
Non-Residential	Indoor Non-CFL Lighting	0.79	1.55
Non-Residential	Indoor CFL Lighting	0.71	1.34
Non-Residential	HVAC Split Package A/C	0.63	2.02
Non-Residential	HVAC Split Package Heat Pump	0.59	1.45
Non-Residential	HVAC Chillers	0.50	1.91
Residential	HVAC Efficiency A/C	0.50	2.01
Residential	Residential Building Shell Insulation	0.37	0.51
Residential	HVAC Refrigerant Charge	0.30	3.14
Residential	HVAC Duct Sealing	0.30	1.78
Residential	HVAC Refrigerant Charge and Duct Sealing	0.16	0.87
Residential	HVAC Efficiency Heat Pump	0.13	0.14
Non-Residential	HVAC Refrigerant Charge	0.11	2.79
Non-Residential	Duct Sealing	0.00	0.19

From this table, we can see that overwhelmingly, residential efficiency measures rank high on the chart. On a critical spring day, most energy efficiency measure savings are over-represented or concentrated in the critical hours: their $RPC_{March\ 31}$ are greater than 1. Most Residential and Non-Residential HVAC measures' savings have low coincidence with the ramp period. But from the RPC_{Annual} column, we can see that few energy efficiency measures' savings are over-represented or concentrated in the critical hours when one looks over the entire year.

This makes sense: HVAC needs are higher in the summer while lighting needs are higher in the spring and fall. The RPC analysis indicates that many energy efficiency measures have load shapes that lend themselves to addressing at least one challenge from high penetration of non-dispactchable renewables: the steep evening ramp in the spring.

Measure Load Shapes

We provide energy efficiency measure load shapes to illustrate the potential for energy efficiency to mitigate the challenges associated with the Duck Chart and reduce the need for flexible generation. As described above, these measure load shapes show the fraction of annual savings that occur in each hour of the year for a particular measure group. Measure load shapes are not end use load shapes. Rather, they are the difference between an efficient end use shape and the baseline end use shape. In effect, they are the shape of the energy savings, not the shape of total consumption. For purposes of determining how various energy efficiency measures can reshape the load curve, it is these measure load shapes, or energy savings shapes, that are pertinent.

Each graph is presented with 12 lines, each color-coded to represent a different month in the year. Winter and spring months are various hues of blue, while summer and fall months are various hues of red. Readers should focus on efficiency’s impact in December (the dark purple line), because evening ramps are greatest in that month, and in spring (blue-green lines), when both overgeneration and ramping are concerns.

Surveyed Energy Efficiency Measures

Residential lighting efficiency. Residential lighting efficiency measures can effectively mitigate problems associated with the Duck Chart and avoid the need for flexible generation. With $RPC_{March\ 31}$ and RPC_{Annual} results of around 1.1, the savings from residential lighting measures are well-distributed in the ramp period. These measures save energy predominantly in the evening hours, when residents return home from work and turn on lights. This evening time period coincides well with the steep ramp of the evening hours in the Duck Chart. By providing the bulk of savings during the evening hours, residential lighting efficiency measures are well-suited to meet the needs of integrating high penetrations of renewable energy.

Figure 2 shows the load shape for a residential compact fluorescent light (CFL) measure. The afternoon through nighttime hours show a striking resemblance to the Duck Chart itself. By reducing energy demand at increasing rates through the net load peak in the evening, residential CFLs effectively mitigate the need for flexible generation to meet that evening ramp. Also, residential indoor CFL measures provide these usefully-timed energy savings consistently throughout the year. That is, during the spring and winter, the energy savings from CFLs will provide energy savings at the right time of day to meet the challenges of the extreme evening ramps of the Duck Chart. On the other hand, the rising savings from the early morning to the mid-day will tend to make the morning downward ramp and overgeneration period more demanding.

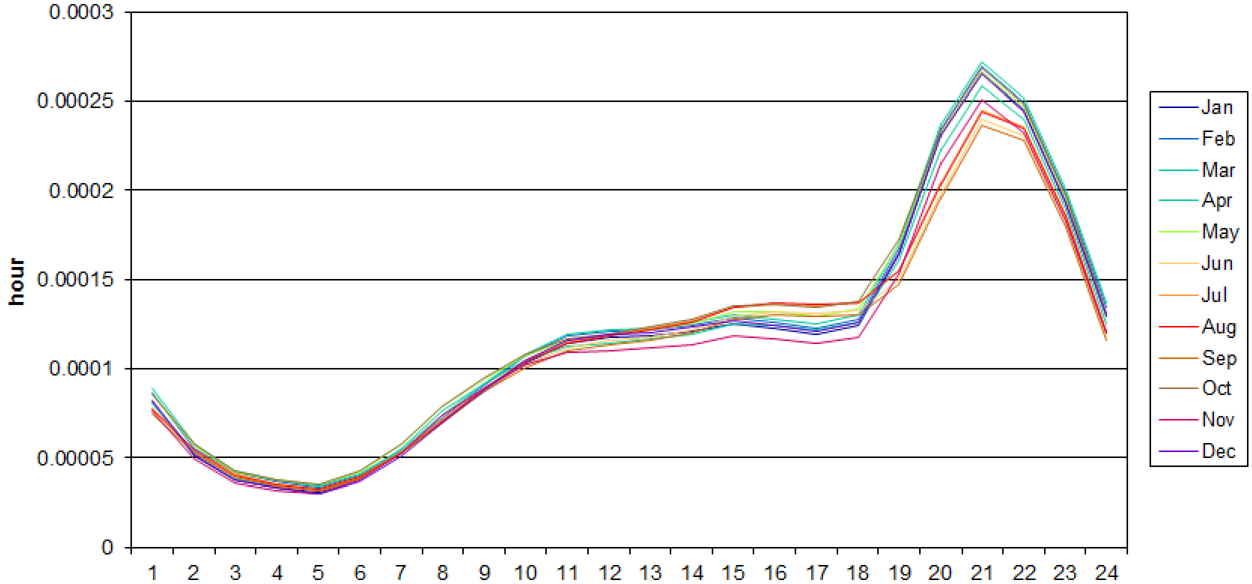

Figure 2. Residential CFL lighting savings for an average weekday. The Y-axis shows the fraction of annual measure savings that occur in an hour of an average day. *Source*: CPUC/CEC 2013.

Residential HVAC heat pump and building shell efficiency. In winter months (but not spring months), residential HVAC heat pump efficiency measures save energy at increasing rates during the evening hours, when residents return home from work and turn on the heat. Because presently, California heating services are largely powered by natural gas, and less commonly by electricity, the potential for this measure's saving is limited. However, looking forward to 2050, if more end uses are electrified (Greenblatt 2013), this measure could become increasingly important as the savings potential increases. Toward meeting the needs on a critical spring day, this measure may be of limited value because according to the available load shapes, these savings occur predominantly after the ramp period has ended. However, during the winter month of December, this measure would be of great value in reducing the ramp: the measure reduces the steepness of the morning downward ramp, by reducing energy savings from morning hours to mid-day hours, when people leave home and adjust their HVAC systems, and then increases during the critical hours of 16 through 19. Figure 3 illustrates the load shape for a residential HVAC heat pump measure.

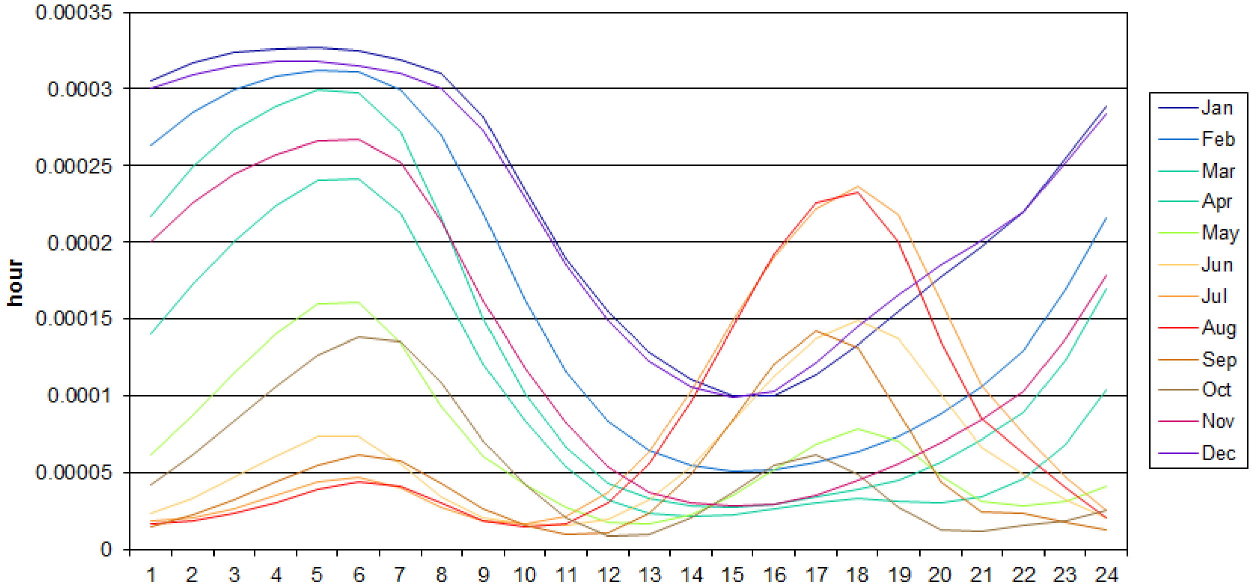

Figure 3. Residential heat pump for an average weekday. *Source*: CPUC/CEC 2013.

Residential building shell measures do not save much electricity during the evening ramp hours of a critical spring day. In winter and spring months, building shell measures do not save much electricity because California homes are mostly heated with natural gas. If end uses like space heating electrify, this may change. A decade from now, the building shell savings profile may look similar to the HVAC heat pump savings profile.

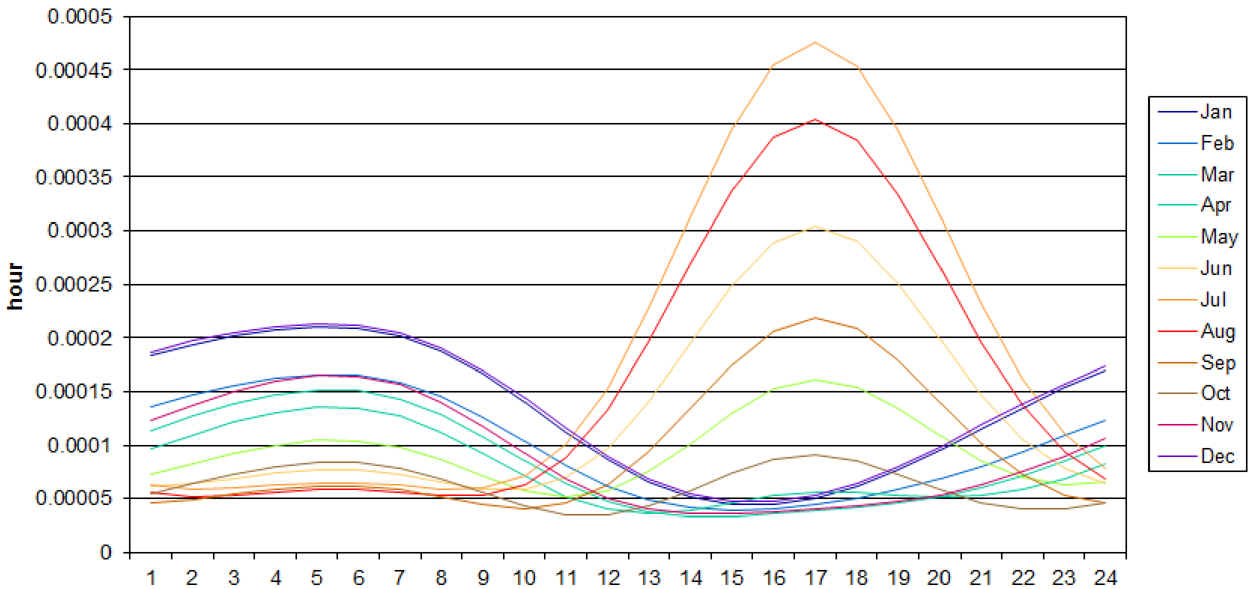

Figure 4. Residential building shell for an average weekday. *Source*: CPUC/CEC 2013.

Residential dishwashers and clothes washers efficiency. Residential dishwasher and clothes washer efficiency measures effectively help mitigate the need for flexible resources during the ramp period, with $RPC_{March\ 31}$ and RPC_{Annual} results greater than 1.2. Residential dish and clothes washer efficiency measures save energy ramping up during the morning hours, slightly decreasing during mid-day hours, and ramping up in evening hours. This evening hour savings ramp is in alignment with the steepest part of the evening ramp. Additionally, the morning ramp down from hours of 9 through 14 of residential dishwasher and clothes washers would alleviate the declining morning net load.

Depending on which issues become more critical in future years, residential dishwasher and clothes washer efficiency measures could be effective in reducing the need for flexible generation to integrate variable renewable energy. For example, if the orderly retirement of inflexible generation (old fossil and nuclear) were deployed as one of the strategies to integrate more variable renewable energy (per RAP's recommendations), or storage were expanded, then overgeneration risks might be secondary to evening ramp needs. In that case, residential dishwashers and clothes washers efficiency could be helpful. Figure 5 shows the load shape for a residential dish and clothes washer measures.

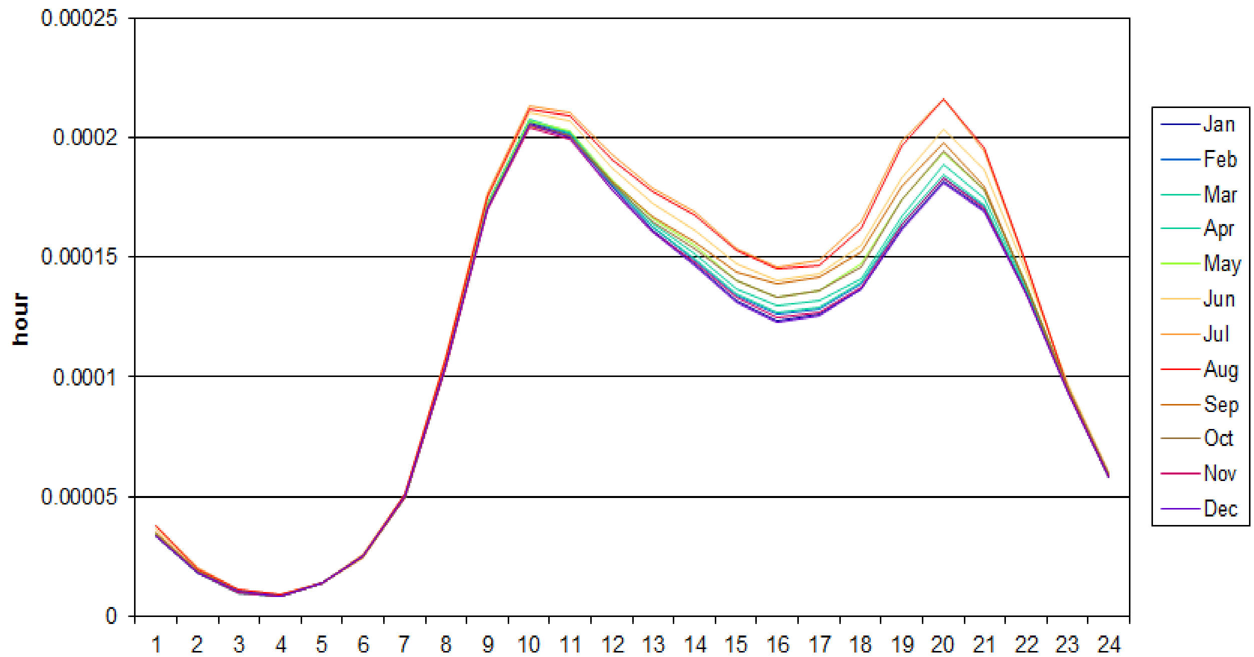

Figure 5. Residential dishwashers and clothes washers for an average weekday. *Source*: CPUC/CEC 2013.

Residential air-conditioning efficiency. Residential air-conditioning efficiency measures are not effective in mitigating the steep evening ramp, primarily because savings occur during the summer months. Figure 6 shows the load shape for a residential ventilation and air-conditioning measure.

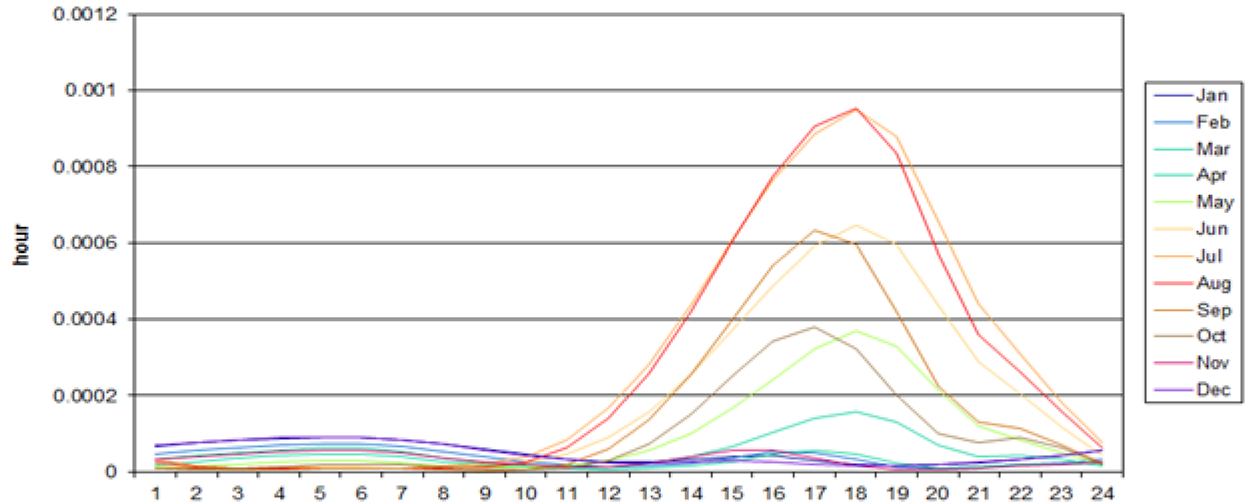

Figure 6. Residential air conditioning efficiency for an average weekday. *Source*: CPUC/CEC 2013.

Commercial indoor CFL lighting efficiency. Commercial indoor lighting efficiency measures actually exacerbate the challenges associated with increasing penetration of non-dispatchable renewables. Commercial indoor CFL lighting measures reshape the load curve in a way that could, based on current projections of California's net load curves, increase the need for flexible resources, as opposed to decrease, all else being equal. Commercial indoor CFL lighting efficiency measures save energy predominantly in the mid-day hours, when businesses operate. This mid-day increase in savings period coincides exactly with the low belly of the Duck Chart, depressing the net load curve further. The evening ramp down in savings coincides with the evening ramp up on the net load curve. By providing the bulk of savings during the mid-day period, commercial indoor CFL lighting efficiency measures are not well-suited to meet the needs of integrating high penetrations of renewable energy. Figure 7 shows the load shape for a commercial indoor CFL lighting measure. While here we only show the savings profile for indoor CFLs, the profile for other commercial lighting measures is similar, and reflective of the general use of lighting in commercial space.

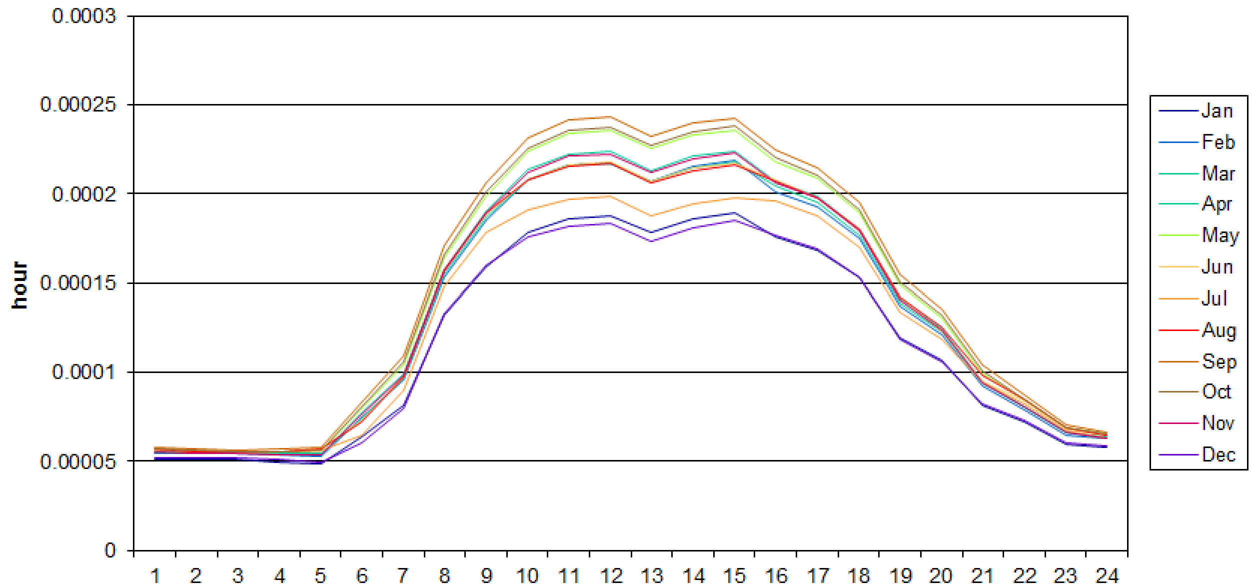

Figure 7. Commercial indoor CFL lighting efficiency for an average weekday. *Source*: CPUC/CEC 2013.

Analysis: Some Energy Efficiency Measures Can Effectively Help Integrate Non-Dispatchable Renewables

California has only begun to study the impacts of various solutions to the problem of integrating large amounts of non-dispatchable renewable resources. The California Public Utilities Commission (CPUC) began the process in its 2013 integrated resource planning process, and has dedicated the current planning process to studying exhaustively this issue. During the CPUC's 2013 proceeding, the Office of Ratepayer Advocates conducted a study to determine whether additional flexible resources would be needed to balance the electric grid in 2022, assuming significant penetrations of variable renewable energy, meeting the 33% Renewable Portfolio Standard targets (ORA/Synapse 2013.)

The analysis revealed that efficiency is effective at helping to integrate significant non-dispatchable energy. As shown in Table 2, the Base Case estimate of the flexible resource need was 2,621 MW of new resources in 2022. However, ORA modeled the impacts that various clean energy solutions would have on that anticipated flexible need. Demand response, load-shifting demand response, solar PV, and energy efficiency were all modeled as potential solutions to mitigate the need for flexible generation. Those solutions were modeled independently and combined as packages of solutions.

Notably, energy efficiency was the only solution that, on its own, reduced the entire need for system-wide flexible resources to integrate the large quantity of variable renewable energy. This is due both to the fact that the evening ramp is lessened as well as positive interactions with other resources on the grid, such as freeing up other supply side resources that can provide flexibility. As seen in Scenario 5 of Table 2, additional energy efficiency produced an 828 MW flexible resource surplus. Energy efficiency was the only single resource to eliminate all hours of shortages.

Table 2. Summary results of ORA Plexos hourly modeling for July 2022

Scenario	Modeled Peak Hour Shortage (-) or Headroom (+), MW	Duration of modeled shortage (hours / days)	Comments
CPUC Scenarios Executed by CAISO			
Base	-2,621	4/1	
TPP (Oct 2013 Revision)[10]	-5,378	17/4	
High DG/DSM	+750	0/0	
ORA Scenarios - Base Load			
1- Shift DR Available	-1,272	3/1	DR 1-7 p.m. instead of 11 a.m. – 5 p.m.
2 -Shift DR Available and High DR	-1,171	3/1	High DR separate from Shift DR Available
3 -High PV	-2,444	2/1	
4- High PV and Shift DR Available	-1,095	2/1	
5- High EE	+828	0/0	
6- High EE, High PV, High DR, Shift DR	+1,912	0/0	
7- Shift DR Available and Relax SCE Import	-1,272	3/1	35% in-area gen – SCE
8- Shift DR Available and Relax CA Import	-1,084	3/1	Use High DG/DSM case import limit
9- 500MW Addition, Shift DR Available, High DR, Relax CA Import	-482	1/1	Add 500 MW SCE Track 4 proxy

Energy efficiency not only eliminated the need for flexible generation, but it reduced the need for flexible generation by more megawatts than the sheer number of energy efficiency megawatts used as an input to the model. The model used approximately 2,200 MW of efficiency as an input (that is, 2,200 MW of peak capacity reductions, determined at the time of gross peak). But energy efficiency peak megawatts are normally stated for the hour of the system gross peak, rather than net peak. (CPUC 2006.) At those critical hours of the net peak load, efficiency actually reduced the need by about 3,400 MW (shortage of 2,621 MW to surplus of 828 MW). Energy efficiency was able to reduce the need for flexible generation by more megawatts than its stated input both because it reduced the net load peak and also because it freed up other flexible resources to meet the evening ramp.

Recommendation: California's Energy Policymakers and Utilities Should Characterize the Ability of Energy Efficiency Measures to Help Integrate Renewable Energy, and Screen Energy Efficiency Measures Partially on This Impact

Preliminary results from recent California's recent study into flexibility need show that energy efficiency is one of the most effective solutions for integrating non-dispatchable renewables. However, current policy frameworks aimed at assessing the value of energy efficiency do not yet incorporate this potential benefit of energy efficiency. Regulatory agencies should incorporate the ability of energy efficiency to save energy at the right time into various policies.

The valuation of energy efficiency savings should include the avoided cost of flexible ramping capacity in addition to other avoided costs, such as energy cost, peak generation capacity, and transmission and distribution capacity. In goal-setting processes for utility programs and efficiency codes and standards, regulators should consider modifying or expand current gross peak savings targets to include net peak savings and ramp rate reduction. In integrated resource planning processes, regulators should deploy ramp mitigating and net peak load reducing energy efficiency measures as top priority resources, before authorizing more costly and more polluting conventional generation. Through all these reforms to efficiency policies, decisionmakers can ensure that efficiency will play a vital role in integrating renewable energy.

State Regulators Need to Update Policy Frameworks to Tap Energy Efficiency Capability to Reduce the Need for Supply-Side Flexible Resources

Energy efficiency has the potential to provide not only energy savings but to help modernize the electric grid through providing renewable integration benefits. The modern grid will need to largely decarbonize in order to meet long term climate goals. Meeting even short-term goals will require the successful integration of significant amounts of non-dispatchable, variable, renewable energy. Due to the variable nature of renewable energy, system planners and grid operators expect to need to rely on flexible resources to meet new ramping requirements in net load. Energy efficiency can reduce the need for flexible resources by reshaping the net load curve and flattening ramps. We describe California's challenges, develop a metric for assessing energy efficiency measures' ability to save energy during the ramp period, and review the ability of various energy saving measures to reduce meet the needs of California's net load curve. We recommend that California's energy efficiency policy framework incorporate the value of reducing flexible capacity into goals, cost-effectiveness analysis, program design and implementation, and measurement and verification of savings, and resource planning. Resource planners should rely on all cost-effective, ramp-mitigating, energy efficiency, before turning to costlier and more polluting flexible fossil generation.

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