Analysis of Structural System-Level Competitiveness in the CAISO Balancing Authority Area

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Introduction

This report summarizes the California Independent System Operator's (CAISO's) analysis of the structural competitiveness of the CAISO market at the system-level within the CAISO balancing authority area. There is the potential for suppliers to exert market power if the market is not structurally competitive.

The CAISO initiated this analysis after the CAISO Department of Market Monitoring (DMM) indicated in its annual report released in June 2018 that there may be an increase in the ability of energy suppliers to exert market power in the day-ahead market at the system level. DMM found that the day-ahead market was structurally uncompetitive during approximately 325 hours in 2017 and projected this to grow to approximately 500 hours in 2018.

The DMM's report raised concerns because it showed potentially uncompetitive *system-level* market conditions. The CAISO market only includes automated local market power mitigation measures, *i.e.*, at the local transmission constraint and EIM balancing area level. The CAISO market design assumes there are competitive conditions in the CAISO balancing area at the system-level.

The CAISO conducted this analysis to evaluate the structural competitiveness of the CAISO markets in its balancing authority area and to inform any future actions that may be warranted to address issues related to the competitiveness of the CAISO markets.

Conclusions

The CAISO's analysis indicates that the CAISO market within its balancing authority area was likely structurally uncompetitive in 55 hours in 2018 using supply and demand assumptions that the CAISO believes most accurately reflect system conditions.[1] This frequency was significantly less than what the DMM analysis identified due primarily to a different assessment of the appropriate supply and demand inputs.

The CAISO's analysis consisted of calculating the Residual Supply Index (RSI) under several different scenarios. The RSI is a standard measure of structural competiveness that the CAISO market uses in its local market power mitigation process and which also formed the basis of DMM's analysis. The RSI calculation is dependent on the supply and demand used as inputs. The CAISO also evaluated structural competiveness using the RSI under a number of other scenarios using various supply and demand inputs. This effectively provides a sensitivity analysis to provide insights into the structural competitiveness under various input assumptions.

The CAISO drew its conclusion that 55 hours were structurally uncompetitive in 2018 based on a scenario using supply and demand inputs it believes are appropriate to examine structural competiveness in the CAISO day-ahead and real-time markets as a whole. As described further in *Study Scope*, below, the CAISO believes this is the appropriate approach, as opposed to evaluating day-ahead

[1] Note that while this analysis appears to have identified periods in which the market was structurally competitive, this analysis did not examine whether suppliers actually exerted market power to raise the energy prices above marginal costs.

and real-time market structural competiveness separately, because both these markets work together to procure supply to meet the ultimate real-time demand.

This scenario used a supply input consisting of all supply bids into the day-ahead market, including virtual supply. This represents the overall supply available for the day-ahead market to schedule so it is available to the real-time market, or, in the case of virtual supply, represents supply available to the day-ahead market that the market anticipates will either be replaced by additional physical supply in real-time or not needed. This scenario used a demand input consisting of the CAISO's day-ahead forecast of real-time demand. This is the demand expectation as of the time of the day-ahead market. This is more appropriate to use than actual real-time demand as it is the demand expectation under which suppliers submitted their supply offers to the day-ahead market.

Similar to the way the CAISO varied the supply and demand assumptions, it also varied the number of "pivotal suppliers" used in calculating the RSI. The RSI calculations test structural competiveness by removing a certain number of the largest, or "pivotal suppliers." The CAISO found that the RSI generally indicates the CAISO market is structurally competitive much more often when the RSI is calculated after removing only one or two pivotal suppliers, rather than three. The CAISO's automated local market power mitigation test calculates RSI removing three pivotal suppliers. Out of the 55 hours tested in the scenario described above, the RSI indicated only 20 hours were structurally uncompetitive if only two pivotal suppliers were removed.

The CAISO's analysis summarized in this report should serve as a basis for the CAISO and stakeholders to assess if changes should be made to CAISO market rules, state resource adequacy requirements, and/or load serving entity energy procurement practices. In its *2017 Annual Report on Market Issues and Performance*, the DMM recommended several actions to reduce and mitigate the potential for system-level market power. These included updates to resource adequacy provisions and a review of out-of-market purchases of imports.[2] The CAISO is evaluating the resource adequacy recommendations in its current *Resource Adequacy Enhancements* initiative. In addition to the DMM, the Market Surveillance Committee also recommended a separate review of out-of-market purchase of imports, which the CAISO will be analyzing in its *Price Performance Analysis*.[3]

The CAISO is also evaluating the need to require suppliers to cost-justify import offers above $1,000/MWh once the CAISO's current $1,000/MWh energy bid-cap increases to $2,000/MWh in compliance with Federal Energy Regulatory Commission's Order No. 831. The current bid-cap provides a measure of market power protection, which will be diluted under the currently planned tariff changes that would allow imports to bid up to $2,000/MWh without cost-justification. This is in contrast to internal resources for which the CAISO will bids above $1,000/MWh to be cost-justified

In evaluating the need for CAISO market rule changes, it is important to recognize that load serving entities can significantly mitigate suppliers' market power through forward contracting for energy. Forward contracting can serve to hedge load serving entities against CAISO market prices and mitigates suppliers' incentives to exert market power. Irrespective of other changes, load serving entities should

[2] When the CAISO purchases import energy outside of the market clearing process, it may encourage imports to further withhold supply from the market.

[3] The Market Surveillance Committee recommended that the CAISO evaluate the extent and impact that out-of-market purchases of imports have on the market in its final opinion of the *Intertie Deviation Settlement* initiative.

consider the results of the analysis presented in this report in their power contracting and hedging activities.

Study Scope

The scope of this analysis extends to evaluating the CAISO market's structural competiveness at a system-level in the CAISO balancing area. Although this analysis is based mostly on day-ahead market information, this study's intent is to evaluate this structural competiveness as a whole, not separately for the day-ahead and real-time markets.

This analysis evaluates structural competiveness for both of these markets as a whole, because both of these markets work together to procure supply to meet the ultimate real-time demand. Load serving entities can submit demand bids to either purchase all their demand needs in the day-ahead market or defer purchasing energy until the real-time market if day-ahead prices are too high. The supply available in the real-time market is dependent on the supply committed in the day-ahead market based on day-ahead market bids. However, actual real-time demand can be different than the day-ahead demand forecast. Consequently, this analysis used varying supply and demand inputs, based on both day-ahead market and real-time market conditions, to evaluate the overall structural competitiveness over both markets and to evaluate the sensitivity of its results to different inputs.

This analysis was limited to the CAISO balancing area because the CAISO market's current market power mitigation provisions assume that the CAISO balancing authority area is structurally competitive at a system level. This analysis did not evaluate the structural competitiveness of Energy Imbalance Market (EIM) balancing areas outside the CAISO because EIM balancing area market power mitigation provisions do not assume EIM balancing authority areas outside the CAISO are competitive. The EIM uses CAISO balancing area prices to set the system marginal energy cost for the broader EIM and to set competitive locational marginal prices used in local marker power mitigation throughout the broader EIM.

The scope of this analysis is to evaluate whether the CAISO market is structurally competitive and consequently whether there is the potential for suppliers to exert market power. A supplier could potentially exercise market power through physical or economic withholding. Physical withholding is exercising market power by not offering available supply. Economic withholding is exercising market power by offering supply above marginal cost to inflate the market clearing price. This analysis does not evaluate whether suppliers have actually physically or economically withheld to exercise market power.

The scope of this analysis is limited to assessing structural competiveness at the system level. The CAISO market mitigates market power at the local-level by screening supply offers when transmission constraints limit the amount of local competition to fulfill demand. When these local market power screens indicate uncompetitive conditions, the market mitigates associated supply offers to the greater of a resource's marginal costs or the competitive price.

Analysis

The CAISO tested the RSI against the single largest, two largest, and three largest suppliers (i.e. pivotal suppliers) in all hours in 2018. While there is a standard calculation for the residual supply index, this study shows that its value, and consequently whether it indicates market power conditions, depends significantly on the supply and demand assumptions used to calculate it. This report first evaluates all hours in 2018 with a scenario that uses the same supply and demand assumptions as the DMM. It then discusses various different supply and demand input assumptions and presents a sensitivity analysis using these various assumptions. This report also uses results of joint pivotal supplier tests to show how often the energy market would exhibit uncompetitive conditions if the largest supplier, the two largest suppliers, and the three largest suppliers withheld production.

Joint pivotal supplier test

The CAISO conducted joint pivotal tests to evaluate the competitiveness of the CAISO markets overall. The joint pivotal test is based on the residual supply index (RSI) that measures the ratio of the total available supply resources, net of the largest supplier or suppliers, to total demand. A supplier is considered to be pivotal when the output of some of its resources is needed to meet demand in the market, as indicated by an RSI of less than one. Pivotal suppliers therefore can control the price by physically withholding generation capacity from the market.

Let P_i be the capacity controlled by the *i-th* single market participant; let P_S be the total system capacity, and let P_D be demand during the same period. The market participant would be considered a pivotal supplier if the CAISO needs the capacity of supplier i to meet total electricity demand during this period. The following equation represents this condition.

$$P_i > P_S - P_D \tag{1}$$

It is possible for multiple firms to be jointly pivotal suppliers. A group of n market participants are joint pivotal suppliers under the following condition.

$$\sum_{i=1}^{n} P_i > P_S - P_D \tag{2}$$

Rearranging ***Equation (2)***, the residual supply index for a n joint pivotal supplier test is

$$RSI_n = \frac{P_S - \sum_{i=1}^{n} P_i}{P_D} \tag{3}$$

If $RSI_n < 1$, that instance will have failed the RSI test and there exists the potential for structural system-level market power.

Supply and demand assumptions

Although the RSI test is straightforward and simple to implement (See ***Equation (3)***), the specific measures of supply and demand used to calculate it can vary depending on the assumptions taken.

The CAISO did evaluated several scenarios using various measures of supply and demand to provide a sensitivity analysis and better evaluate an array of assumptions that may affect the ability to exercise system wide market power.

This section first discusses the DMM assumptions and analysis. Then, the CAISO explores other variations on the supply and demand assumptions and discusses its reasoning for considering those variations. By evaluating a range of scenarios, one can observe the impact different supply and demand assumptions have on the number of hours of structural uncompetitive system-level conditions.

DMM analysis

The Department of Market Monitoring assumes the following supply and demand inputs in its residual supply index calculation.

Total Demand P_D

The total demand is composed of the day-ahead forecast plus upward ancillary services requirements (including regulation up, spinning and non-spinning reserves).

Total supply P_S and pivotal supply P_i

The total supply includes all internal generation plus supply provided by intertie resources. Supply associated with wheeling transactions is discounted in a way that may reduce import supply, resulting in an under-estimation of import supply up to few hundred megawatts.[4] Additionally, the DMM's estimates only consider supply associated with energy-only bids. Supply offers associated with bids that are not supported by energy bids are not included.[5]

The DMM uses a set of supply bids that under-estimate the actual supply available to the day-ahead market by relying on supply bids that have an adjusted maximum limit, estimated by the processing of the market solution. Furthermore, DMM's analysis only uses bids associated with physical resources (internal and intertie), but does not include virtual bids. In the day-ahead market, however, any market participant that complies with the credit requirements can use virtual bids. Virtual bids participate and contribute to available supply capacity and market competitiveness. Therefore, given the same physical resources in the market, virtual bids impact the market clearing process and the marginality of the solution.

[4] A wheeling transaction is a pair of intertie transactions, one import and one export which have a requirement to clear the same value and they only pass through the CAISO system; consequently, they do not represent any additional supply or demand to the balancing of the ISO system.

[5] In the day-ahead market, certain bids for ancillary services do not need to be covered by an energy bid.

The DMM removes all supply controlled by the same a market participant in the pivotal supply test. Since a market participant may use more than one scheduling coordinator identifier, the DMM groups supply controlled by all affiliates under the same market participant.

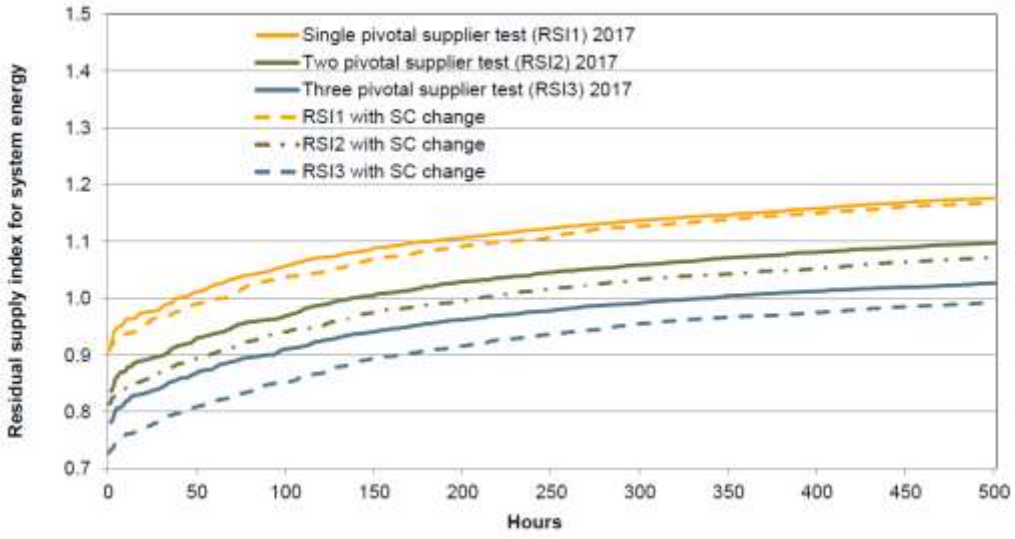
In the CAISO markets, certain participants may both buy and sell power. A *net buyer* is a market participant that transacts more demand than supply. The CAISO assumes that net buyers have no incentive to exercise market power because any artificial price inflation influenced by its supply offers would directly raise its overall cost due to its net demand position. Consequently, the DMM does not screen net buyers for pivotal position. In other words, net buyers are not treated as a pivotal supplier P_i even though its supply is still considered as part of the total supply P_S.

The Department of Market Monitoring Analysis Results

The DMM identified potential structural system-level uncompetitive conditions. It found that the residual supply index in 2017 fell below its key threshold indicating that there were approximately 325 hours in which pivotal suppliers had structural system-level market power. At the time, the DMM also projected that pivotal suppliers would have structural system market power during approximately 500 hours in 2018 once more than 3,750 megawatts of gas generation would be re-assigned to different suppliers.

Error! Reference source not found. below displays the first 500 hours of the DMM's 2017 residual supply index duration curve spanning the lowest to the highest calculated residual supply index values. [6]

Figure 1: 2017 residual supply index estimated by DMM

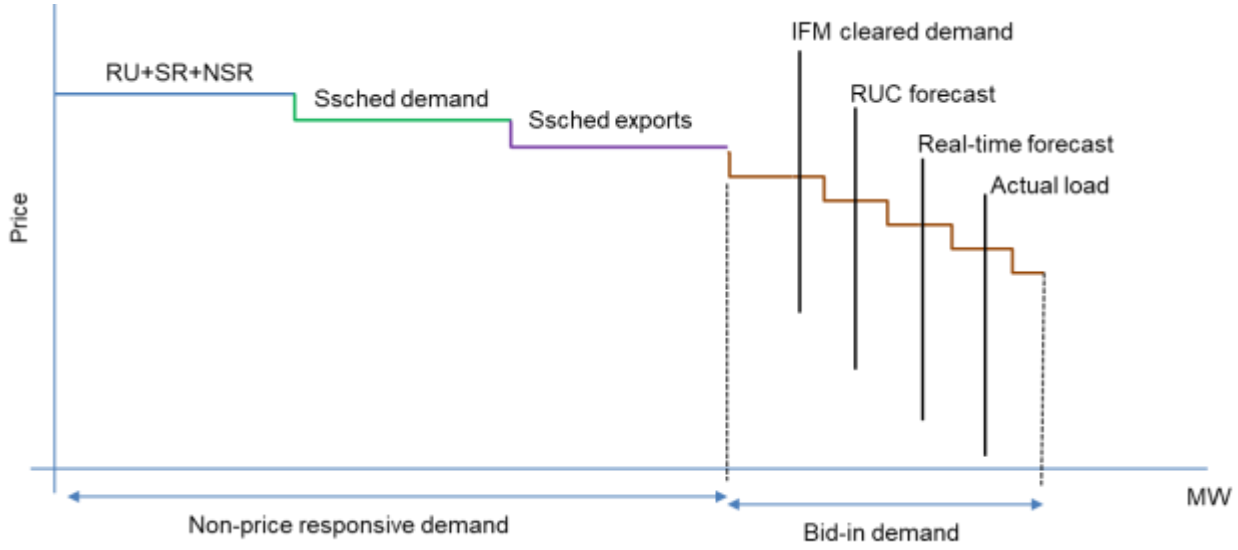


[6] Metric is available in the DMM's annual report at http://www.caiso.com/Documents/2017AnnualReportonMarketIssuesandPerformance.pdf

Other demand assumptions

There are multiple options to use for demand in the residual supply index calculation. ***Figure 2*** shows the different options to consider in the determination of which demand inputs will lead to an accurate market power assessment. In general, the demand is composed of energy demand and ancillary service requirements.

Figure 2: Illustration of a demand bid stack composition.



The CAISO could consider the day-ahead forecast demand (currently used by the DMM) or the real-time forecast demand. Both demand quantities are a forecast, however, the day-ahead forecast typically will be less accurate than real-time forecast or actual demand because it is determined long before the actual time of consumption. The further ahead of time that the CAISO develops the forecast, the more uncertainty and inaccuracy will be incorporated. These uncertainties and inaccuracies will be more acute during extreme weather conditions, which can impact the forecast in either an upward or downward direction.

An alternative to forecasted energy demand is the measurement of actual load, which has no errors or use the amount of demand cleared in the day-ahead market.

Finally, it may be helpful to consider the flexibility of demand in the context of market power in the day-ahead market. Since demand can actively participate in the integrated forward market by submitting either self-schedules or economic bids, market power results could be curbed by the price-responsive demand, which is cleared based on economic merit. One may wish to consider only the portion of self-scheduled demand in the RSI calculation because it is not price-responsive.

All the above demand options give different quantities of demand to consider in the RSI calculation, leading to different conclusions on the likelihood of structural uncompetitive conditions.

When the market clears supply and demand, the power balance constraint also takes into account any transmission losses that supply must meet. It is reasonable for the CAISO to include transmission losses in its evaluation of the RSI because the aggregate supply must meet these demands. There are several sources for estimated transmission losses such as the integrated forward market, the residual unit

commitment, and the real-time market. The CAISO created two scenarios that include transmission losses from the integrated forward market.

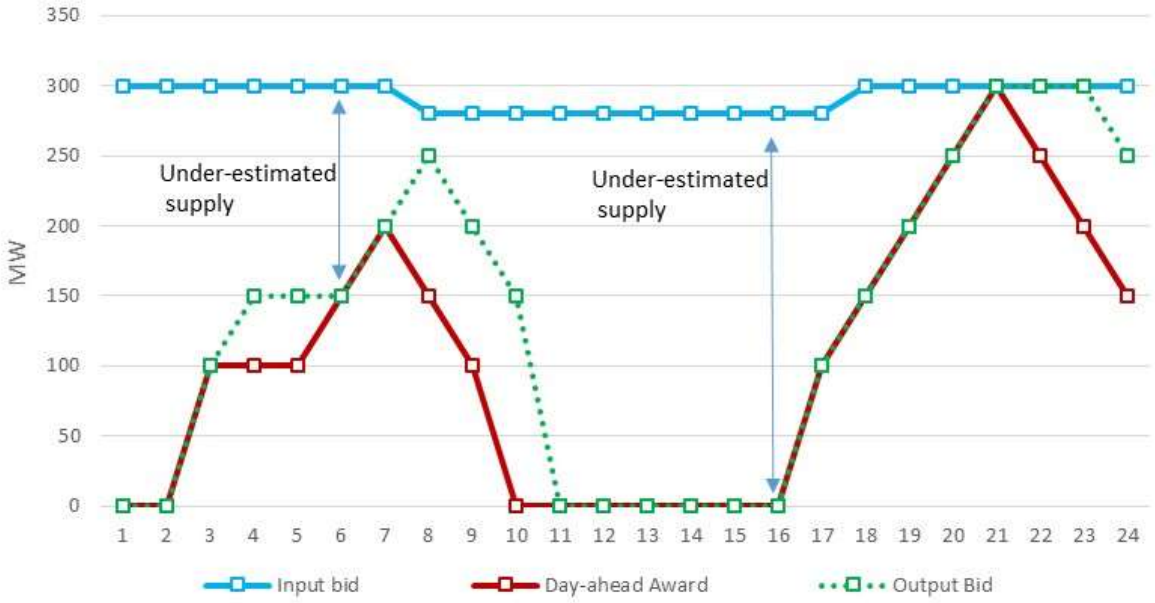
Other supply assumptions

There are more than one set of supply bids that can be used in the residual supply index calculation. One way to represent total supply is to use DMM's reference of adjusted bids on the current day-ahead market solution, which will generally underestimate available supply. It would be more accurate to represent total available supply in the residual supply index as supply offers adjusted only for outages and de-rates. This set of supply inputs will better represent the supply available to the market because they are the true inputs into the market and do not depend on the result of the day-ahead market itself.

The CAISO market systems validate and process submitted supply offers prior to clearing the market to account for outages, de-rates, and self-schedule priorities. These validated and processed bids are then used in the market optimization to clear bid-in supply against bid-in demand. The CAISO also has an hourly "output" bid-set that estimates the maximum available MW associated with resource bids and market awarded quantities. These "output" bids reflect the ramp capability that a resource may reach for the following hour, based on its current-hour award and hourly commitment status. The "output" bid-set value may show that no supply is available when the market determined that a unit should not be committed in a certain hour. This maximum "output" bid-set value may not always be an accurate measure of the actual supply available in the day-ahead market since the value depends largely on the market solution defined by the market clearing process.

Below, ***Figure 3*** shows the implications of using the maximum value provided in the "output" bid set. The blue line represents the nominal bid of 300 MW available for a resource adjusted by 20 MW for midday outages and de-rates. The red line is the optimal trajectory determined by the market clearing process. The green line is the maximum MW in the "output" bid-set, which accounts for the maximum ramp capability of the resource for next hour based on the optimal award in the current hour. In this example, the green line shows that at Hour 5 the ramp capability of this resource is 50 MW per hour, meaning the resource can only move upward an additional 50 MW in the next hour. In contrast, in Hour 16 the resource is optimized to be offline, its maximum available value is 0 MW. Therefore, when the values along the green line are used (instead of the blue line), the residual supply index calculation will underestimate the actual supply available to the day-ahead market. Note that the capacity between the blue line (full bid adjusted for outages and de-rates) and the green line (maximum availability estimated as part of the market solution) is pre-determined by the optimal dispatch and is not considered in the DMM's residual supply index calculation. However, this capacity is available to the day-ahead market since the optimization could determine a different commitment and dispatch for that resource.

Figure 3: Illustration of underestimation of supply capacity in DMM's estimates



Below, ***Figure 4*** compares the trend of supply when using either the full set of supply bids made available to the day-ahead market ("input bids") versus the adjusted input bids based on the market solution ("output bids"). Naturally, the capacity accounted with the full set of supply bids made available to the day-ahead market will be higher and will remain relatively more constant over time. In contrast, the capacity based on the solution-based adjusted bids will have a more pronounced pattern that generally follows the load pattern because the available capacity is heavily influenced by the optimal solution estimated by the market.

Convergence bids (i.e. virtual supply and virtual demand) can also be considered in the estimation of total supply since they effectively add capacity to the day-ahead market bid stack. There are many ways to account for virtual bids in the residual supply index calculation. One option is to evaluate only the virtual supply bids. Another option is to consider only the net supply of virtual bids (virtual supply less virtual demand). However, the latter option may be less intuitive when the net supply is negative (i.e. when virtual demand is greater than virtual supply). The CAISO could consider the virtual supply in both the total supply stack and supply for the pivotal participant. The CAISO considered virtual supply in only the total supply stack, but not in the supply of a pivotal supplier's capacity because suppliers cannot physically or economically withhold non-physical capacity.

The CAISO does consider import supply and demand in its scenarios. However, it did not consider supply associated with wheels because wheels flow through and do not add capacity to the supply stack of the CAISO system.

At the initial states of the CAISO analysis, its assumptions aligned with DMM's to only consider energy bids (as opposed to also considering ancillary services bids in excess of energy bids). However, the CAISO determined that accounting for ancillary services bids in excess of energy bids seemed to be another reasonable scenario to consider because these are available to the day-ahead market to meet ancillary service obligations (which are included in the residual supply index total demand). If the CAISO were to

include these additional supply offers in its analysis, it would lead to higher calculated residual supply index values, which in turn would result in the RSI tests failing in less hours. The CAISO may enhance its analysis to account for ancillary service bids in excess of energy bids in the future.

Figure 4: Comparison of accounted supply by using two different data sets for input bids

Sensitivity analysis scenarios

While analysts use a standard formulation to calculate the residual supply index, this study shows that the selected inputs for supply and demand have a significant impact on the results, and therefore may lead to different conclusions regarding the prospect of system-level uncompetitive conditions. This report provides a sensitivity analysis for residual supply index tests as a vehicle to estimate the likelihood of structural conditions that may be indicative of system-level market power. The CAISO built the sensitivity analysis using numerous scenarios for the supply and demand inputs. The CAISO observed a wide range of outcomes depending on the supply and demand assumptions used, ranging from zero hours the residual supply index test to almost all hours the residual supply index test.

Table 1 describes the different supply and demand assumptions the CAISO used in the residual supply index calculation in its various scenarios.

Table 1: Table I. Inputs on the Supply and Demand Side for RSI Tests.

Supply	Demand
1. **Input physical.** All input bids for physical resources. Net buyers not subject to pivotal test. 2. **Output physical.** All input bids for physical resources adjusted based on optimal solution. 3. **Output physical - Net buyer.** All inputs bids for physical resources adjusted based on optimal solution. Net buyers not subject to pivotal test. 4. **Output physical + Virtual - Net buyer.** All inputs bids for physical resources adjusted based on optimal solution and convergence bids for supply. Net buyer not subject to pivotal test. 5. **Input bids + Virtual - Net buyer.** All input bids for physical resources and convergence bids for supply. Net buyers not subject to pivotal test.	1. **Measurement demand.** Actual demand. 2. **Cleared demand.** Demand cleared in IFM which includes both internal demand and exports from either self-schedules or economical bids. 3. **Self-schedule.** Self-schedules for bid-in demand. 4. **DA forecast.** Load forecast for CAISO demand in the day-ahead market. 5. **RT forecast.** Load forecast for CAISO demand in the real-time market.

Below,

Table 2 shows 25 different scenarios, which represent each combination of supply and demand inputs from ***Table 1***. This case enumeration used throughout the remainder of this document to refer to specific cases.

Table 2: Case Description for RSI Tests

Case #	Supply Assumption	Demand Assumption
1	Input physical	Measurement demand
2	Input physical	Cleared demand
3	Input physical	Self-schedule
4	Input physical	DA forecast
5	Input physical	RT forecast
6	Output physical	Measurement demand
7	Output physical	Cleared demand
8	Output physical	Self-schedule
9	Output physical	DA forecast
10	Output physical	RT forecast
11	Output physical - Net buyer	Measurement demand
12	Output physical - Net buyer	Cleared demand
13	Output physical - Net buyer	Self-schedule
14	Output physical - Net buyer	DA forecast
15	Output physical - Net buyer	RT forecast
16	Output physical + Virtual - Net buyer	Measurement demand
17	Output physical + Virtual - Net buyer	Cleared demand
18	Output physical + Virtual - Net buyer	Self-schedule
19	Output physical + Virtual - Net buyer	DA forecast
20	Output physical + Virtual - Net buyer	RT forecast
21	Input bids + Virtual - Net buyer	Measurement demand
22	Input bids + Virtual - Net buyer	Cleared demand
23	Input bids + Virtual - Net buyer	Self-schedule
24	Input bids + Virtual - Net buyer	DA forecast
25	Input bids + Virtual - Net buyer	RT forecast

Using ***Equation (3)***, this analysis provides estimates for RSI_1, RSI_2 and RSI_3 for 2018 and more detailed metrics for the peak load day in 2018 for each of these 25 scenarios.

Analysis of the 2018 peak demand day

The CAISO first measured the impact the various input assumptions would have on residual supply index results of a high demand (e.g. "peak") day in 2018. The CAISO selected the peak demand day of July 24, 2018 because it is more likely to have conditions that cause structural market power on high demand days.

Figure 5 shows three different supply-side inputs (corresponding to P_i and P_S in ***Equation (3)***). Each sub-figure shows three different demand-side inputs and illustrates how any input used in ***Equation (3)*** would affect the residual supply index test results.

Figure 5(a) shows the residual supply index test results when the supply-side input, P_S, represents the physical bids submitted to the day-ahead market. The suppliers are ranked by their MW bid. The largest supplier (1st Pivotal) is put at the top of the total system capacity stack, followed by the 2nd, 3rd, and nth pivotal supplier. The demand-side inputs, P_D, are presented in three cases: market cleared MW, real-time forecast, and self-scheduled MW.

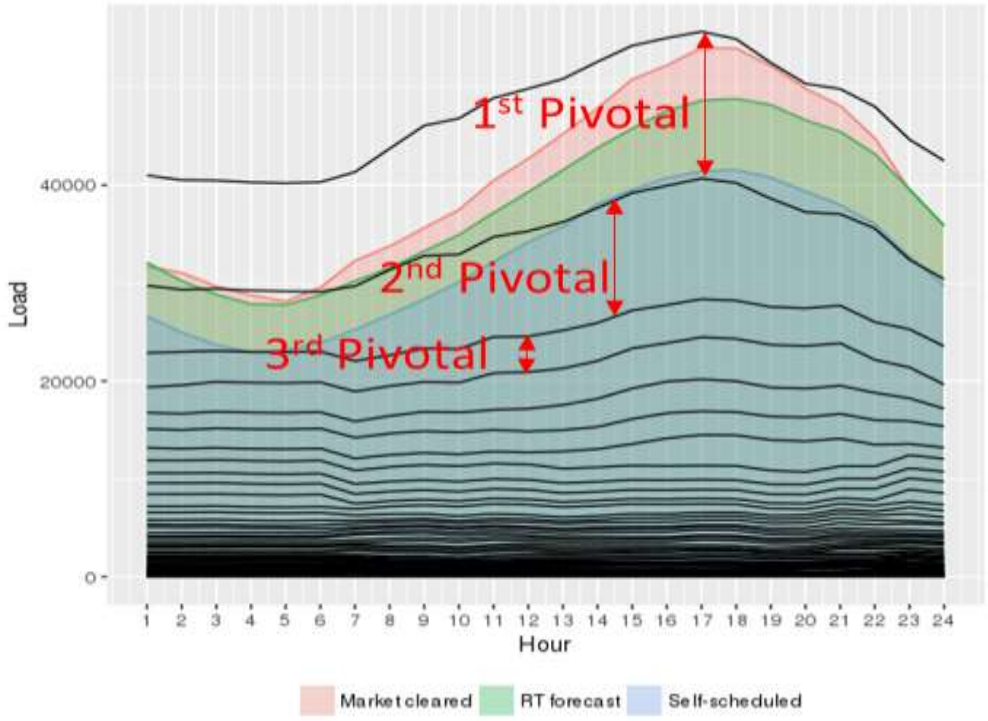
The RSI_n test can be visualized by removing the top n pivotal suppliers together. When the residual system capacity is less than demand, the removed pivotal suppliers are considered to have market power. For example, in the RSI_1 (single pivotal supplier) test, the residual capacity is less than the market clear MW and real-time forecast during most of the day, but is less than the self-scheduled MW during the peak hours. In contrast, in the RSI_3 (three pivotal suppliers) test, the residual capacity is less than all the demand inputs during the day.

Figure 5(b) illustrates the impact of excluding net buyers as potentially pivotal on the residual supply index test results. The inputs in ***Figure 5(b)*** are the same as in ***Figure 5(a)***, except that net buyers are excluded from the pivotal suppliers, P_i, tests. The net buyers' supply is still counted in the system capacity, P_S. The CAISO determines "net buyer" status quarterly based on participants' settlements.

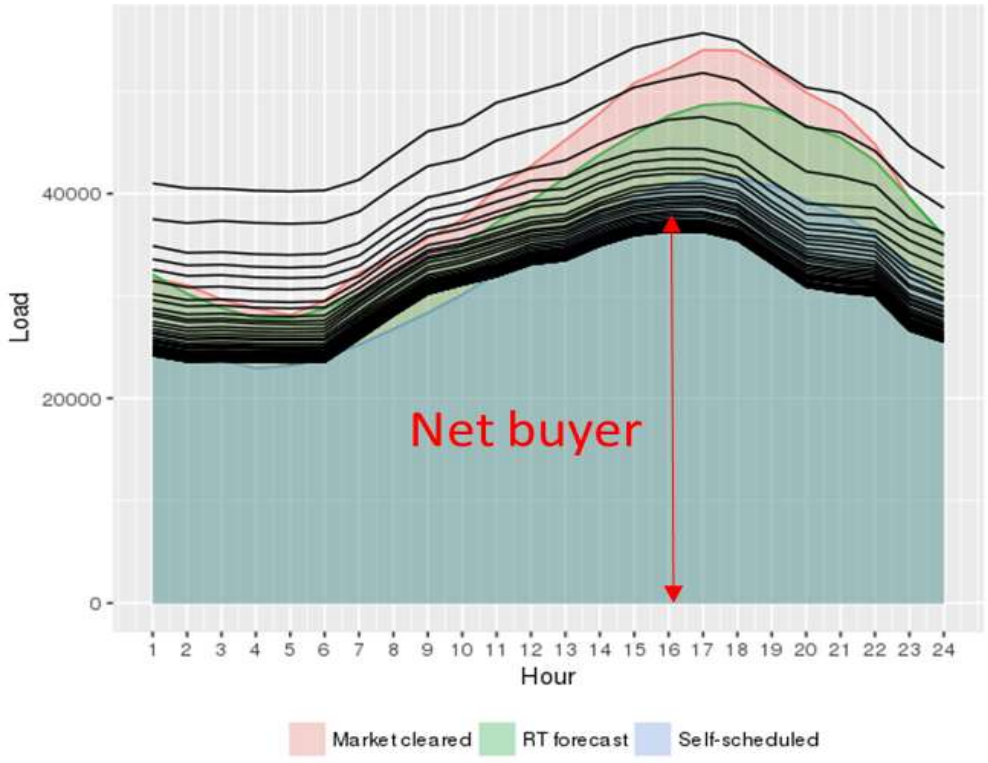
Figure 5(b) shows that the pivotal suppliers (i.e., the suppliers ranked on top) in ***Figure 5(a)*** are net buyers. The net buyers are aggregated and pushed down to the bottom of the system capacity stack. In RSI_1 test, the residual system capacity is less than market cleared MW only during the peak hours and greater than the real-time forecast and self-scheduled during the day. In RSI_3 test, the residual capacity is less than the market cleared MW and real-time forecast during the peak hours, but is always greater than self-scheduled MW.

Figure 5(c) illustrates the impact of virtual bids in detecting system-level uncompetitive conditions. The system capacity,P_S, in ***Figure 5(c)*** represents the physical and virtual bids submitted to the day-ahead market. Since virtual bids are not subject to mitigation, they are excluded from the pivotal suppliers' bids. Unlike the exclusion of net buyers, only the virtual bids' MW are aggregated and pushed down to the bottom of the system capacity stack, while the affiliate groups submitting virtual bids are still counted as pivotal suppliers, P_i, if they possess physical bids. ***Figure 5(c)*** shows the residual supply index will be much higher when using this methodology because virtual bids raise total system residual capacity.

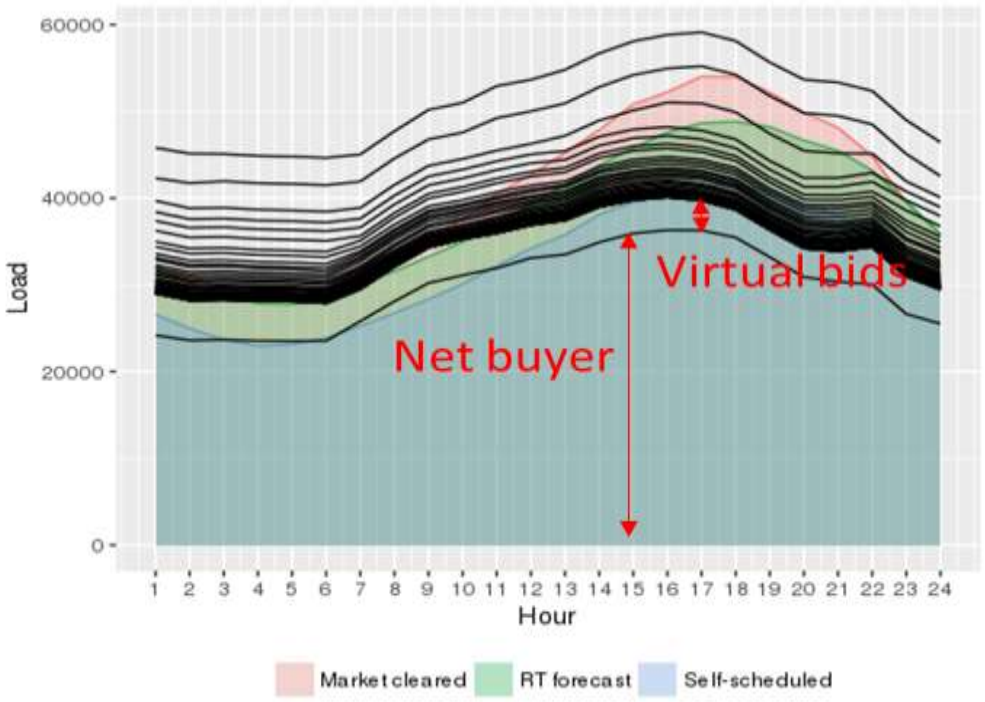
Figure 5: Inputs' impact on RSI calculation on July 24th, 2018



(a) Input physical bids. Pivotal suppliers include net buyers



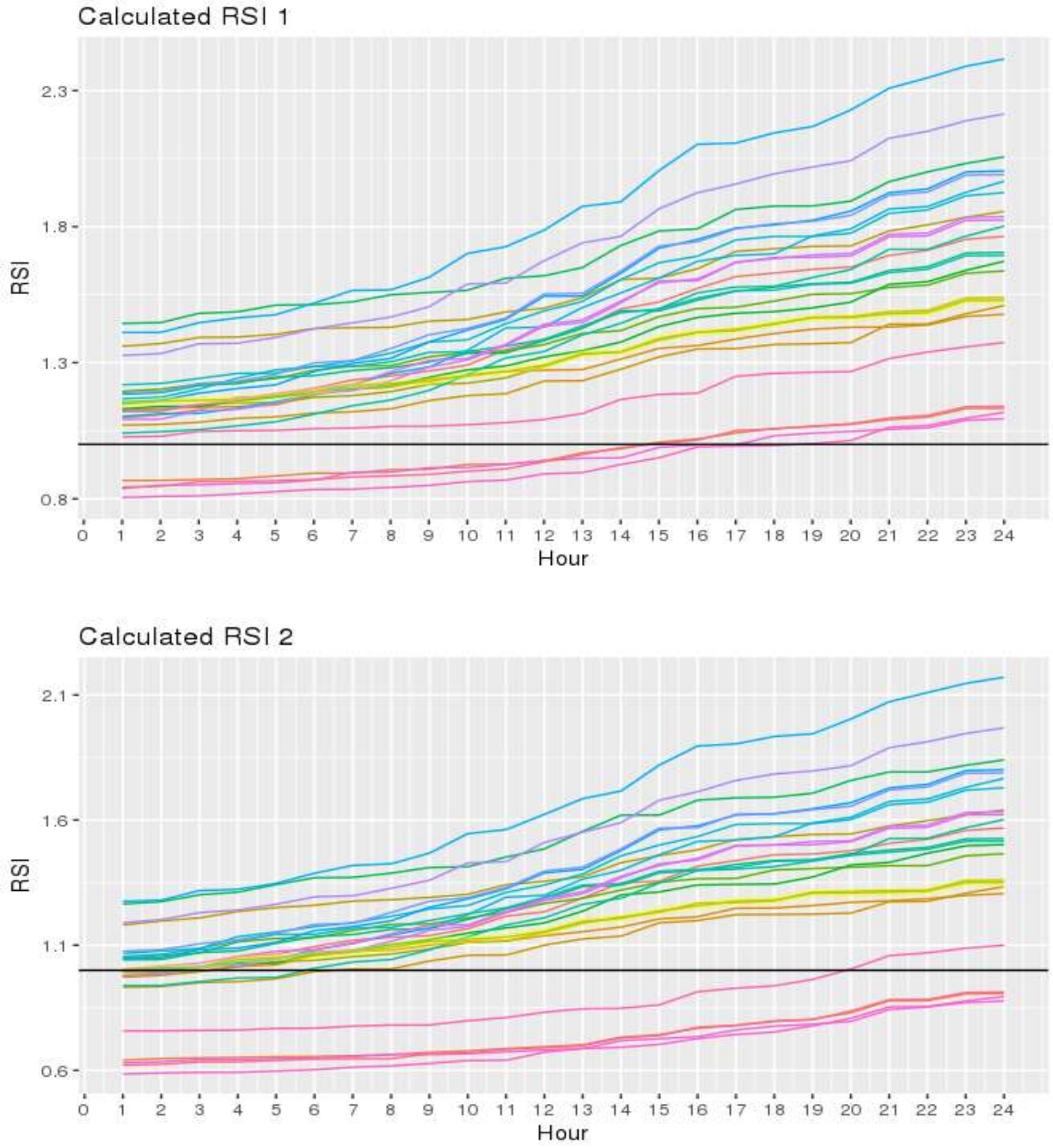
(b) *Input physical bids. Pivotal suppliers exclude net buyers*

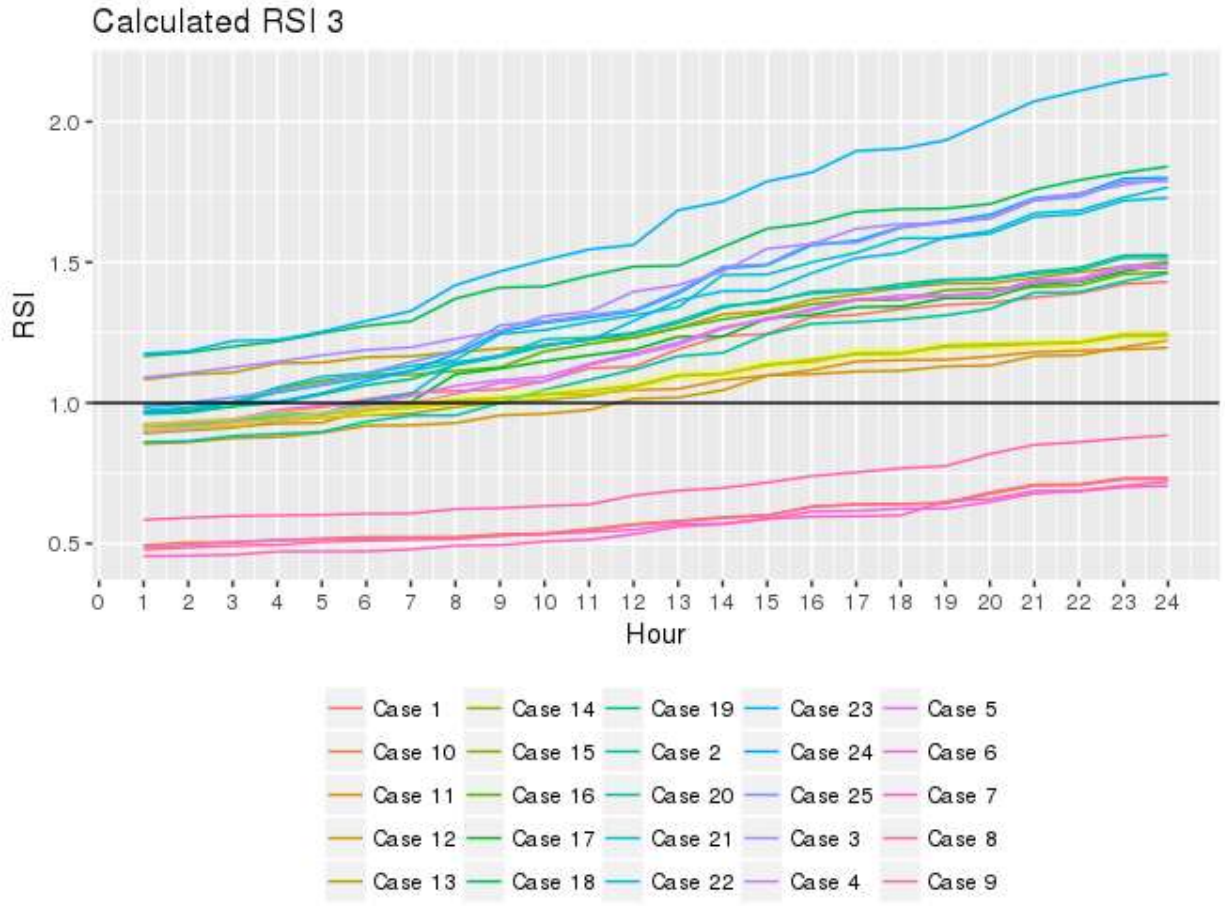


(c) Input physical bids plus virtual bids. Pivotal suppliers exclude net buyers.

Figure 6 shows the duration curve of July 24, 2018 that includes all 25 sensitivity analysis scenarios. On July 24, there are three scenarios where the RSI_1 fails (is less than 1) at least one hour of the day, nine scenarios where the RSI_2 fails, and over 15 scenarios where the RSI_3 fails. For reference, the case (***Case 14***) highlighted below in yellow represents the case the DMM calculated.

Figure 6: RSI tests for July 24th, 2018




Calculated RSI 3
RSI
2.0
1.5
1.0
0.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour
Case 1
Case 14
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Case 24
Case 6
Case 11
Case 16
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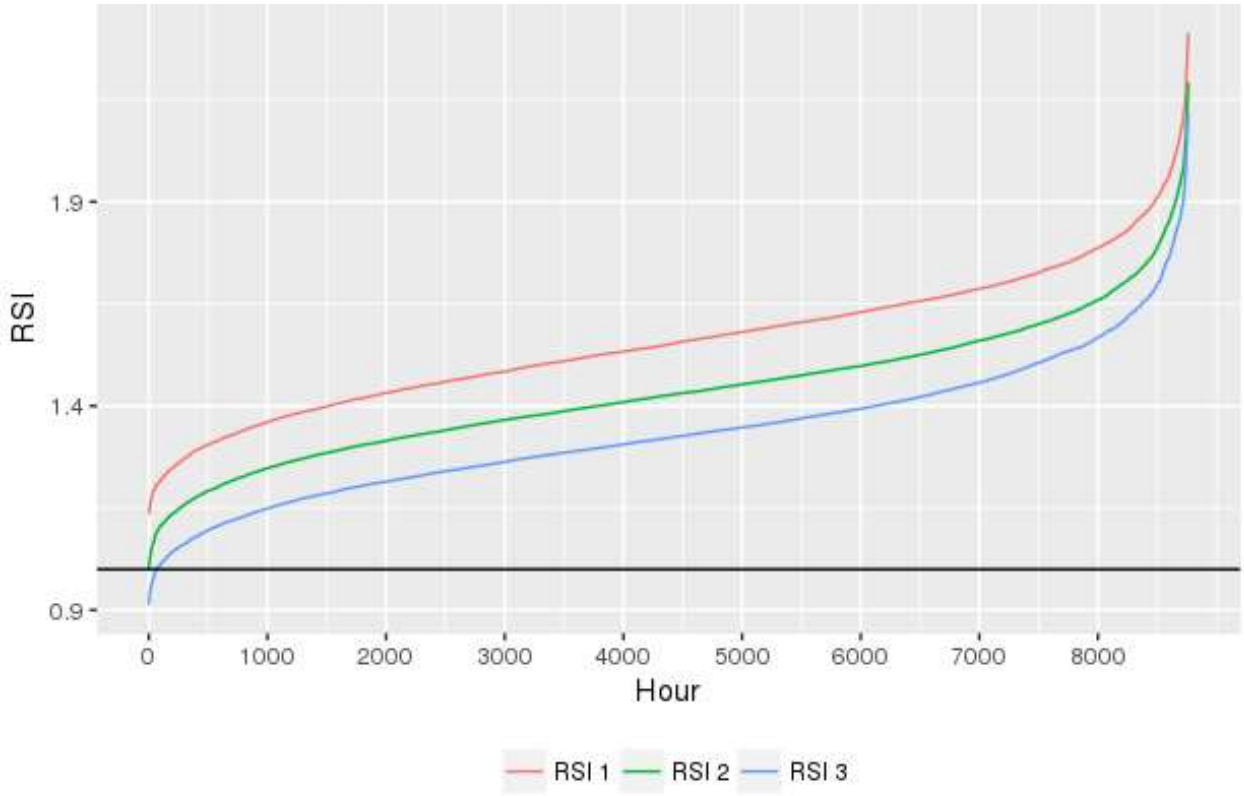
Case 25
Case 7
Case 12
Case 17
Case 21
Case 3
Case 8
Case 13
Case 18
Case 22
Case 4
Case 9

Analysis of the 2018 full calendar year

The CAISO calculated the residual supply index of all 25 sensitivity analysis scenarios for the 2018 calendar year. As an initial example, consider ***Case 24*** which represents supply as Input bids including virtual bids excluding net buyers as pivotal suppliers and represents demand as the DA forecast. The results show that the RSI_1 fell below 1 in zero hours in 2018, the RSI_2 fell below 1 in six hours in 2018, and the RSI_3 fell below 1 in 23 hours in 2018. Below, ***Figure 7*** presents the duration curves for **Case 24**.

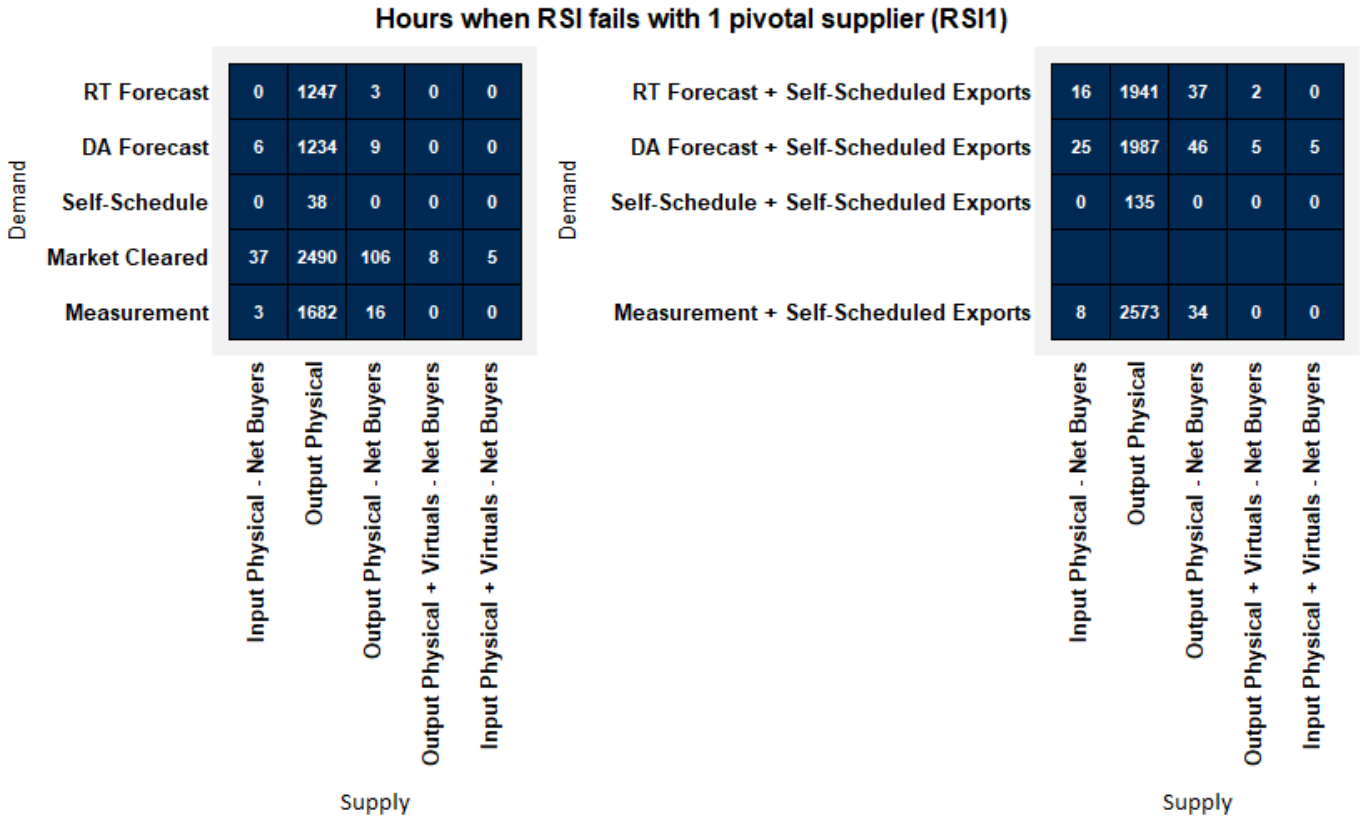
Figure 7: Case 24: RSI test for 2018 calendar year



Below, *Error! Reference source not found.* summarizes the hours in which the residual supply index test failed for each of 45 sensitivity analysis scenarios. Each residual supply index test has two matrices: the matrix on the left contains different scenarios for consideration of the demand as indicated and the matrix on the right has the same scenarios for demand, but with the self-scheduled exports included as demand in the calculation.[7] In the matrix on the right, self-scheduled exports are added to the demand to consider the case in which the market has to clear both internal demand and self-schedule exports. This case occurs because self-scheduled exports are treated with a higher priority than economic bids, such that they generally will clear the day-ahead market.

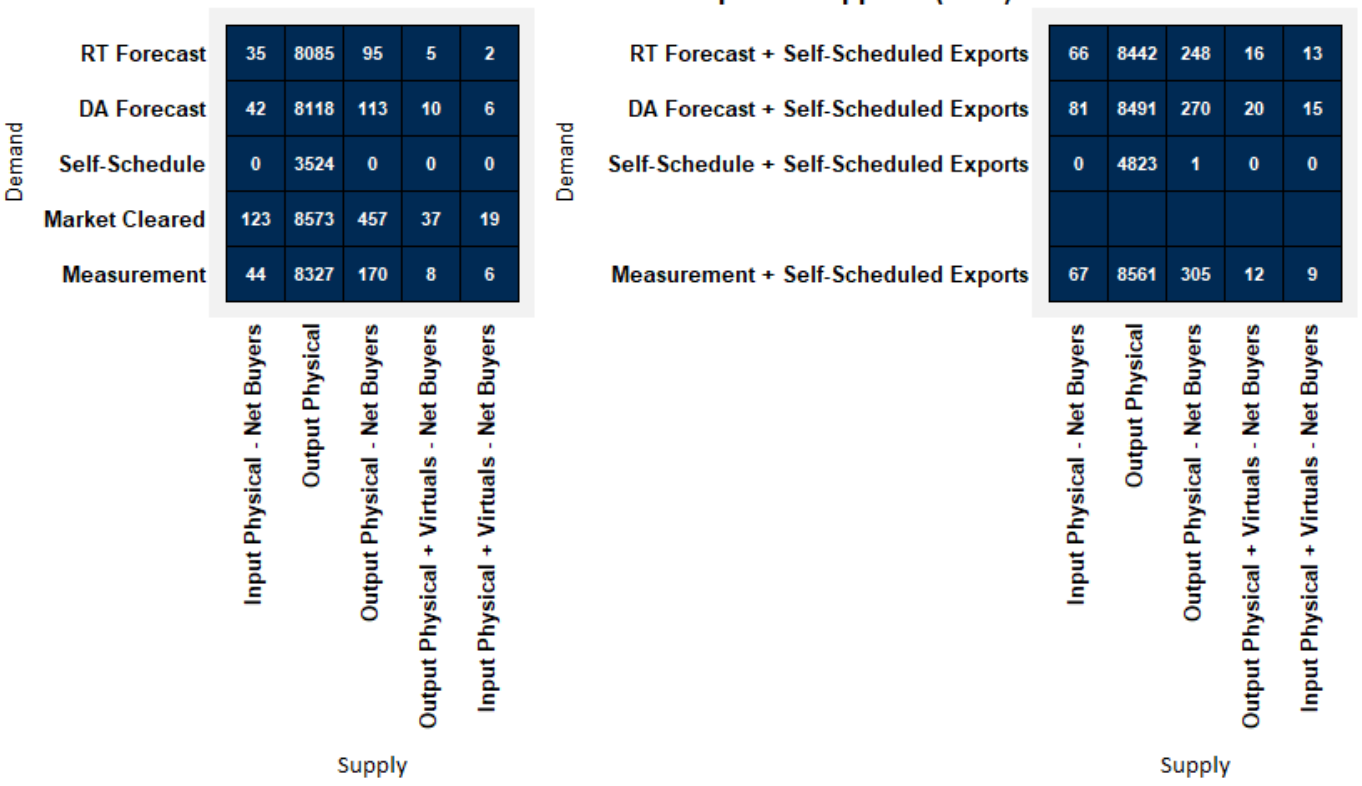
The figures below have results of three joint pivotal supplier tests (RSI1, RSI2, and RSI3) to show if the energy market exhibited uncompetitive conditions by assuming the largest supplier, the two largest suppliers, or the three largest suppliers withheld production. By comparing results among the different RSIs, one can observe how susceptible the energy market was to one, two or three market participants affecting price by withholding production.

Figure 8: *Hours with System Market Power in 2018.*

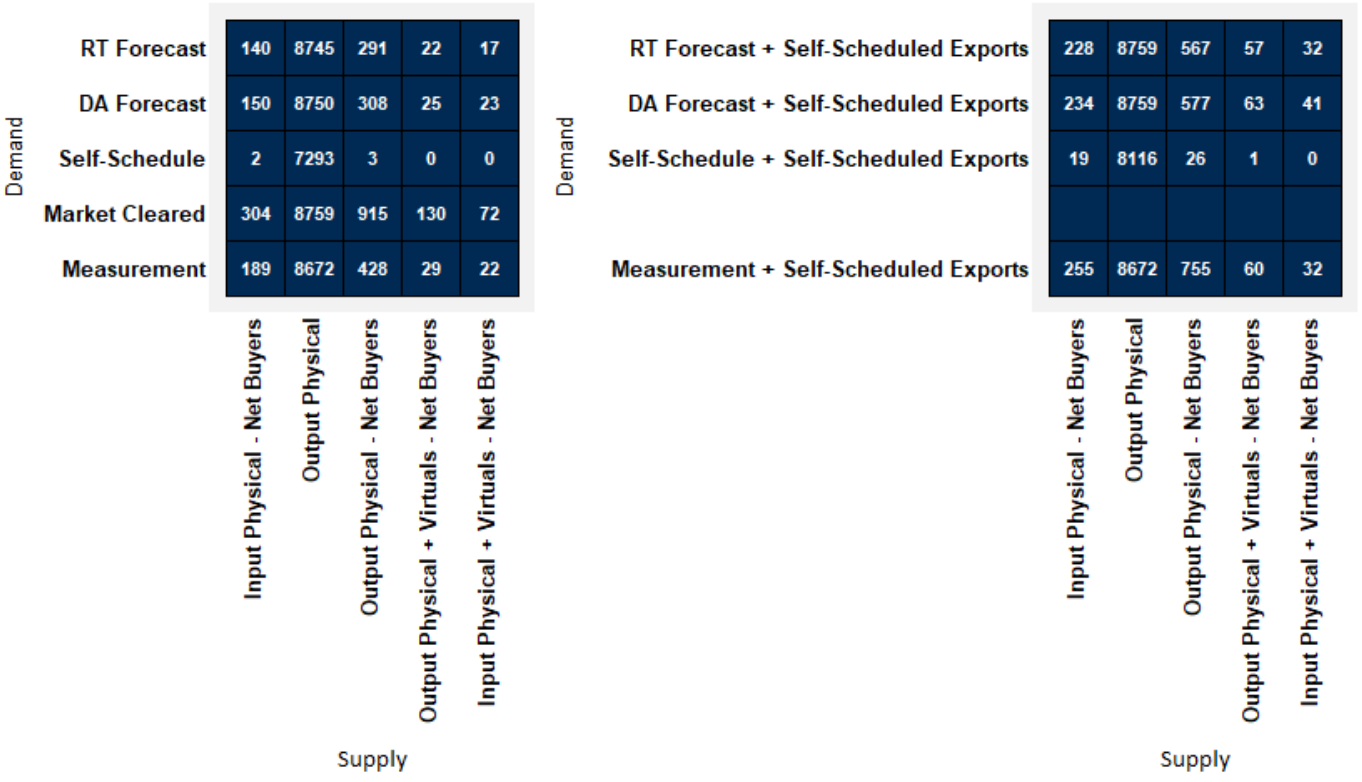


[7] The self-schedule exports are not added to the scenario in which the demand is considered to be the cleared IFM demand because that scenario already includes all the exports cleared, including those with self-schedules.

Hours when RSI fails with 2 pivotal suppliers (RSI2)



Hours when RSI fails with 3 pivotal suppliers (RSI3)



The matrices above outline a wide range of residual supply index outcomes based on the different sensitivity analysis scenarios constructed. The residual supply index test failed the greatest number of hours when the supply input is based on "output physical" bids, as this represents the lowest volume of apparent supply in the scenarios. As noted above in the *Other supply* assumptions section, the scenarios considering "output physical" bids as available supply may not be the best representation of actual supply available to the market.

As more factors are included in the supply input (such as not testing the net buyers or including virtual supply), the residual supply index test will fail less frequently. In terms of supply inputs:

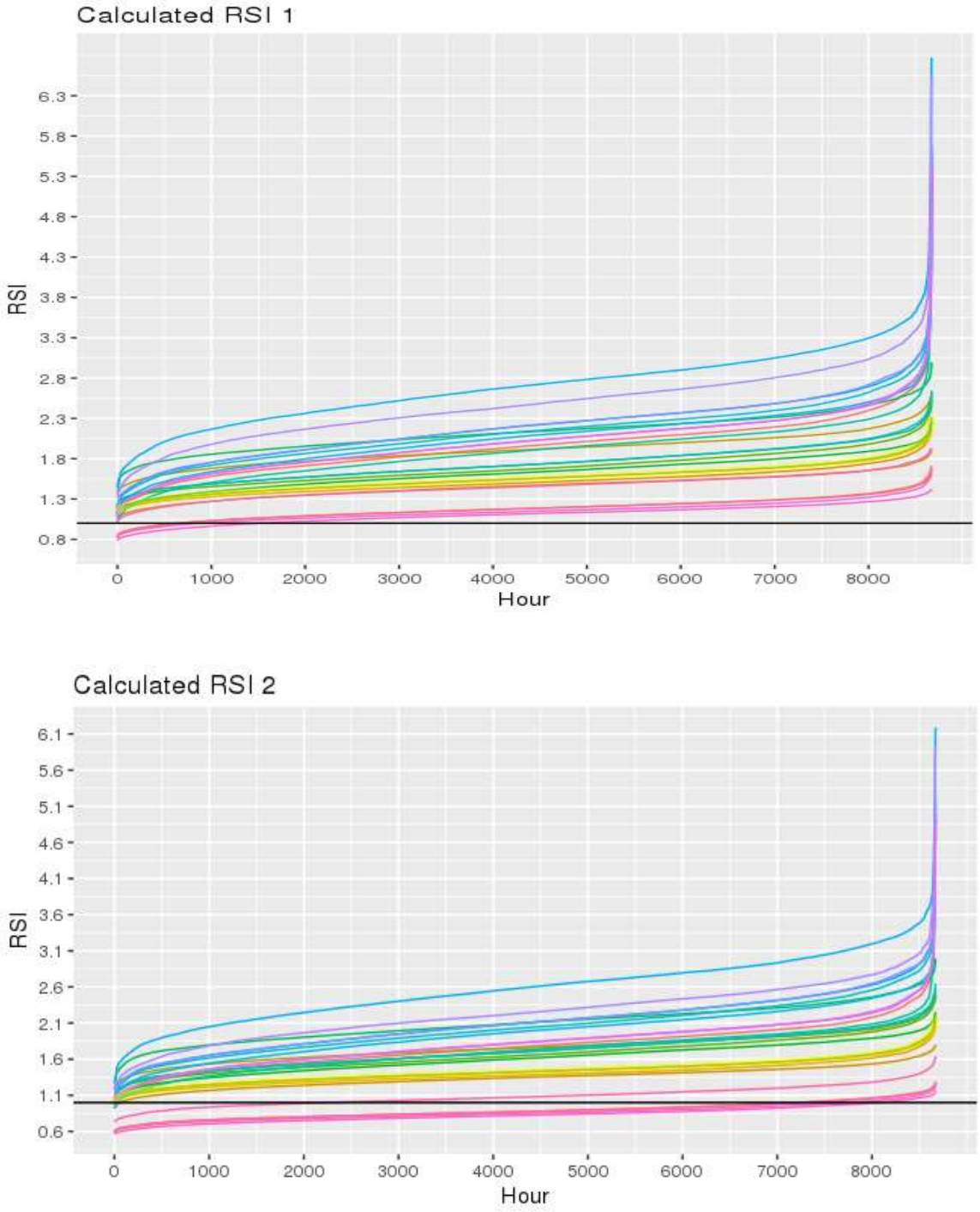
- Excluding net buyers from pivotal suppliers reduces the number of times when the residual supply index tests fail. Specifically, a supply input using "output physical-net buyers" shows fewer hours of $RSI_n < 1$ than using *output physical* alone.

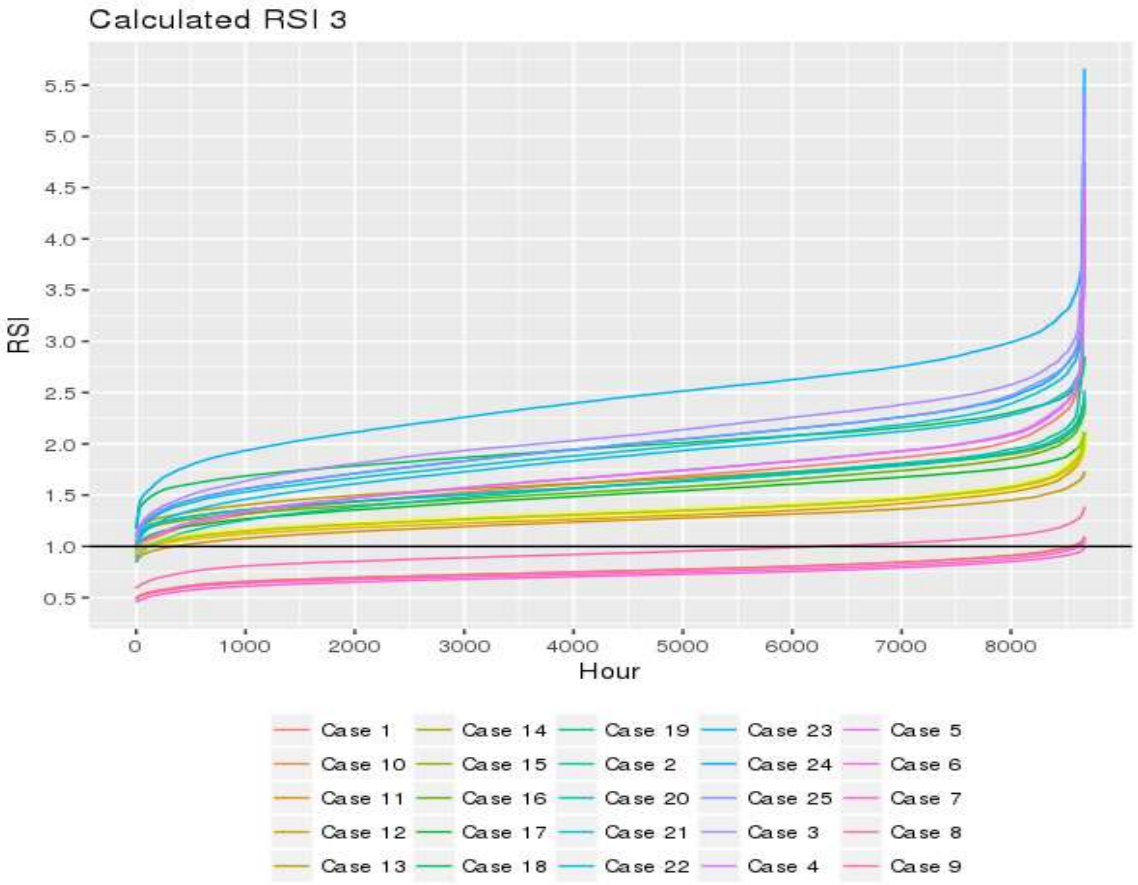
- Virtual bids add system capacity and reduce the number of failing hours in the residual supply index tests. Specifically, the supply input using "output physical + virtual -net buyers" shows fewer hours of $RSI_n < 1$ than using *output physical – net buyers* as an input.

- Using bids submitted to the day-ahead market (*input bids*) instead of bids from generators committed in the day-ahead market (*output bids*) reduces the number of hours that fail the residual supply index test. Specifically, the supply input using "input physical-net buyers" shows fewer hours of $RSI_n < 1$ than using *output physical – net buyers* as inputs.

On the demand side, residual supply index tests fail the greatest number of hours when using *Market Cleared* MWs and failed the least number of hours using *Self-Scheduled* MW. This is because *Market Cleared* MW considers virtual demand bids, while the other demand inputs do not, and *Self-Schedule* MW represents the least amount of demand the market must meet. These outcomes follow a simple logic: RSI test will fail less frequently when the test accounts for higher supply and lower demand. Below, ***Figure 9*** shows the RSI test results for 2018 using a duration curve for each of the first 25 scenarios. As shown, there is a large spectrum of outcomes depending on the assumptions made in each of the 25 scenarios.

Figure 9: Results of RSI Test in 2018.





Most representative reflection of system-level market power conditions

Among all of the scenarios presented, the most representative scenario that reflects structural competitive conditions and may be indicative of system-level market power is the one in which the total supply considers all day-ahead offers from physical resources and virtual resources not limited by commitment or ramping constraints. The total demand considers the sum of the day-ahead demand forecast, upward ancillary services requirements, and self-scheduled exports.

The supply assumption in this scenario is reasonable for at least three reasons. First, it is reasonable to use day-ahead offers because the total amount of supply available to meet real-time demand is ultimately dependent on the amount of supply offered and committed in the day-ahead market.

Second, it is reasonable to not limit the available supply offers due to commitment or ramping constraints determined by the day-ahead market solution because the CAISO uses all supply offered into the day-ahead market to make the ultimate feasible commitment and dispatch decision. The day-ahead market allows for different resource commitment configurations to meet bid-in demand at lowest cost, optimizes all 24 hours of the day, and is executed well in advance of the actual trade date. The CAISO considers all supply offers in its estimation of supply because under different market conditions the day-ahead market solution may commit and dispatch resources differently to the original solution.

Third, the day-ahead offers are preferred over real-time offers because real-time supply offer availability is dependent on commitment and dispatch decisions occurring throughout the day as well as unit-specific ramping constraints. It would be complicated to meaningfully evaluate real-time market offers because the optimization timeframe, the commitment options, and the dispatch options are dependent on prior market decisions and much less flexible. Even if suppliers offer plenty of supply to the real-time market, these offers may not be readily available for the real-time market to use because of market timing or prior economic commitment and dispatch decisions. While it would be very difficult to truly untangle these dependencies from real-time market supply offers to evaluate for system-level uncompetitive conditions, the CAISO believes it is more practical to consider suppliers' day-ahead offers.

The demand assumption in this scenario is reasonable because it is the best representation of the demand conditions leading to the supply offered to the day-ahead market.

This scenario excludes net buyers from the pivotal test because net buyers do not have an incentive to raise energy prices by exercising market power.

The CAISO understands that these supply and demand assumptions may not fully capture overarching system-level uncompetitive conditions, so it also provided analysis results with varying inputs to show the sensitivity of the results to the various input assumptions.

As discussed below in the *Further refinement to select scenarios* section, the CAISO enhanced this scenario to account for transmission losses.

Further refinement to select scenarios

The CAISO re-calculated the residual supply index for two scenarios after adding transmission losses to the total demand in the reference case mentioned above to observe the variation of results.[8] ***Table 3*** summarizes the number of hours that fail each residual supply index test. The inclusion of transmission losses into the demand resulted in a modestly higher number of hours that fail the residual supply index test.

Table 3: Comparison of RSI results by including transmission losses in the demand

Demand	Supply	RSI1	RSI2	RSI3
Demand+SS Export	Output bid	5	20	63
Demand+SS Export+Losses	Output bid	8	31	98
Demand+ SS Export	Input bid	5	15	41
Demand+SS Export+ Losses	Input bid	6	20	55

The CAISO's analysis found that the RSI indicated system-level uncompetitive conditions in 55 hours in 2018 using supply and demand assumptions that the CAISO believes most accurately reflect supply and demand conditions in the day-ahead market. This scenario assumed that aggregate demand consists of the day-ahead energy forecast, upward ancillary service requirements, self-scheduled exports, and transmission losses. It also assumed that aggregate supply consists of all available energy bids from

[8] At a recent Market Surveillance Committee meeting, the Market Surveillance Committee noted that transmission losses may be another important factor to consider.

physical resources, virtual resources, and non-wheeled import supply. The CAISO's result differs from the DMM's result because the CAISO's scenario evaluates all energy offers available to the day-ahead market, while the DMM only evaluated ramp- and commitment-limited energy offers (both of which are dependent on the market clearing rather than inputs into the market). The CAISO believes it is appropriate to include all energy offers because the day-ahead market uses all energy offers to contribute toward meeting demand, losses, and ancillary services requirements.

Similar to the way the CAISO varied the supply and demand assumptions, it also varied the number of "pivotal suppliers" used in calculating the RSI. The RSI calculations test structural competiveness by removing a certain number of the largest, or "pivotal suppliers." The CAISO found that the RSI generally indicates the CAISO market is structurally competitive much more often when the RSI is calculated after removing only one or two pivotal suppliers, rather than three. The CAISO's automated local market power mitigation test calculates RSI removing three pivotal suppliers. Out of the 55 hours tested in the scenario described above, the RSI indicated only 20 hours were structurally uncompetitive if only two pivotal suppliers were removed.