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California ISO

CAISO time-of-use periods analysis

January 22, 2016

Table of Contents

1. Executive summary 3
2. Background 5
3. Purpose 10
4. Scope of CAISO's TOU period analysis 10
5. Methodology and data 11
5.1. Step 1: analyzing historical data 12
5.1.1. Step 1 findings 17
5.2. Step 2: comparing trends with projected data 18
5.2.1. Step 2 findings 23
5.3. Step 3: comparing historical and projected analyses 23
5.4. Step 4: develop TOU periods 26
5.4.1. Step 4 findings 29
6. Proposed TOU periods and next steps 30
7. Backup data 31

1. Executive summary

Energy production patterns are changing as clean renewable resources serve a greater share of California's electricity demand. As the electricity system changes, so too must the underlying support and cost-recovery mechanisms such as rates, including time-of-use (TOU) rate designs.

TOU rates are an important tool for signaling consumers when to consume or reduce consumption of energy such that energy prices under a TOU rate design better align with electricity production costs and system needs compared to traditional flat and tiered rate structures. Time-varying rates give consumers the information and choice to manage their energy use and save money, while beneficially reducing production costs and minimizing greenhouse gas emissions.

Like the evolving electricity system, it is prudent to evaluate current TOU rate periods to ensure time differentiated price signals are occurring at the right times and sending consumers the right "grid aligned" signals. In this spirit, the California Independent System Operator (CAISO) collaborated with the California Public Utility Commission (CPUC) and California Energy Commission (CEC) to conduct a TOU study to determine revised TOU rate periods that would better align with system and operational needs given the growing portfolio of renewable resources.[1]

The CAISO's primary engagement in this study was to apply its critical operational experience and analytical capabilities to evaluate the data and inform policy makers about the system's changing needs and how TOU rate periods could be structurally revised for the system's benefit. As counseled by CPUC staff, the CAISO sought to minimize complexity and time-period variations when evaluating potential TOU periods and structures. The CAISO was aware of the CPUC's and CEC's efforts to complete the elements of the study pertaining to rate setting and potential load impacts, but it was not directly engaged in those efforts. The CAISO intends for the content of this paper to be incorporated into the record of the CPUC order instituting rulemaking to help inform the Commission's decision so that future TOU rate periods can align with the needs of the grid.[2]

The CAISO proposes the following TOU periods to signal periods of conservation (peak demand periods) and periods of consumption (off-peak demand periods).

1. **Super-peak** (in red) – a period during which conservation or load-shifting is critical to the system. The super-peak drives steep ramps on the CAISO system that are difficult to manage and may result in high wholesale electricity prices, especially during warm weather and on weekdays. The super-peak period is 4:00 p.m. to 9:00 p.m. on July and August weekdays.

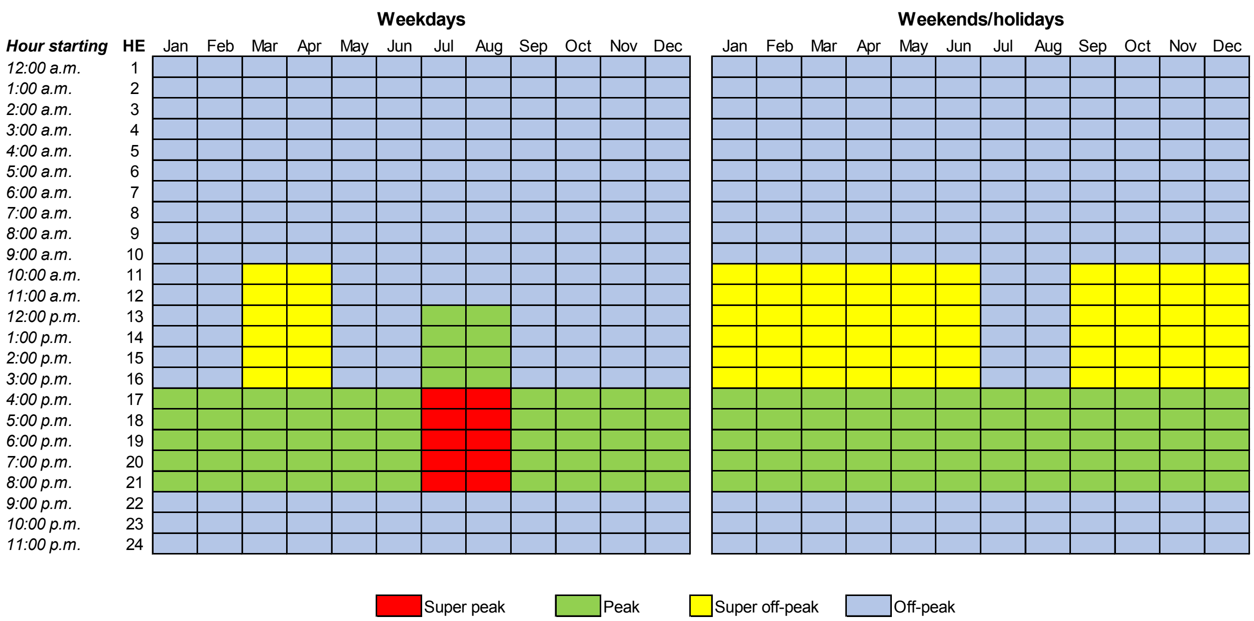
[1] Bender, Sylvia. "Presentation - Joint Agency Staff Supplemental Time of Use Analysis," December 15, 2015 at the California Energy Demand 2016-2026 Revised Electricity Forecast IEPR Workshop.

[2] California Public Utilities Commission, "Peak Electricity Usage Patterns and Consider Appropriate Time Periods for Future Time-of-Use Rates and Energy Resource Contract Payments," filed on December 17, 2015 and issued on December 28, 2015. ("TOU OIR")

2. **Peak** (in green) – a typical period of high demand that drives ramping need on a daily basis. The peak period is 4:00 p.m. to 9:00 p.m. on all days except for July and August weekdays. During July and August weekdays, the peak period is from 12:00 p.m. to 4:00 p.m.
3. **Super off-peak** (in yellow) – a period during which additional consumption is highly encouraged to avoid oversupply conditions that may result in persistent negative wholesale electricity prices[3] or cause a steeper ramp for the CAISO to manage later. The super off-peak period is 10:00 a.m. to 4:00 p.m. on weekdays in March and April and 10:00 a.m. to 4:00 p.m. on weekends/holidays in all months except July and August.
4. **Off-peak** (in blue) – all other periods.

The periods are differentiated by seasons, weekdays, and weekends/holidays based on the demand and generation patterns the CAISO has observed and projected. The figure below shows the TOU periods based on the "hour starting," which reflects the time a proposed TOU period would start.

CAISO proposed weekday and weekend/holiday TOU periods



Periods were simplified to provide a CAISO system-wide uniform approach and limit variation in peak and off-peak periods.

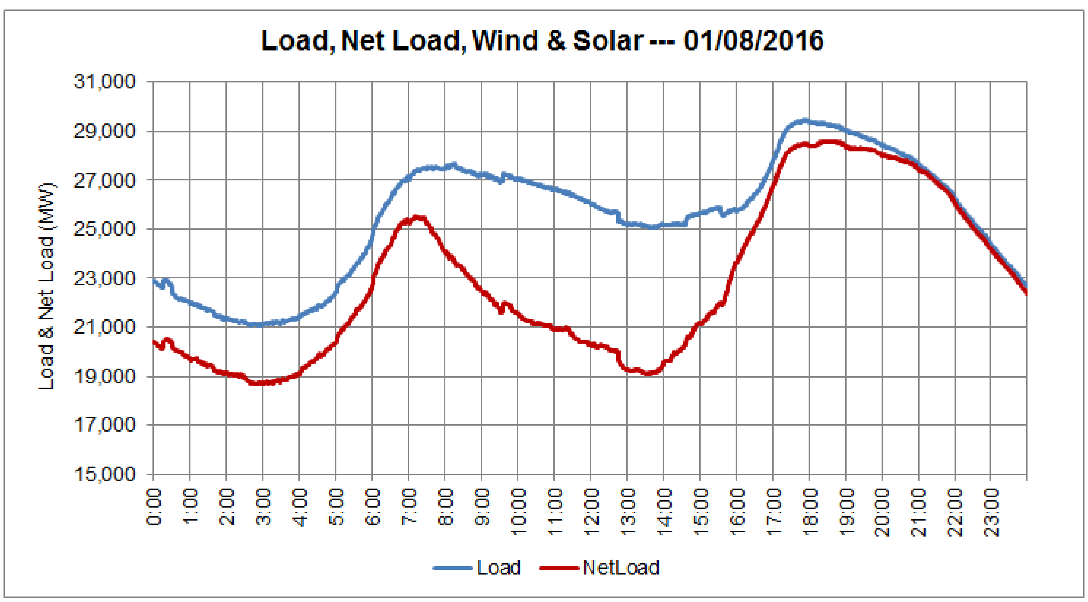
[3] Negative prices in the wholesale market are not considered to be good or bad outcomes, but they do signal an opportunity for wholesale market participants to be *paid* to consume energy.

2. Background

The CAISO is committed to supporting California's energy and environmental goals that strive to significantly "green the grid." The CAISO is responsible for reliably planning and operating the high voltage transmission system serving approximately 80 percent of California's electricity demand. The CAISO strives to ensure reliability through markets by setting transparent wholesale market clearing prices that align with the needs of the grid. High prices signal the need for less consumption and more production, and low prices signal the need for more consumption and less production. For example, low prices could indicate there is an oversupply of renewable energy, signaling the need for greater consumption and energy storage. If acted upon, such actions could prevent renewable resource curtailment and the loss of clean energy production.

The CAISO has been carefully tracking the growth of renewable generation and assessing its impact on the operation of the state's electrical grid. Figure 1 below is an illustrative example of the "traditional" electricity demand curve on a normal weekday, stylized as the smooth blue curve. Electricity consumption increases in the early morning as people start their day around 7:00 a.m. and "peaks" in the early evening around 6:00 p.m. as people return home. To maintain reliability, the CAISO must continuously match the demand for electricity with its supply on a second-by-second basis. Historically, this has meant dispatching conventional, power plants up and down to match the variability of demand.

Figure 1: Typical weekday demand and net load curve

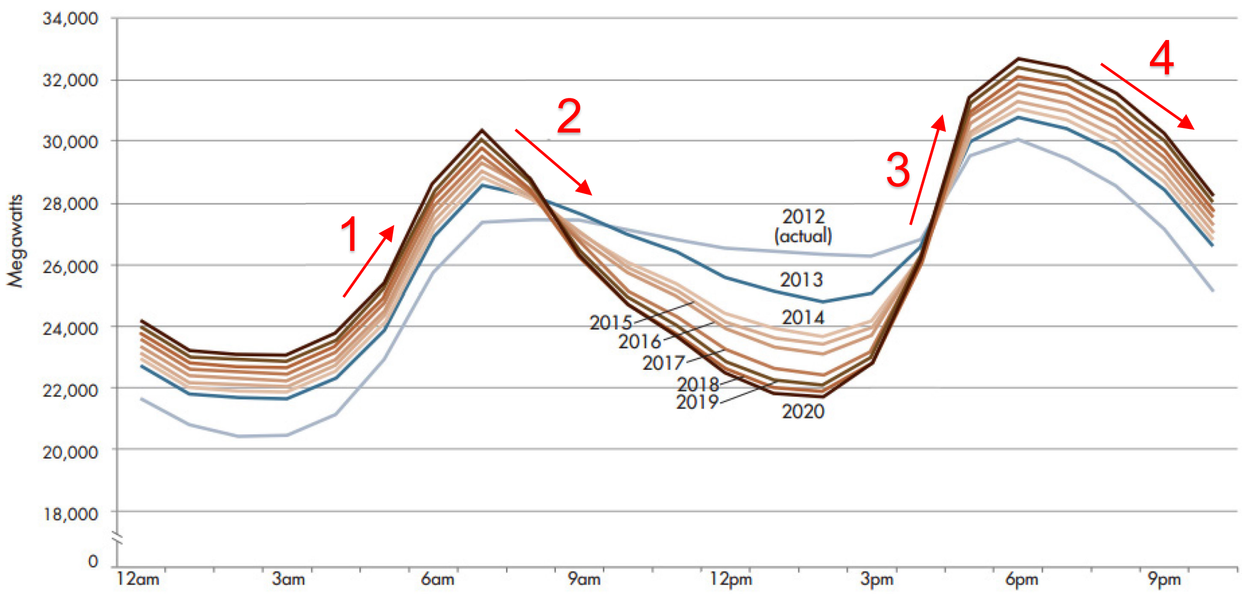


Over the past few years, the CAISO has observed that balancing the grid requires greater resource flexibility, *i.e.* the ability for resources to move up and or down frequently and quickly, as renewable energy policies are realized. This occurs because the growing number of intermittent renewable resources being added to the system typically have a more variable energy production pattern than traditional thermal resources. Therefore, the CAISO must direct "controllable" or dispatchable resources to match both variable demand and variable supply. A simple way to understand the impact of both variable demand and supply is through the "net" load. The CAISO calculates forecast net load by taking the forecasted load and subtracting the forecasted electricity production from variable wind and solar resources. The net load curve assumes that the contribution from low production cost intermittent renewable resources is maximized and higher production cost resources that must burn fuel will be turned down because there is no significant existing means to store megawatt hours of energy for later use.[4] In other words, low-cost renewable energy production is taken as a "given," and that energy must be consumed the moment it is produced. Thus, the net load curve represents the remaining demand unserved by wind or solar energy that must be served from conventional generation resources and imports in order to balance supply and demand balance and maintain reliability. The net load curve is shown in red in Figure 1 above.

Figure 2 below shows the actual net load on the CAISO system on January 11, 2012 and the projected net load curves from 2013 to 2020 assuming same conditions but with a growing portfolio of wind and solar resources. The figure shows a net load curve for a single study day of January 11 for years 2012 through 2020. The curves show the megawatt (MW) amounts of demand the CAISO must follow on the y-axis across the different hours of the day shown on the x-axis. Four distinct ramp periods emerge as labeled on the graph.

[4] Interestingly, properly structured time-of-use rates and periods may spur the storage of renewable energy when the supply is plentiful and prices are low.

Figure 2: net load curve showing ramping needs – January 11



In the "ramping flexibility curve[5]," the first ramp of about 8,000 MW in the upward direction (from about 22,000 MW to 30,000 MW) occurs in the morning starting around 4:00 a.m. as people get up and go about their daily routine. The second ramp, in the downward direction, occurs after the sun comes up around 7:00 a.m. when on-line conventional generation is displaced by supply from solar generation resources (setting the lowest net load on the system during the middle of the day). Around 4:00 p.m. solar generation decreases so the CAISO must dispatch conventional resources to meet the system peak demand. This is the largest upward daily ramp (labeled as 3), which is in excess of 11,000 MW (from a 22,000 MW at the lowest net load to 33,000 MW at the peak). After the peak, system demand quickly decreases across the evening hours, and the CAISO must reduce or shut down conventional generation resources to meet the final downward ramp (labeled as 4).

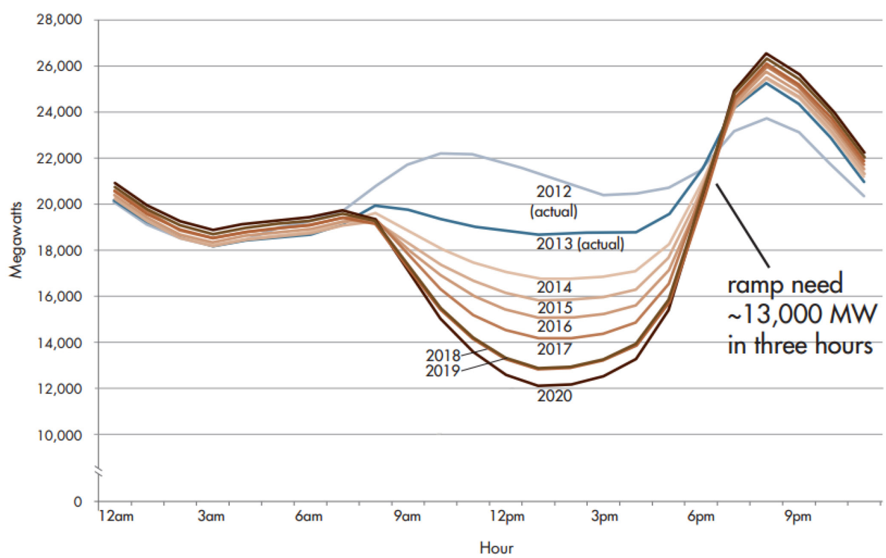
If conventional resources cannot ramp down fast enough or far enough, oversupply conditions can result. Oversupply happens when the CAISO's market software does not have enough economic bids to balance an excess of electricity generation against demand. The CAISO experiences oversupply in two main operating conditions. The first occurs as the CAISO prepares to meet the upward ramps that occur in the morning and in the late afternoon. The existing fleet includes many long-start resources that need time to "warm up" before they can support upcoming ramps. Therefore, they produce some minimum amount of power when their electricity is not yet needed. The second oversupply situation occurs when output from any non-

[5] For more information on the ramping flexibility curve, see http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.

dispatchable/must-take resource further increases supply in times of low electricity need, typically in the off-peak hours.

Figure 3 below is similar to Figure 2 but shows the actual net load on the CAISO system on *March 31, 2012* and the projected net load curves from 2013 to 2020. The difference in the date is significant as it changes the historical data analysis from a weekday (January 11, 2012 was a Wednesday) to a weekend (March 31, 2012 was a Saturday) and from winter to spring. During weekend spring conditions, the CAISO has observed that a combination of abundant solar, wind, and hydro production during the middle of the day, combined with only moderate demand, can encroach upon the minimum generation threshold, thus leading to oversupply conditions. Figure 3 below is also referred to as the "duck curve" because it resembles a duck where the oversupply risk increases as the "belly of the duck" grows.[6] Also of note is the larger ramping need of 13,000 MW from the belly of the duck to the peak hour.

Figure 3: duck curve showing oversupply risk – March 31



In the CAISO's wholesale electricity market, prices reflect the balance of supply and demand against transmission congestion and losses. High prices signal a need for more generation (or conservation), while low prices signal an opportunity to use electricity because demand is low and/or supply is abundant. When there are oversupply conditions, prices tend to be lower and provide increased opportunities to for export renewable energy outside of California, increasing flexibility and bidding capability for both conventional and intermittent resources, and energy

[6] For more information on the duck curve, see http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.

storage and electric vehicle charging. Conversely, higher prices can incentivize more generation or conservation.

The CAISO's wholesale market prices are largely not visible to retail customers. However, TOU rates and rate periods, if appropriately structured, can prove a simple and effective proxy for communicating periods of low cost, driven for example, by abundant renewable energy, or high cost when the system is peaking and conservation is most effective. The CAISO notes that TOU rates with little differentiation between peak and non-peak periods may not be sufficient to encourage desired customer behaviors and therefore generally prefers well-differentiated TOU rates.

TOU rates have existed in California since the 1970's and were largely designed to address summer peak demands. These traditional TOU rate structures may soon do more harm than good given growing oversupply concerns as a result of increasing numbers of renewable resources with variable production. For example, TOU rates based on a traditional demand curve encourages conservation from noon to the peak demand at 6:00 p.m. This is misaligned with today's net load curve, which shows very low net demand between 10:00 a.m. and 4:00 p.m. and a steep ramp after 4:00 p.m. leading to a later peak closer to 8:00 p.m.

In March 2015, the CAISO published an analysis of hourly net loads to recommend new TOU periods.[7] The significant penetration of renewables and potential oversupply conditions creates an opportunity to encourage consumption during the middle of the day, which corresponds to the minimum demand on the system that must be served by conventional resources. Although conservation is still needed during the peak, the net load peak shifts to later in the day because solar energy production is still strong even after working hours during the summer, and does not decline until later in the evening. Additionally, there are potential oversupply periods during weekends and spring and fall periods when loads are light but wind, solar, and hydro production are strong. Based on these findings, the CAISO created proposed TOU periods that identify new off-peak times that coincide with the net load curve, new peak periods that reflect the "late shift" in peak demand times, and seasonal variations.

This paper is organized as follows. Section 3 explains the purpose of this paper and details the goals of CAISO's TOU period analysis. Section 4 discusses the scope of the analysis, and Section 5 explains the methodology and data used to develop the proposed TOU periods. Section 6 presents the proposed TOU periods and proposed next steps. Section 7 provides a link to the backup data used to produce the analysis and graphics in this paper as well as additional data that was not shown.

[7] See "Matching Time-of-Use Rate Periods with Grid Conditions Maximizes Use of Renewable Resources" available at: http://www.caiso.com/Documents/MatchingTimeOfUsePeriodsWithGridConditions-FastFacts.pdf and "CAISO's TOU period analysis to address 'High Renewable' grid needs available at: http://www.caiso.com/Documents/CaliforniaISO_Time_UsePeriodAnalysis.pdf

3. Purpose

The purpose of this paper is to inform the CPUC and build the record in this proceeding that results from the CPUC's order instituting rulemaking to assess the appropriate time periods for TOU rates ("TOU OIR").[8] As mentioned, the CAISO has not previously submitted a detailed discussion of the CAISO's TOU period analysis in any proceeding or rate design window due to staffing and resource constraints. Therefore, the CPUC created the proceeding to accomplish the following goals:

> *First, this proceeding will increase efficiency for the CAISO, parties, and the Commission. All parties with an interest in TOU time periods will have an opportunity to participate in a single proceeding, which should allow for a complete and robust record not only of data, but also comments on policy implications of potential changes. In addition, addressing TOU time periods for all utilities in one proceeding will provide an opportunity to compare relevant load, usage, cost, and other data statewide and across different utility jurisdictions. This could facilitate the determination of whether TOU periods should be consistent for different utilities and customer classes.*[9]

The TOU OIR will evaluate the findings of CAISO's analysis and recommended TOU periods. The TOU OIR included CAISO's analysis as an attachment and requested that the CAISO provide "a detailed explanation of the data, assumptions, and analytical methods supporting the analysis."[10] The CAISO intends for this paper to satisfy the CPUC's request and become part of the record in the TOU OIR proceeding.

As described in Section 2, the CAISO has been analyzing TOU rate periods to address renewable integration challenges. Although the analysis in this paper reflects a unique system operator perspective, the findings directly relate to consumer costs and supports state policies. For instance, well-reasoned and structured TOU rates and rate periods can help integrate zero-emission resources such as solar and wind power, unlock storage potential, manage electric vehicle charging, and maximize the use of demand response and load management.

4. Scope of CAISO's TOU period analysis

CAISO staff began with the assumption that a successful TOU rate period design should smooth and flatten the net load curve by season. This can be done by:

- Shifting peak load demand;
- Incentivizing load to consume during low demand periods to minimize oversupply; and

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[8] California Public Utilities Commission, "Peak Electricity Usage Patterns and Consider Appropriate Time Periods for Future Time-of-Use Rates and Energy Resource Contract Payments," filed on December 17, 2015 and issued on December 28, 2015. ("TOU OIR")
[9] California Public Utilities Commission, TOU periods OIR, p. 20.
[10] California Public Utilities Commission, TOU periods OIR, p. 22.

- Reducing the magnitude of upward and downward ramps through managed load response.

The CAISO's analysis sought to answer the following questions:

A. Does the time of the CAISO's coincident demand vary by season?
B. Does the time of the CAISO's coincident peak coincide with each of the major investor owned utility's (IOU's) peak demand?
C. Is there a noticeable difference between weekdays and weekends/holidays?
D. Is there a need for IOU-specific TOU periods?
E. Can all three IOUs establish common TOU periods based on the CAISO's needs?
F. Should TOU periods be grouped by months?

For ease of analysis, the CAISO did not consider additional load serving regions beyond the three large IOUs: Pacific Gas and Electric Company (PG&E); Southern California Edison Company (SCE); and San Diego Gas & Electric Company (SDG&E).

5. Methodology and data

As described in Section 2, the net load is a simple way to illustrate the interplay between variable supply and variable demand, and it represents the remaining demand, after removing the contribution from wind and solar production, that conventional resources must serve. TOU rates can take the net load positon of the system by day-type and season and incent conservation, the use of behind-the-meter resources, energy storage, electric vehicle charging, and other energy use or consumption alternatives in lieu of solely relying on conventional generation to balance the remainder of the system. Calculating and studying net loads across time and geography is the foundation of CAISO's TOU period analysis.

The CAISO conducted the analysis in four steps as described in Figure 4 below. The first step was to study historical data to identify trends in renewable generation compared to electric demand on the system by answering the questions posed in Section 3. In the second step, the CAISO applied the findings from step 1 to a near-term projected year to verify that the trends persisted across time. In step 3, the CAISO compared the findings in steps 1 and 2. In the fourth step, the CAISO developed the proposed TOU periods based on a balance of meeting CAISO's operational needs and a simplified design to foster customer acceptance.

Figure 4: Analysis steps

Step 1	analyzing historical data
Step 2	comparing trends with projected data
Step 3	comparing historical and projected analyses
Step 4	develop TOU periods

The subsections below describe each step in the process.

5.1. Step 1: analyzing historical data

The CAISO selected the most complete and available historical load data, and wind and solar generation data from 2013 and 2014.[11] The load data is available on a 1-minute basis for each of the three major IOUs. Solar and wind generation data is also available on a 1-minute basis but only for the aggregated CAISO system.[12] It was not possible to parse the generation and "assign" it to each of the IOU footprints. Therefore, the CAISO could only calculate net load for the CAISO-wide footprint. Table 1 below shows how the CAISO aggregated the data and analysis to answer each of the questions posed in the scope and identifies the step under which the analysis is performed. The 1-minute granular load data allows the CAISO to show results across different geographies (CAISO or IOU footprint) and timeframes (weekday, weekend/holidays, monthly, seasonal, and annual).

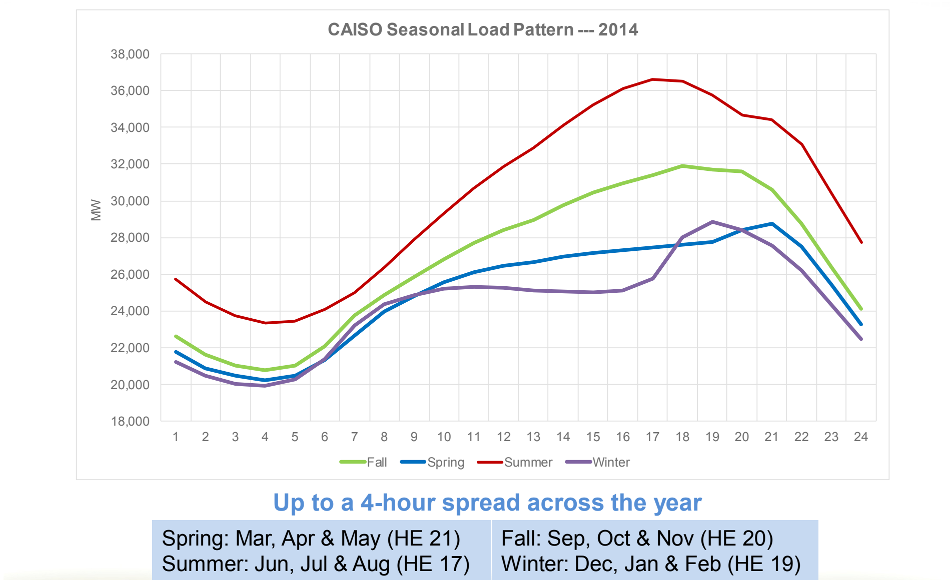
Table 1: Data and analysis mapped to scope questions

	Questions	***How the data addresses each question (Where the question is addressed)***
A	Does the time of the CAISO's coincident demand vary by season?	Compare the load data's peak period across seasons. (Step1)
B	Does the time of the CAISO's coincident peak coincide with each of the IOU's peak demand?	Compare each IOU's annual and seasonal peak demand with CAISO's annual and seasonal peak demand. (Step1)
C	Is there a noticeable difference between weekdays and weekends/holidays?	The net load can be compared on a weekday versus weekend/holiday basis. (Steps 1 and 2)
D	Is there a need for IOU-specific TOU periods?	Based on the findings in questions A through C, analyze the periods when high and low demand persists and whether that is specific to each IOU. (Step 4)
E	Can all three IOUs establish common TOU periods based on the CAISO's needs?	Based on the findings in question D, decide whether the results per IOU are similar enough to have common TOU periods. (Step 4)
F	Should TOU periods be grouped by months?	The net load can be analyzed by month, season or year to compare. (Step 4)

[11] With additional time and resource commitments, this analysis can be repeated for 2015.
[12] References to wind and solar data refer only to wholesale generation. Distribution-connected or behind-the-meter generation is considered in the load forecast.

The answer to **Question A** informs whether TOU periods should vary by season. Figure 5 graphs the day with the peak demand per season for the CAISO footprint in 2014.[13] It is clear that the coincident[14] peak occurs at different times depending on the season. For example, the summer coincident peak occurred during hour ending[15] (HE) 17 (4:00 p.m. to 5:00 p.m.) while the spring coincident peak occurred during HE 21 (8:00 p.m. to 9:00 p.m.). All times shown are in Pacific Prevailing Time, which already accounts for daylight savings.

Figure 5: CAISO seasonal load pattern – 2014



The answer to **Question B** informs whether TOU periods should be considered on a sub-CAISO footprint basis (*i.e.*, based on each IOU footprint). Based on the answer to Question A, the CAISO understands that the peaks should be analyzed on a seasonal basis, at minimum. Figure 6 compares the CAISO coincident peak for each season to the individual IOU peak demands. The data is presented on a normalized basis for ease of comparison where the peak or coincident peak is set to “1” and the remaining demand is a number between zero and one. The actual peak or coincident peak (in megawatts or MWs) is provided at the bottom of each seasonal graph.

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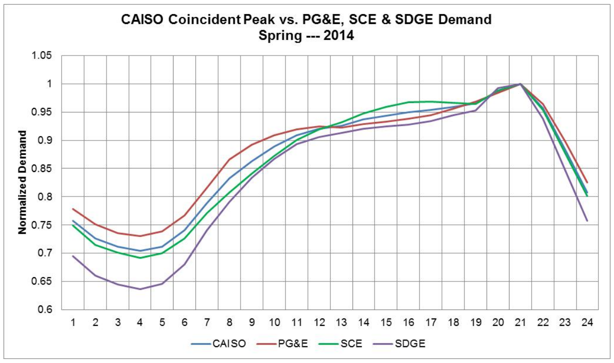
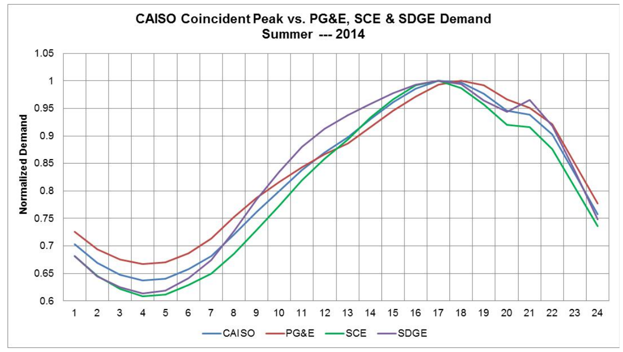
[13] The main body of this paper shows analyses and results for historical year 2014. Results from 2013 are similar and are provided as backup data to this paper (see Section 7).
[14] Coincident for the three IOUs. References to CAISO’s peak in this paper imply the coincident peak.
[15] The “hour ending” is an electric industry-wide term encompassing the hour leading up to the hour ending number. For example, hour ending 17 starts one second after 4:00 p.m. and ends at 5:00 p.m. Therefore, demand in a single day can be represented as hour ending 1 through 24. Outside of the electric industry, most readers are more comfortable thinking about the hour from which something starts (*e.g.*, 4:00 p.m. rather than hour ending 17). Throughout this paper, we use the hour ending nomenclature in all graphs and figures but note the starting hour in the text.

Figure 6: CAISO coincident peak vs. PG&E, SCE, and SDG&E demand (MW) – 2014 by season

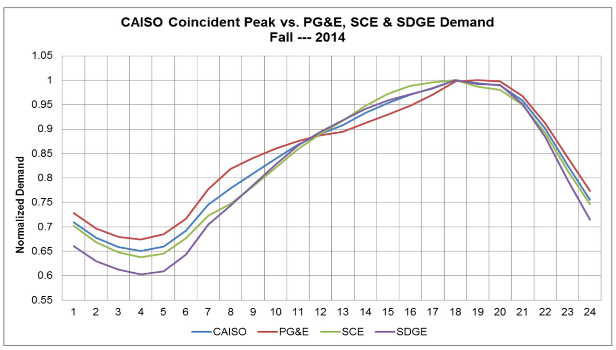
Spring: The ISO and three IOUs coincident peak occurs between 8 p.m. and 9 p.m.



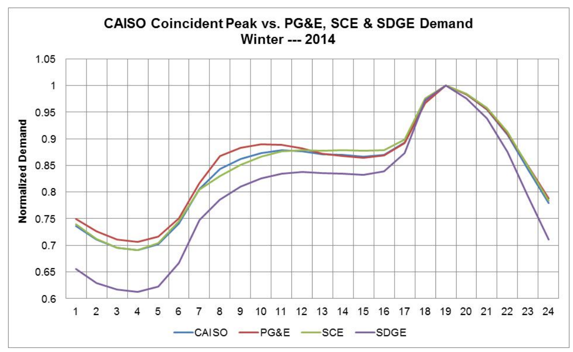
Summer: The ISO, SCE & SDG&E coincident peak occurs between 4:00 p.m. and 5:00 p.m. PG&E is an hour later



Fall: ISO and three IOUs coincident peak occur between 7:00 p.m. and 8:00 p.m.



Winter: ISO and three IOUs coincident peak occur between 6:00 p.m. and 7:00 p.m.



The CAISO's coincident peak aligns well with the individual IOU peaks across all seasons except for PG&E, which peaks an hour later than the CAISO during the summer. With this one exception, the analysis shows a fairly consistent pattern across IOUs and seasons.

The answer to **Question C** informs whether the TOU periods should be differentiated by weekdays versus weekends/holidays. Because the peaks occur at relatively the same time across the IOUs, the CAISO used the aggregated CAISO-wide average demand. This was paired with the average wind and solar generation to calculate the net load.

The CAISO first grouped aggregated CAISO-wide average demand by month and then divided it into weekdays and weekends/holidays. The CAISO calculated average demand as the average of the MW demand in each hour of the day over the month. For example, January has 31 days, so there are 31 hour-long data points for hour ending 1 (*e.g.*, midnight through 1:00 a.m.). The CAISO averaged these 31 data points to form the first hour of the load profile. The CAISO performed this calculation for each of the 24 hours in a day.

Next, the CAISO aggregated the wind and solar output data on the same basis as load (*i.e.,* 1-minute data is aggregated and averaged for each hour of each month, separated into weekdays and weekends/holidays). The CAISO subtracted the wind and solar output from the average demand to calculate the net load. Figure 7 below graphs the monthly load and net load profiles for weekdays over an averaged 24 hours. The monthly aggregation shows a wide variation in periods of peak and low demand, reflecting changes in temperature-driven demand and weather-driven renewable output.

Figure 7: 2014 CAISO monthly load and net load profiles (MW) – weekdays

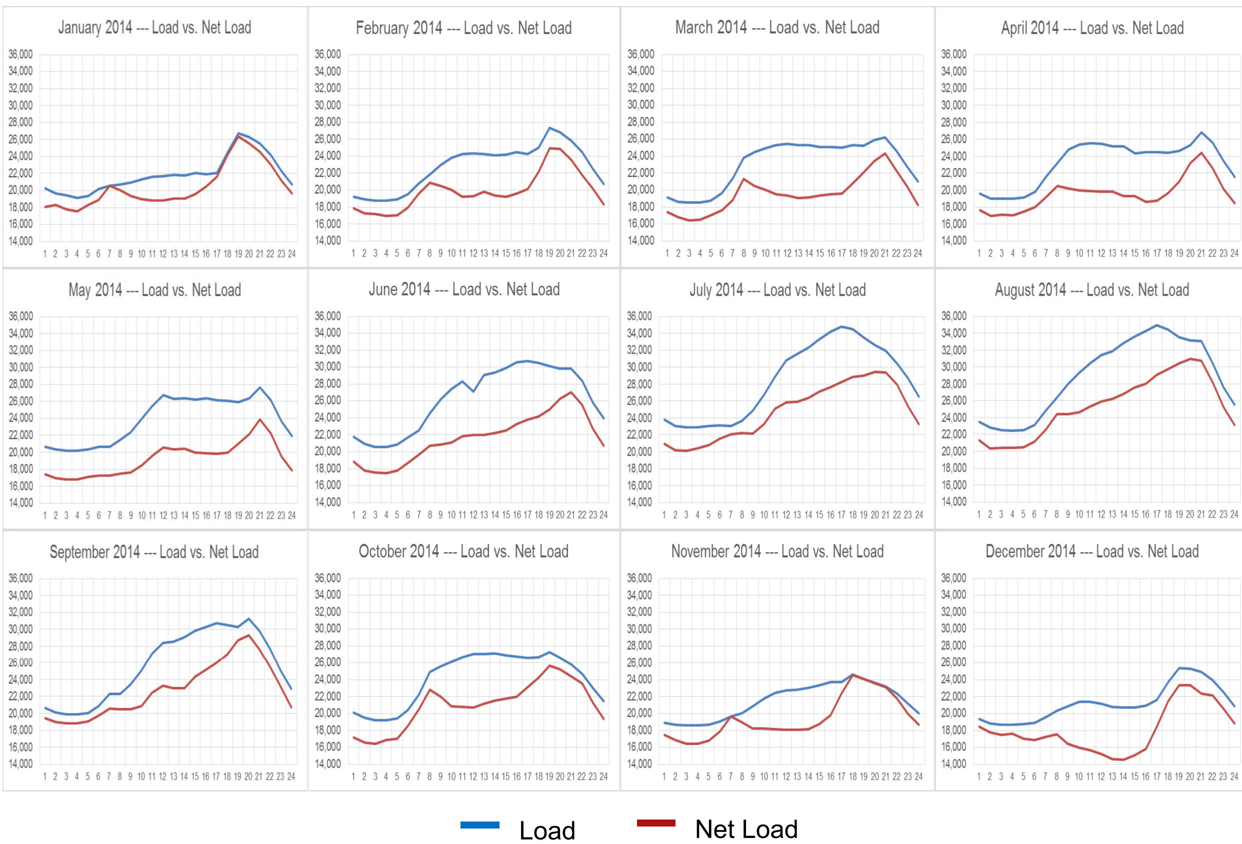


Figure 8 below graphs the monthly load and net load profiles for weekends/holidays over an averaged 24 hours. The patterns are similar to weekdays, but overall demand is much lower.

Figure 8: 2014 CAISO monthly load and net load profiles (MW) – weekends/holidays

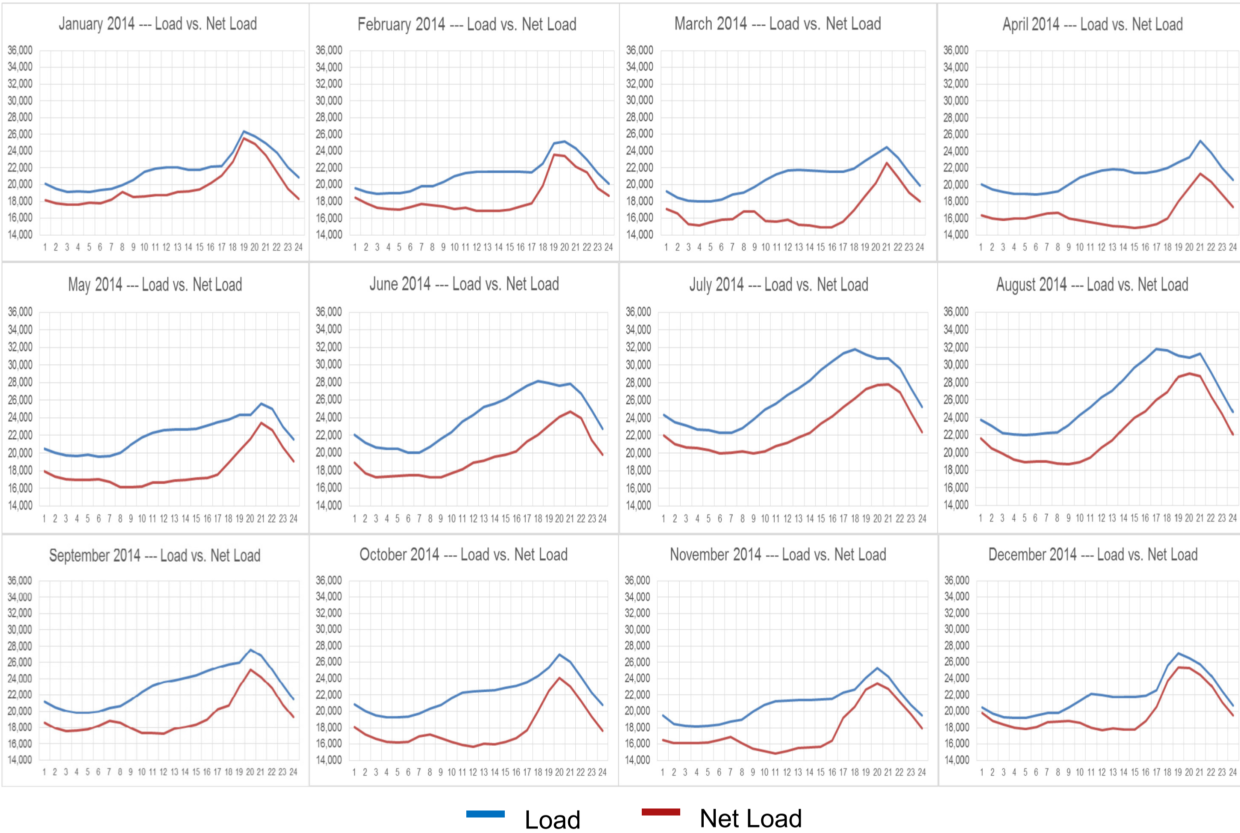


Figure 9 below provides a side-by-side comparison of the average March weekdays on the left versus weekends/holidays on the right. Oversupply conditions tend to be more prevalent in March because demand is typically lower while renewable energy production can be strong. Focusing on the red net load lines, both graphs have a “duck curve” shape and ramp up in the morning around 8:00 a.m. and peak around 9:00 p.m. However, the minimum weekday net load is above 18,000 MW; whereas, the weekend/holiday minimum demand is almost 3,000 MW less at 15,000 MW. The peak is similarly 2,000 MW lower on the weekend, 22,000 MW versus 24,000 MW on the weekday. There are similar patterns for other spring months as well as fall months where demand is low and renewable generation can be strong.

Figure 9: March 2014 CAISO load and net load profiles (MW)

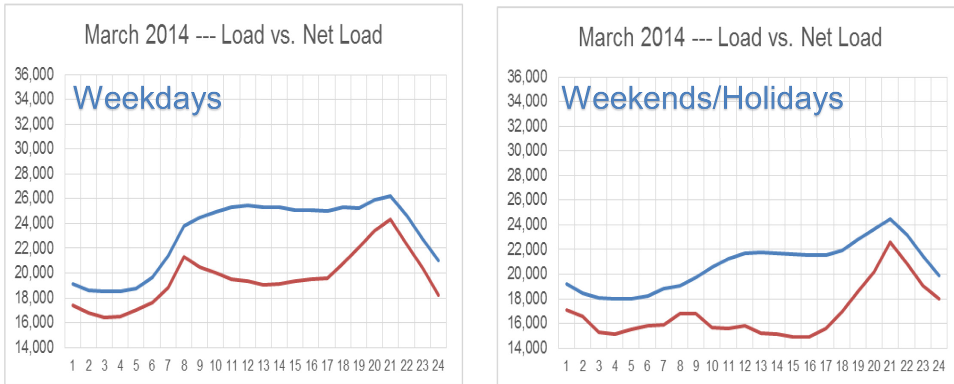
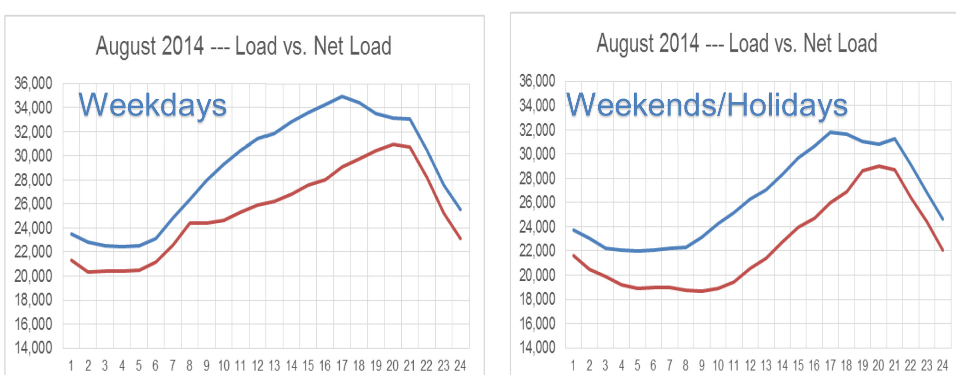


Figure 10 below provides a side-by-side comparison of the average August weekdays on the left versus weekends/holidays on the right. August is an interesting time of analysis because CAISO often experiences its annual peak during this month. Focusing on the blue load profile, both weekdays and weekends/holidays peak around 5:00 p.m. The graphs do not have a pronounced "duck curve" due to high demand during the day, but still exhibit the steep ramp up towards the peak hour. However, the red net load profile shows that after netting out the solar and wind generation, the actual peak occurs later at around 8:00 p.m. There are similar patterns for other summer months when the renewable generation "shifts" the net load peak to later in the day. Similar to March, the minimum net load for weekdays is 2,000 MW higher than weekends/holidays (20,000 MW versus 18,000 MW). The weekday peak is 2,000 MW higher than weekends/holidays (31,000 MW versus 29,000 MW).

Figure 10: August 2014 CAISO load and net load profiles (MW)



5.1.1. Step 1 findings

Table 2 provides the step 1 responses to the scope questions. The CAISO's analysis shows that the CAISO's coincident peak varies by season, but largely does not vary by IOU, with the exception of an hour delay for PG&E during the summer. There were also large minimum and maximum demand differences between the weekdays and weekends/holidays; although the general shape of the curves remained the same.

Table 2: Step 1 responses to scope questions

	Questions	***Step 1 responses (Where the question is addressed)***
A	Does the time of the CAISO's coincident demand vary by season?	Yes. (Step1)
B	Does the time of the CAISO's coincident peak coincide with each of the IOU's peak demand?	Yes. (Step1)
C	Is there a noticeable difference between weekdays and weekends/holidays?	Yes for Step 1. (Steps 1 and 2)

5.2. Step 2: comparing trends with projected data

Step 1	analyzing historical data
Step 2	comparing trends with projected data
Step 3	comparing historical and projected analyses
Step 4	develop TOU periods

In step 2, CAISO tested the findings from step 1 by repeating the net load analysis with data for each projected year. This step tests whether current trends persist to ensure a robust TOU period design. CAISO selected year 2021 as a test year because California would have just reached the 33 percent renewable portfolio standard target in 2020, and the date is still relatively near-term so that TOU periods developed based on historical data could still be applicable.

For demand data, the CAISO began with the 2021 demand forecast from the California Energy Commission's 2013 Integrated Energy Policy Report (2013 IEPR) under the "mid case scenario" and then updated with the 2014 report.[16] The 2013 IEPR and 2014 IEPR update provide the monthly MW peak but does not provide a more granular load shape. For the load shape, CAISO relied on the minute-by-minute demand data used in the CPUC's 2014 Long-term Procurement

[16] California Energy Commission, 2013 Integrated Energy Policy Report, docket # 13-IEP-1 and California Energy Commission, 2014 Integrated Energy Policy Report Update, docket # 14-IEP-1.

Process for year 2024.[17] The minute-by-minute 2024 data was scaled down to 2021 based on the fixed monthly ratio of 2021 to 2024 peak demand. For example, if the January peak is 30,000 MW in 2021 and 32,000 MW in 2024, then the fixed ratio for the month is 0.94 (30,000 MW divided by 32,000 MW). The CAISO then applied this ratio to every minute of the 2024 January data to create a scaled 2021 load profile. The CAISO calculated a ratio for every month and applied it to each minute within the month. The Long-term Procurement Process also provided behind the meter solar generation for the entire state of California, which CAISO adjusted to the CAISO footprint and netted out of the load.[18]

For wind and solar generation, the CAISO first started with the projected generation build-out in the CPUC's renewable portfolio standard (RPS) Calculator, which has the quantity and capacity factor information for each new RPS project by year. The CAISO developed minute-by-minute generation profiles for transmission-connected wind and solar for 2024.[19] These generation profiles were not readily available for 2021. To develop 2021 profiles, the CAISO first subtracted from the 2024 total installed capacity of wind and solar generation the incremental capacity with in-service dates after 2021.[20] This yielded the total installed capacities of each resource in 2021 (*i.e.*, 2024 total installed capacity minus new builds in-service after 2021 through 2024).

The CAISO scaled down the minute-by-minute 2024 data to 2021 based on the fixed monthly ratio of 2021 to 2024 installed capacity by resource. For example, if the January solar installed capacity is 12,000 MW in 2021 and 15,000 MW in 2024, then the fixed ratio for the month is 0.80 (12,000 MW divided by 15,000 MW). The CAISO then applied this ratio to every minute of the 2024 January data to create a scaled 2021 solar generation profile. The CAISO calculated a ratio for every month and applied it to each minute within the month per resource.

Figure 11 below graphs the monthly load and net load profiles for weekdays over an averaged 24 hours. The monthly aggregation shows a wide range periods of peak and low demand, reflecting changes in temperature-driven demand and weather-driven renewable output.

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[17] California Public Utilities Commission, Order Instituting Rulemaking to Integrate and Refine Procurement Policies and Consider Long-Term Procurement Plans, Rulemaking 13-12-010.
[18] Behind the meter generation was not netted out of the historical analyses because they are already embedded in the load data.
[19] Phase I.A. Direct Testimony of Dr. Shucheng Liu on Behalf of the California Independent System Operator Corporation, Order Instituting Rulemaking to Integrate and Refine Procurement Policies and Consider Long-Term Procurement Plans, Rulemaking 13-12-010, page 5.
[20] There were no incremental wind generation builds between 2021 and 2024 so the data did not need to be scaled.

Figure 11: 2021 CAISO monthly load and net load profiles (MW) – weekdays

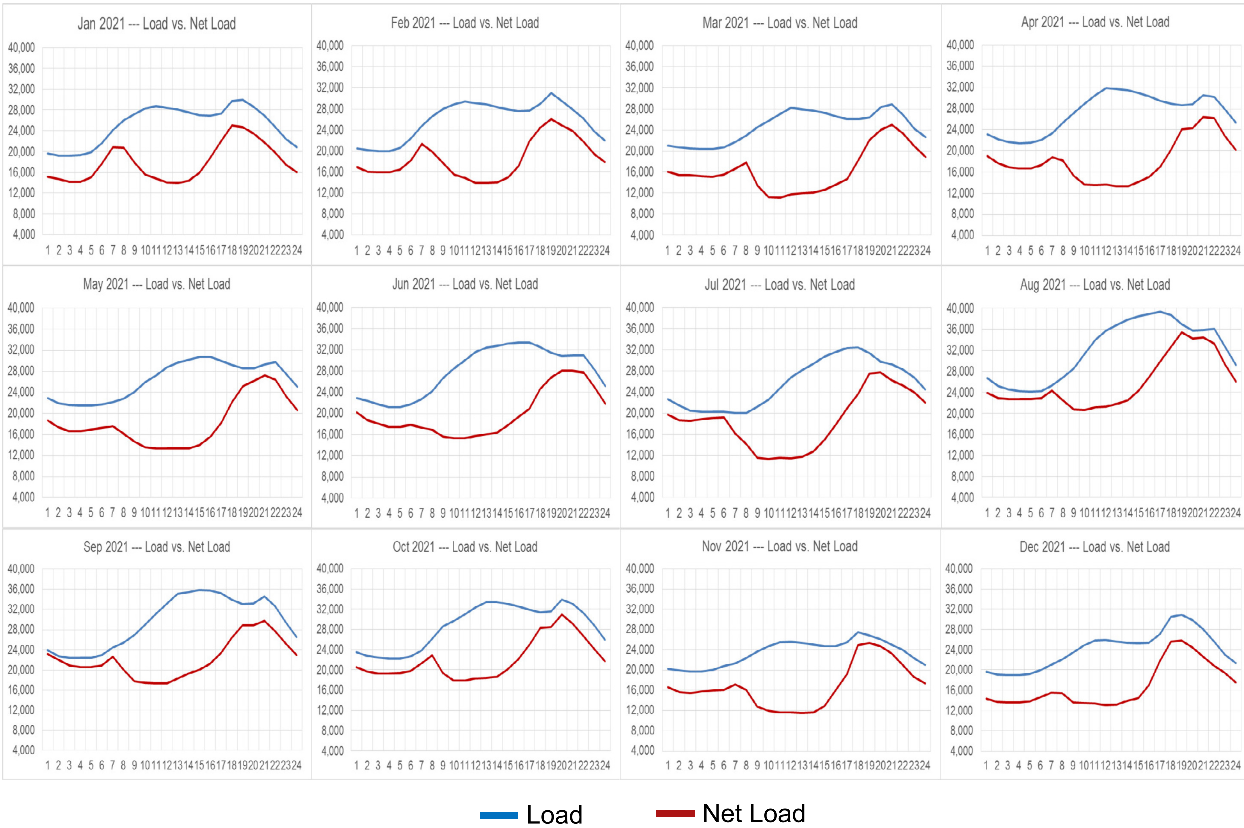


Figure 12 below graphs the monthly load and net load profiles for weekends/holidays over an averaged 24 hours. The patterns are similar to weekdays, but overall demand is much lower.

Figure 12: 2021 CAISO monthly load and net load profiles (MW) – weekends/holidays

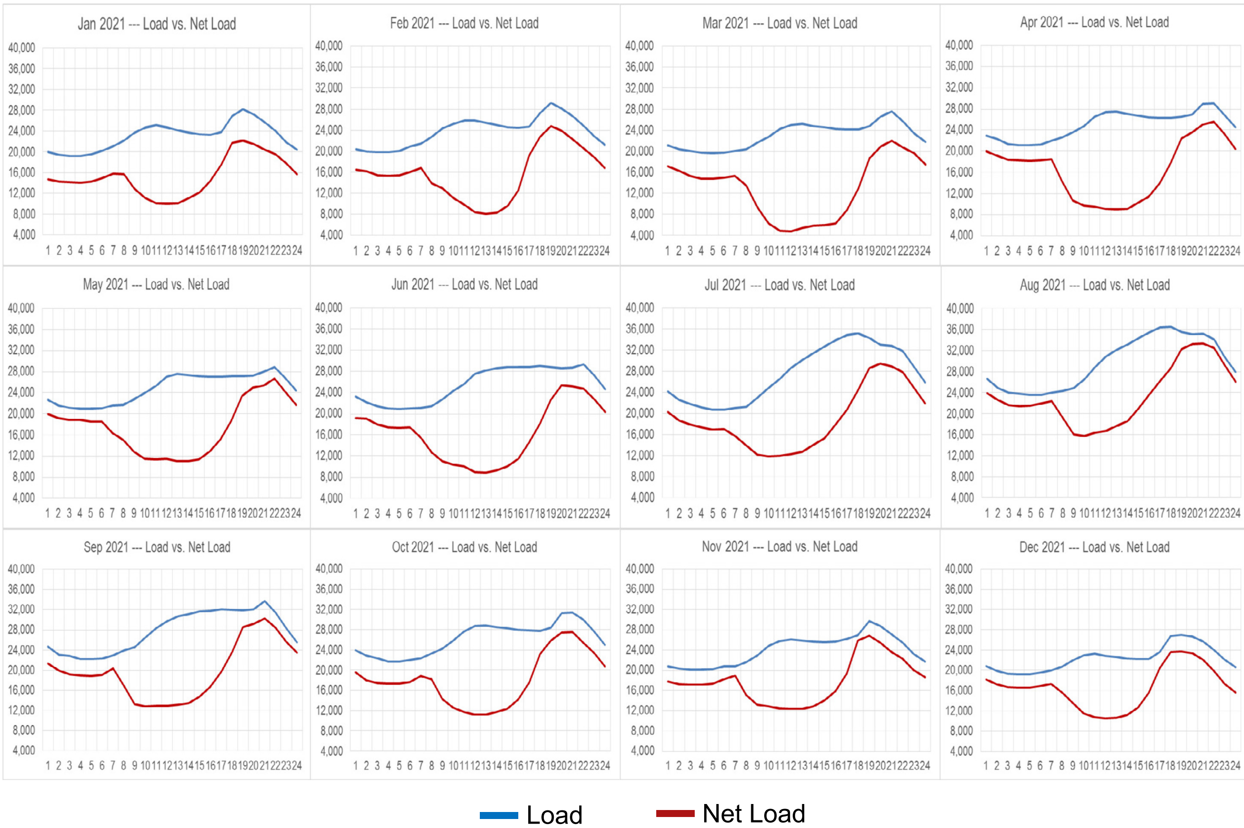


Figure 13 below provides a side-by-side comparison of the average March weekdays on the left versus weekends/holidays on the right. The figures show that oversupply conditions seen in March 2013 and 2014 continue into 2021. Focusing on the red net load lines, both graphs have a "duck curve" shape, ramp up in the morning around 8:00 a.m., and peak around 9:00 p.m. However, the minimum weekday net load is about 12,000 MW; whereas, the weekend/holiday minimum demand significantly lower at 4,000 MW. The reduction in peak demand is less dramatic. The weekday peak averages 24,000 MW versus 22,000 MW on the weekends/holidays. There are similar patterns for other spring months as well as fall months where demand is low and renewable generation remains strong.

Figure 13: March 2021 CAISO load and net load profiles (MW)

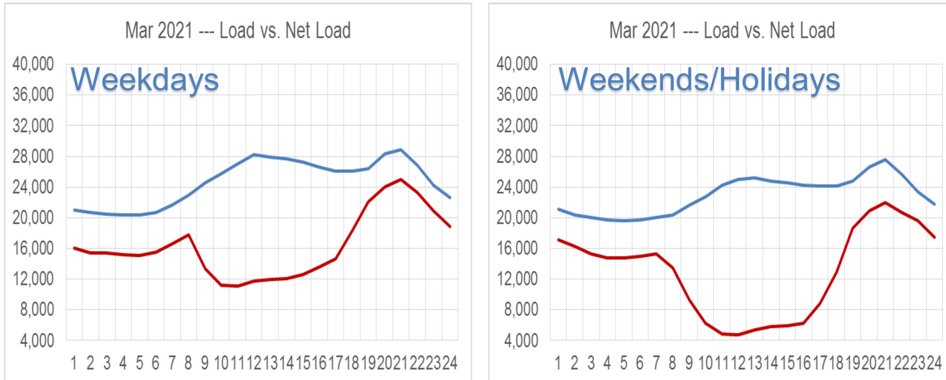
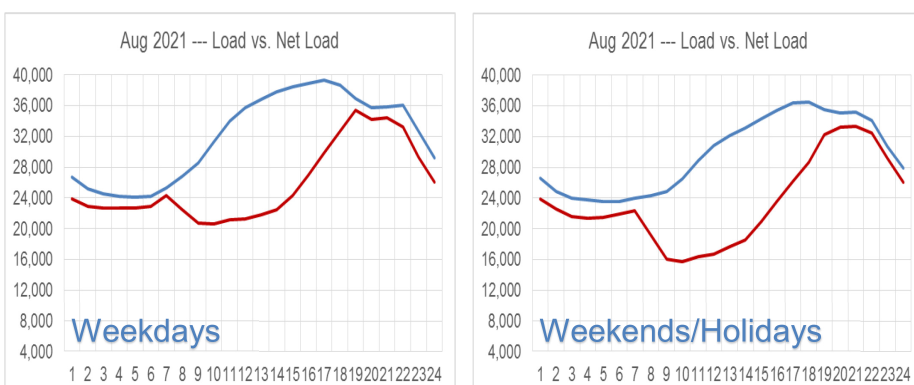


Figure 14 below provides a side-by-side comparison of the average August weekdays on the left versus weekends/holidays on the right. August is an interesting time of analysis because CAISO often experiences its annual peak during this month. Focusing on the blue load profile, both weekdays and weekends/holidays peak around 5:00 p.m. Unlike the 2013 and 2014 analyses, these graphs have a more “duck curve” shape due to increased renewable penetration to meet the 33% renewable standard. The red net load profile shows the actual peak occurring later at around 7:00 p.m. to 8:00 p.m. There are similar patterns for other summer months when the renewable generation “shifts” the peak to later in the day. The minimum net load for weekdays is 4,000 MW higher than weekends/holidays (20,000 MW versus 16,000 MW). The weekday peak is 3,000 MW higher than weekends/holidays (36,000 MW versus 33,000 MW).

Figure 14: August 2021 CAISO load and net load profiles (MW)



5.2.1. Step 2 findings

Table 3 provides the step 1 and 2 responses to the scope questions. Based on the analysis, the CAISO verified that its findings based on historical data persist to projected year 2021. There were also large minimum and maximum demand differences between the weekdays and weekends/holidays; although, the general shape of the curves remained the same.

Table 3: Step 1 and 2 responses to scope questions

	Questions	***Step 1 responses (Where the question is addressed)***
A	Does the time of the CAISO's coincident demand vary by season?	Yes. (Step1)
B	Does the time of the CAISO's coincident peak coincide with each of the IOU's peak demand?	Yes. (Step1)
C	Is there a noticeable difference between weekdays and weekends/holidays?	Yes for Steps 1 and 2. (Steps 1 and 2)

5.3. Step 3: comparing historical and projected analyses

Step 1	analyzing historical data
Step 2	comparing trends with projected data
Step 3	comparing historical and projected analyses
Step 4	develop TOU periods

The analysis thus far has been based on average demand. In this step, the CAISO studies the demand distribution across each hour and validates that the historical patterns hold when applied to projected data. As described above, the CAISO had averaged the demand for each hour in the day to create monthly load and net load profiles. In step 3, the CAISO tracks four additional data points for each hour for a more granular analysis to validate our previous findings: (1) maximum demand, (2) the range of demand covering two standard deviations, (3) median demand, and (4) minimum demand. The maximum demand is the highest MW demand for that hour. Two standard deviations covers 95 percent of the total range of demand data points for the hour. The remaining five percent is equally divided between the very highest and lowest demand experienced in that hour of the day. The median demand is the number that is halfway in the data set so that there are exactly the same number of data points above and below this number. The median may be different than the average. Lastly, the minimum demand is the lowest MW demand for that hour. The CAISO further categorized the data by year, month, and weekdays versus weekends/holidays.

Figure 15 below is a sample "box-and-whisker" graph combining all four data points. The graph shows the four data points for hour ending 1 for January 2014 and 2021. The top "whisker" shows the maximum demand for a given hour. For example in 2021, the maximum demand was 33,000 MW, the minimum demand was 14,000 MW. For 95% of the 1-minute intervals shown by the red box, the load demand ranged from 19,000 MW to 29,000 MW. The median demand was 24,000 MW, indicating that the load demand for half of the 1-minute intervals was above and below 24,000 MW for hour ending 1 in 2021.

Figure 15: Sample box-and-whisker graph (MW)

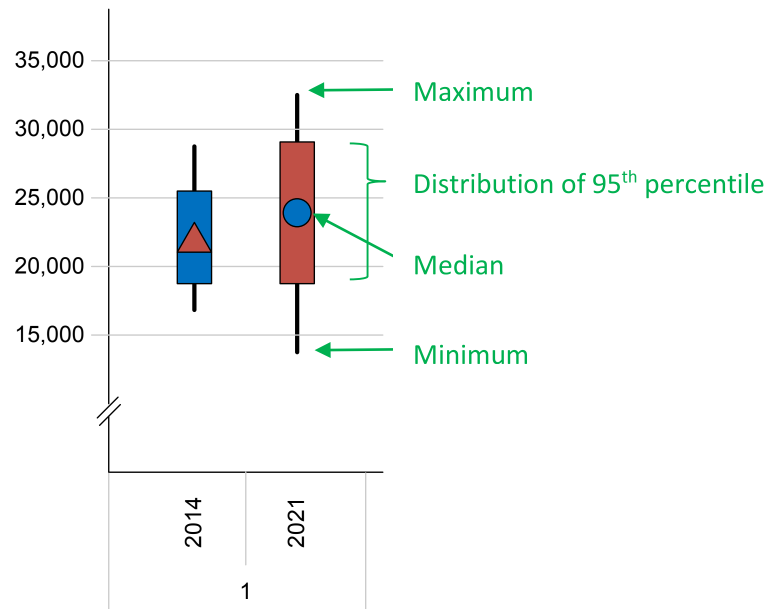


Figure 16 and Figure 17 are whisker-and-box graphs comparing the net load distribution for 2014 and 2021 on weekdays and weekends/holidays, respectively. By 2021, the distribution of net load is wider than in 2014. For example, during hour ending 19, the 2014 net load minimum and maximum demand distribution is 19,000 MW (from 21,000 MW to 40,000 MW) whereas the distribution is 23,000 MW for 2021 (23,000 MW to 46,000 MW).

As observed from the step 2 analysis, the average minimum demand (the belly of the duck) is lower than 2014. The net load distribution provides additional detail showing that the *median demand* in 2021 is at times *lower than the 95th percentile of demand* in 2014. This occurs from hour ending 10 through 14 in Figure 16 and hour ending 10 through 15 in Figure 17. These graphs show the increased sagging in the belly of the duck curve largely driven by solar generation during the day.

Figure 16: Comparison of 2014 and 2021 net load distribution (MW) – weekdays

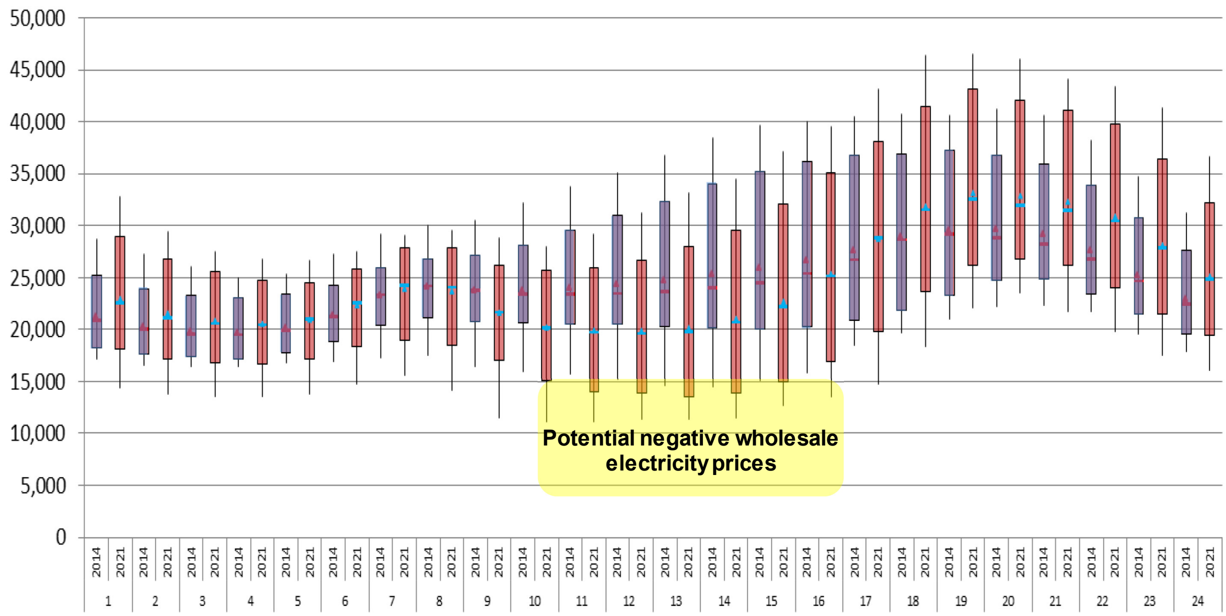
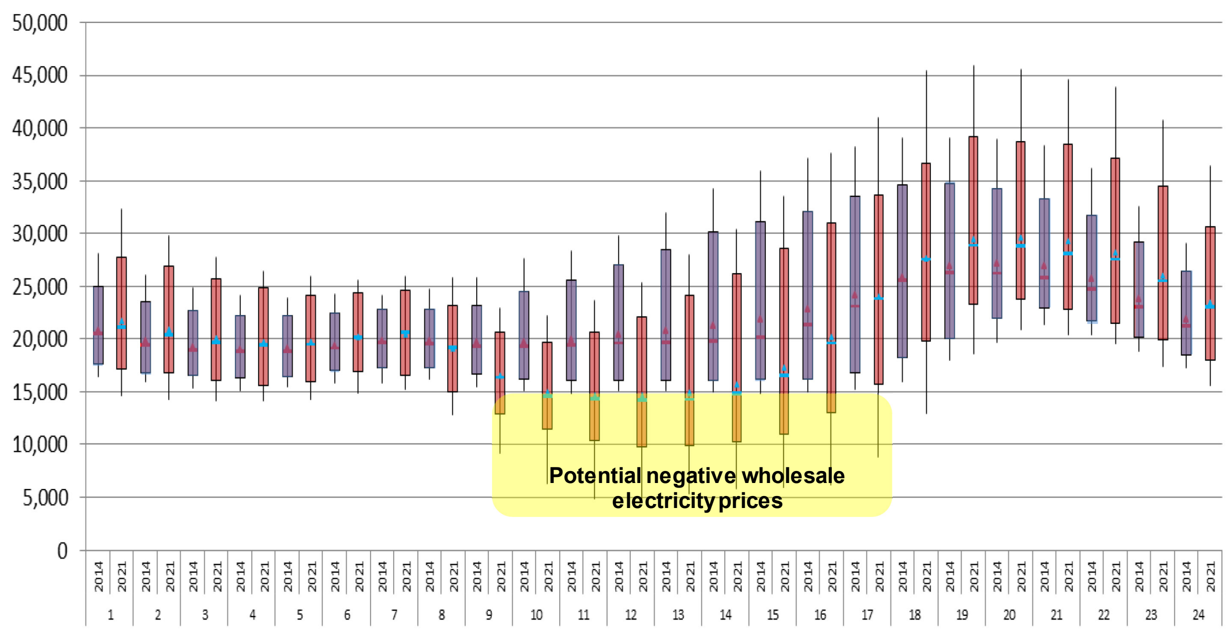


Figure 17: Comparison of 2014 and 2021 net load distribution (MW) – weekends/holidays



The CAISO did not analyze retail price impacts or costs. This TOU period analysis is limited to the operational needs of the system as reflected in the generation fleet's capability to meet the net load. Nonetheless, CAISO's wholesale electricity prices reflect the balance of supply and demand where low prices signal an opportunity to use electricity because demand is low and/or supply is abundant. The CAISO has noted that approximately 15,000 MW is the threshold where the system may experience negative prices. This is highlighted in yellow in Figure 16 and Figure 17.

In concluding step 3, the CAISO finds that the trends observed in 2013 and 2014 are expected to become more pronounced in 2021 after California has reached the 33 percent renewable portfolio standard target. In step 4, the CAISO used data for 2021 only to consider robust TOU periods that take into account future system conditions.

5.4. Step 4: develop TOU periods

Step 1	analyzing historical data
Step 2	comparing trends with projected data
Step 3	comparing historical and projected analyses
Step 4	develop TOU periods

The CAISO established the following parameters to limit the design of TOU periods so that the needs of the system are balanced with a simplified design to foster customer acceptance.[21]

- Weekdays can be different than weekends
- Time blocks can differ by up to 4 seasons
- Maximum of 3 to 4 time blocks per day
- Needs will be based on system needs and not geography

As noted in step 1, there are differences between IOU footprint peaks that may need to be considered beyond this operational analysis. However, for ease of analysis CAISO has purposely limited the complexity and variation of the proposed TOU periods. As noted above, CAISO does not have any rate setting authority, and this paper does not opine on any aspect of rates that may be developed for the proposed TOU periods or whether the rates are acceptable to customers.

Questions D through F are closely intertwined. Whether each IOU needs a specific TOU period design may depend on the length of each peak or off-peak period. If there is little variation between each IOU, a common TOU period design may be both efficient and effective. While there is seasonal variation, TOU period groupings may not follow the traditional winter, spring, summer, and fall definitions.

[21] CAISO did not conduct any customer outreach or incorporate any analysis on customer acceptance to develop these periods. Guidance was provided by CPUC energy staff and their rate setting experience.

Figure 18 and Figure 19 below disaggregate the annual net load distributions for 2021 into months for weekdays and weekends/holidays, respectively. The box-and-whisker format remains the same except that the blue triangles showing the median demand is replaced by a blue curve for each month.

Figure 18: 2021 monthly net load distribution with proposed TOU periods (MW) – weekdays

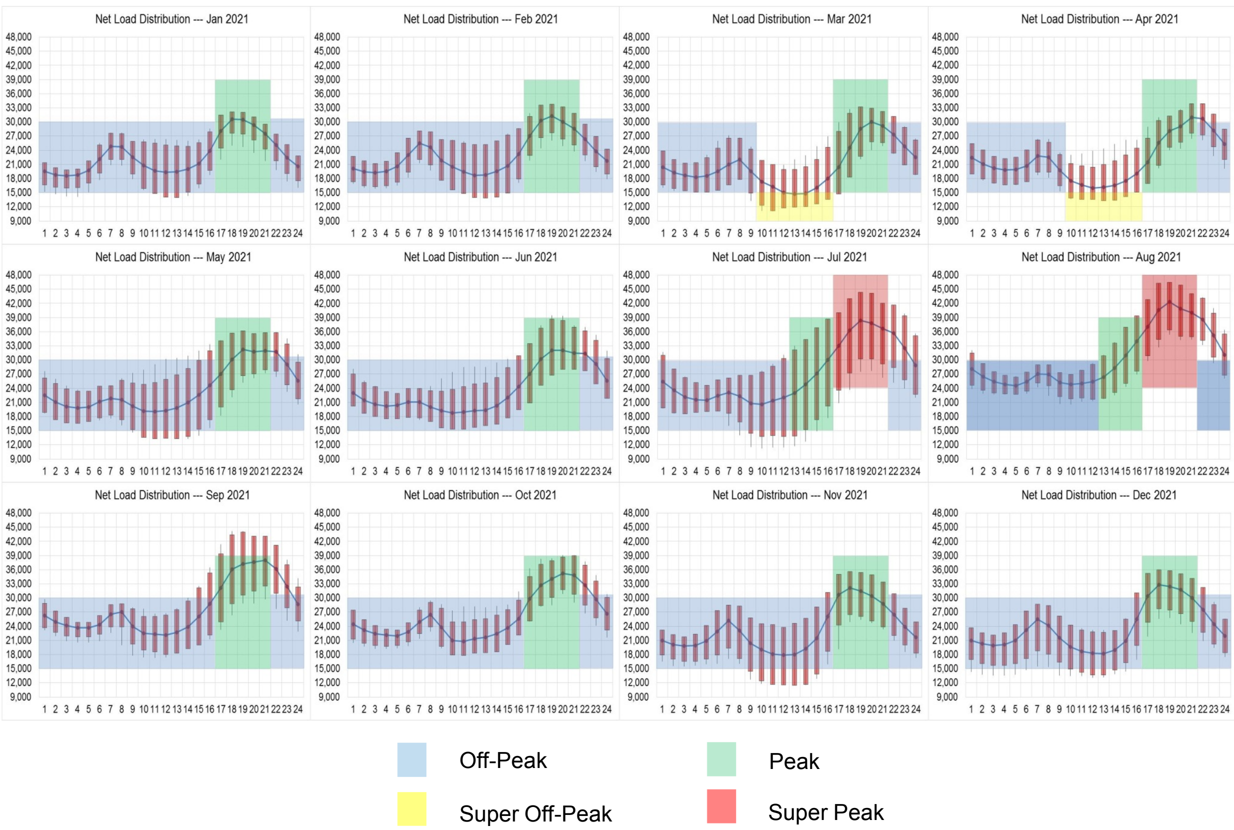
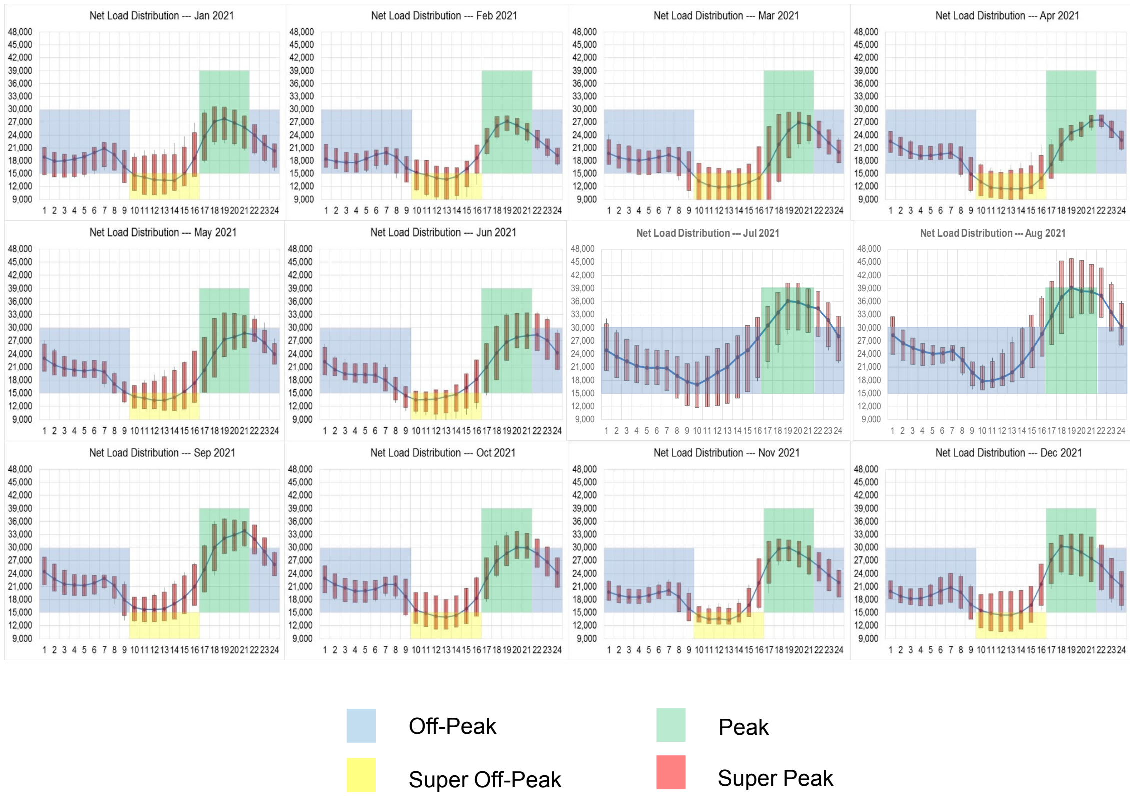


Figure 19: 2021 monthly net load distribution with proposed TOU periods (MW) – weekends/holidays



Superimposed on each month are the following proposed TOU periods:

1. **Super-peak** – a period during which conservation or load-shifting is critical to the system. The super-peak drives steep ramps on the CAISO system that are difficult to manage and may result in high wholesale electricity prices, especially during warm weather and on weekdays.
2. **Peak** – a typical period of high demand that drives ramping need on a daily basis.
3. **Super off-peak** – a period during which additional consumption is highly encouraged to avoid oversupply conditions that may result in persistent negative wholesale electricity prices[22] and may cause a steeper ramp for the CAISO to manage later.
4. **Off-peak** – all other periods.

The CAISO identified July and August as having super peaks that drive steep ramping needs on weekday evenings. Super peak periods are shown in red in Figure 18. The difference between the median demand at 10:00 a.m. (HE 10) and the peak hour at 7:00 p.m. (HE 19) is 18,000 MW in July and 17,000 MW in August. The difference for September is slightly lower

[22] Negative prices in the wholesale market are not considered to be negative or positive outcomes but do signal an opportunity for wholesale market participants to be *paid* to consume energy.

than this amount, but no other month has this significant spread. Between July and August, the super-peak period starts from 4:00 p.m. (HE 17) and lasts through to 9:00 p.m. (HE 21). For weekends/holidays, the CAISO did not find the same significant spread between the net loads; so, it did not propose a super-peak period in any month for those days.

The CAISO identified peak periods times for every month and for both weekdays and weekend/holidays because the CAISO expects them, and they occur regularly. Peak periods are shown in green on both Figure 18 and Figure 19. The CAISO found that this generally occurred between 4:00 p.m. and 9:00 p.m. (HE 16 and HE 21). Because July and August already have super-peak periods during this time, the peak is shifted back to noon to 4:00 p.m. (HE 12 to HE 16). Conservation during this time would still be beneficial to the system and may reduce ramping requirement to reach the super peak period.

On the other hand, super off-peak periods should incentivize use of abundant renewable generation typically when demand is below the 15,000 MW threshold, and wholesale electricity prices may be negative. Super off-peak periods are shown in yellow on both Figure 18 and Figure 19. For weekdays, CAISO found that the greatest likelihood of super off-peak periods are in March and April when spring loads are light, but renewable energy production is strong. Based on the data in Figure 18 one can argue that November should also have a super off-peak period. However, in balancing CAISO's operational needs with the goal of achieving a simple and understandable TOU period design, the CAISO limited the super off-peak periods to just two months in the same season.

On the other hand, weekends/holidays are generally light load days and super off-peak periods exist for all months except in July and August. Based on the data in Figure 19 one can argue that July should also have super off-peak periods. In balancing the CAISO's operational needs with the goal of a simple and understandable TOU period design, the CAISO proposed to consistently treat July in the same manner as August to avoid complexity.

Lastly, all other periods are designated off-peak. Off-peak periods are shown in blue on both Figure 18 and Figure 19.

5.4.1. Step 4 findings

Table 4 provides the complete responses to the scope questions. Based on the analysis, the CAISO proposes a single CAISO-wide TOU period design, rather than differentiated periods for each IOU. Most importantly, the CAISO found significant differences in net load patterns between weekdays and weekends/holidays to warrant different TOU periods designs that include a super peak period during July and August and super off-peak periods for most weekends/holidays.

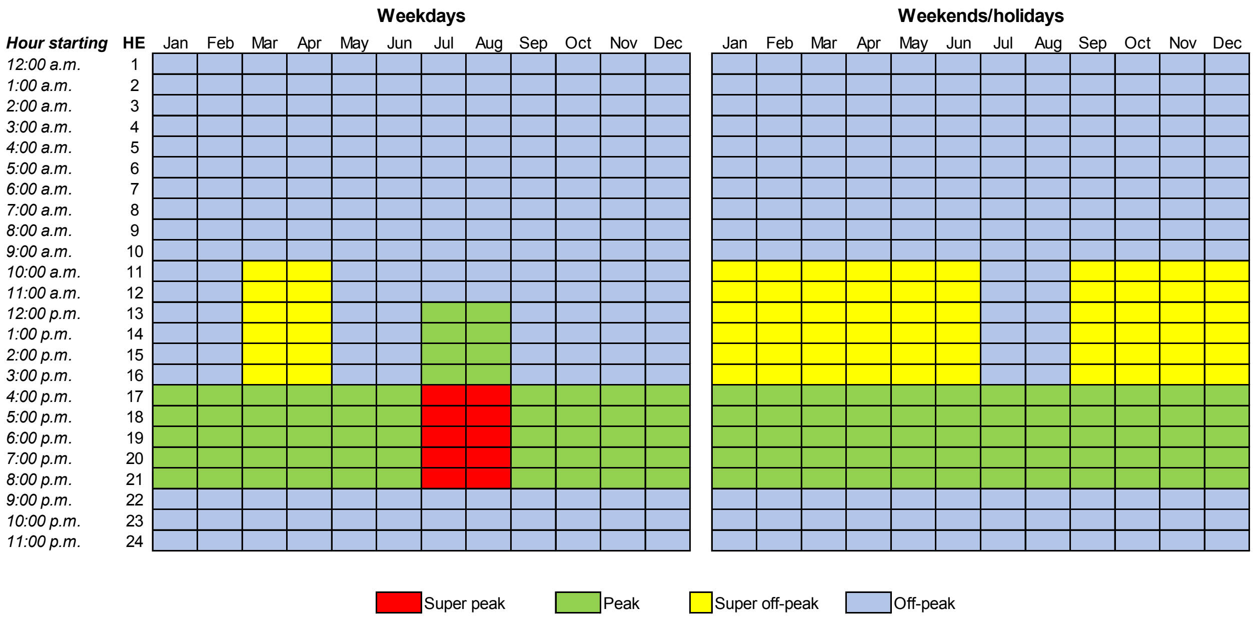
Table 4: Step 4 responses to scope questions

	Questions	*How the data addresses each question (Where the question is addressed)*
A	Does the time of the CAISO's coincident demand vary by season?	Yes. (Step1)
B	Does the time of the CAISO's coincident peak coincide with each of the IOU's peak demand?	Yes. (Step1)
C	Is there a noticeable difference between weekdays and weekends/holidays?	Yes for Steps 1 and 2. (Steps 1 and 2)
D	Is there a need for IOU-specific TOU periods?	Likely no. (Step 4)
E	Can all three IOUs establish common TOU periods based on the CAISO's needs?	Likely yes. (Step 4)
F	Should TOU periods be grouped by months?	Yes with an emphasis on months with significantly high peaks, significantly low demand and differentiation between weekdays and weekends/holidays. (Step 4)

6. Proposed TOU periods and next steps

Figure 20 below is a graphical representation of the proposed TOU periods showing the super peak (in red), peak (in green), super off-peak (in yellow), and off-peak (in blue) for each month with weekdays on the left and weekends/holidays on the right. The figure shows the periods based on the hour ending to correspond with previous figures but also shows the "hour starting" reflecting the time at which a proposed TOU period will start.

Figure 20: CAISO proposed weekday and weekend/holiday TOU periods



Periods were simplified to provide a CAISO system-wide uniform approach and limit variation in peak and off-peak periods.

The CAISO's analysis proposes TOU periods that better address the balancing area needs over existing TOU rate periods. The CAISO purposefully simplified the proposed periods to facilitate a dialogue and further study. The CAISO will participate in the CPUC's TOU period OIR.

7. Backup data

The CAISO has provided backup files for the data presented in this paper as well as for 2013, which was not shown as it is largely similar to 2014 data. Four Microsoft Excel documents are zipped together into one file (~177 MB) can be accessed publically at: http://www.caiso.com/Documents/Jan22_2016ExplanationofDataAssumptionsandAnalyticalMethods-TOUPeriodBackup-R1512012.zip