Flexible Ramping Product Performance

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Content

1 Executive Summary

This report supplements the FRP pricing performance analysis presented by the CAISO in the Market Surveillance Committee (MSC) meeting on February 11, 2021.[1] Historically, Flexible Ramping Product (FRP) prices have been predominantly *de minimums* and mostly at zero levels for most of the CAISO market footprint. This report presents analysis of market outcomes for July 9, 2021, when FRP exhibited zero prices even though the CAISO system faced tight supply conditions. This report also details the current FRP formulation, which is foundational for understanding the analysis.

There are three main factors driving the FRP pricing outcomes in the in the real-time market.

1. **FRP requirements are generally reduced by import capability.** The current framework assumes the total l import capability of WEIM areas can be available to meet each WEIM area's specific FRP requirements. Since the import capability is usually greater than the total uncertainty requirement, the effective requirement for individual areas will typically be zero. With zero requirements to meet for the individual areas, prices will tend to be zero. This will result in the system-wide area requirements being the main driver for FRP procurement. The framework of upcoming enhancement for nodal procurement in fall 2022 will no longer consider the import capability in the determination of the FRP requirements.

2. **Congestion continues to limit the performance of FRP.** FRP continues to be procured from resources that are behind a congested area. Congestion may result in the market assuming the resource is not available for energy and therefore does not dispatch the resource, or dispatches, creating the impression that the capacity is available for FRP. However, because there is congestion, the FRP cannot be deployed subsequently for energy. Being able to procure FRP from such stranded capacity means the requirement will be typically met, which in turn will tend to clear at zero prices. CAISO has developed a solution to address this issue by using a new formulation for nodal procurement. This is scheduled for implementation in fall 2022.

3. **FRP pricing is based on opportunity costs to procure FRP and energy.** FRP pricing is based on opportunity costs, which in a given interval reflects the tradeoff between the need for energy versus reserving capacity for ramping capability. Unlike other market products with explicit bids, the FRP price will be nonzero only when such opportunity costs between energy and FRP exist. CAISO's formulation utilizes demand curves to price the amount of relaxation of the FRP requirements, which will set the clearing price. The two factors described above create conditions for no opportunity costs and, therefore, there the FRP price is zero, i.e., there are no nonzero prices to be reflected.

[1] Presentation available at http://www.caiso.com/Documents/FlexibleRampProduct-Presentation-Feb11_2022.pdf

2 List of Tables

3 List of Figures

4 Acronyms

AZPS	Arizona Public Service
BAA	Balancing Authority Area
BANC	Balancing Authority of Northern California
CAISO	California Independent System Operator
CS	California West
DSW	Desert Southwest
FMM	Fifteen Minute Market
FRP	Flexible Ramping Product
HASP	Hour Ahead Scheduling Process
HE	Hour Ending
IPCO	Idaho Power Company
LADWP	Los Angeles Department of Water and Power
LES	Limited Energy Resources
LMP	Locational Marginal Price
MNW	Mountain Northwest
NEC	Net Export Capability
NEVP	NV Energy
NIC	Net Import Capability
NOB	Nevada-Oregon Border
NWMT	Northwestern Energy
PACE	PacifiCorp East
PACW	PacifiCorp West
PDR	Proxy Demand Response
PGE	Portland General Electric
PNM	Public Service Company of New Mexico
PNW	Pacific Northwest
PSEI	Puget Sound Energy
RTM	Real-Time Market
SCL	Seattle City Light
SMEC	System Marginal Energy Component
SRP	Salt River Project
TIDC	Turlock Irrigation District
VER	Variable Energy Resources
WEIM	Western Energy Imbalance Market

5 Background

On November 1, 2016, CAISO introduced the Flexible Ramping Product (FRP) to the real-time market (RTM) operation. This product was introduced to help manage uncertainty from load, wind and solar production. Similar to other products, there is an FRP requirement enforced in the market in order to procure flexible capability from resources in the system. The FRP secures flexible capability that can be dispatched in subsequent market runs to cover realized uncertainty. This product is in place for both CAISO and all balancing authority areas (BAA) participating western energy imbalance market (WEIM). There are no explicit FRP bids submitted by resources. The current market does not consider locational constraints when procuring the FRP. Procurement of the FRP is based on opportunity costs, which arise from the tradeoffs between the needs for energy and reserving ramping capability.

FRP is formulated taking into account the WEIM framework, which relies on diversity and leverages on the transfer capability among areas. Under this construct, FRP requirements in one area can be met by either internal resources or from other areas' capability through transfers. Each WEIM area, including CAISO, has its own FRP requirement and additionally there is an overall requirement for the system-wide WEIM area.

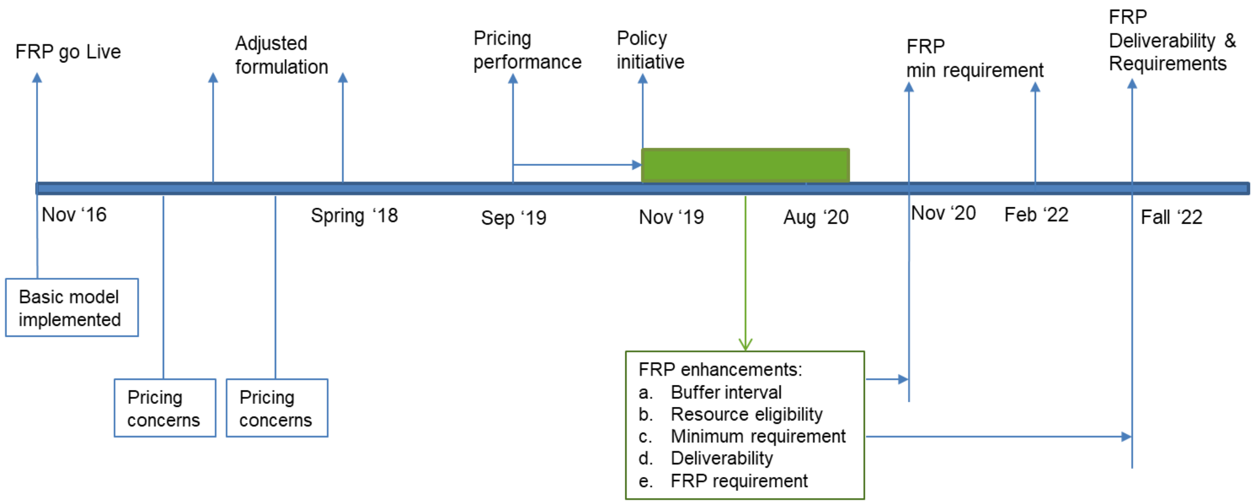
In 2019, CAISO performed a comprehensive assessment of pricing at the CAISO's markets and identified several issues impacting the FRP performance[2], including the award of FRP to proxy demand response (PDR) resources that could not deploy the capacity, the need for a minimum FRP requirement for areas with a significant share of the overall requirements, and persistent non-deliverability of FRP due to congestion. CAISO undertook a policy initiative to address these issues[3] . CAISO implemented the first phase of this project in November 2020 and plans to implement the second phase in the fall of 2022. This second phase addresses the deliverability of FRP by using a formulation for nodal procurement, and also enhances the calculation of the FRP uncertainty requirements.

Figure 1 illustrates the evolution and AISO efforts to assess and enhance the performance of the FRP since its implementation in 2016. The subsequent sections describe in details the different efforts.

[2] CAISO's analysis report can be found at
http://www.caiso.com/Documents/SummerMarketPerformanceReportforJuly2021.pdf

[3] All the material of the Policy initiative for FRP issues can be found at
https://stakeholdercenter.caiso.com/StakeholderInitiatives/Flexible-ramping-product-refinements

Figure 1: Evolution of the flexible ramping product



6 Mathematical Formulation

On November 1, 2016, CAISO implemented the FRP functionality for the real-time market, in both the FMM and RTD markets. This functionality consists of minimum requirements for FRP procurement at the individual and system-wide areas. This section describes the original formulation, changes implemented afterwards and the current functionality. This will help understand the drivers for the observed market price trends.

6.1 Initial formulation

The FRP formulation is based on a constraint to meet the FRP requirement for each individual area[4]. This is expressed as an inequality constraint that ensures that at least the FRP requirement is met and allows the market to procure more than the requirement if the capacity is available.

$$\sum_{i \in BAA_j} FRU_{i,t} + S_{j,t} \geq FRUR_{j,t} - NIC_{j,t} \tag{1}$$

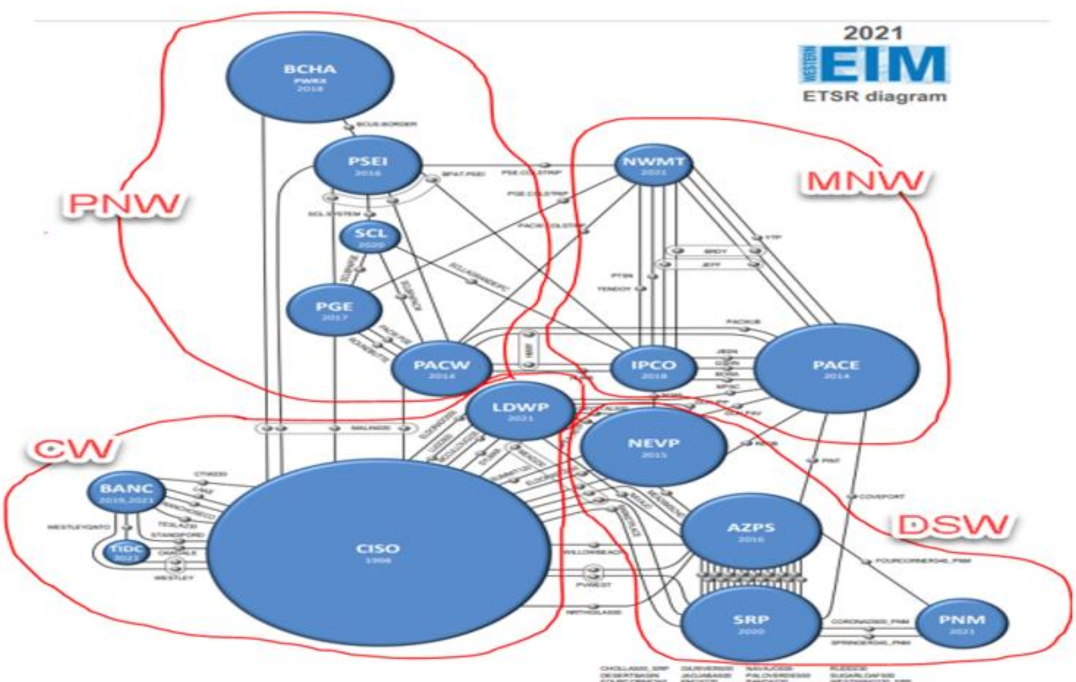
The left hand side of the equation defines the procurement where *i* stands for the index of resources within the WEIM area *j* and *t* is the time interval. The term $FRU_{i,t}$ is the FRP procured from the *i-th*

[4] The description in this paper is simplified to highlight the main concepts and ease the understanding of the core elements. The description is limited to describe only the upward FRP and only for cases where there were no failure of flexibility requirements tests imposed on WEIM balancing authority areas. If a test failure exists, the requirements for the constraints are slightly different to reflect the failure. Analogous expressions apply to the downward FRP and the constraints are also very similar for conditions under test failures. Since the focus is on understanding the price formation, this limited scope will properly capture the elements at play.

resource; thus the summation over all resources *i* defines the total FRP procured by all resources in area *j*. The term $S_{j,t}$ represents a slack variable for WEIM area *j* for interval t to allow the requirement constraint to be violated (relaxed). The value this slack variable will take depends on two factors i) there is actual capacity available in area *j* but also ii) at what prices that capacity can be procured. The procurement of the FRP capacity is price-sensitive and driven by demand curves, which reflect the value of procuring FRP at different prices. This is analogous to a bid-in demand curve for energy. The higher the price, the less FRP will be procured. The maximum price define for the demand curve is at $247/MWh. It means that if the FRP price is equal or greater than the $247/MWh, the market may not procure any FRP capacity even when the capability is available. This slack variable is a classic optimization concept; in the context of the FRP framework, this is referred as surplus variable and its value is determined as part of the overall market optimization.

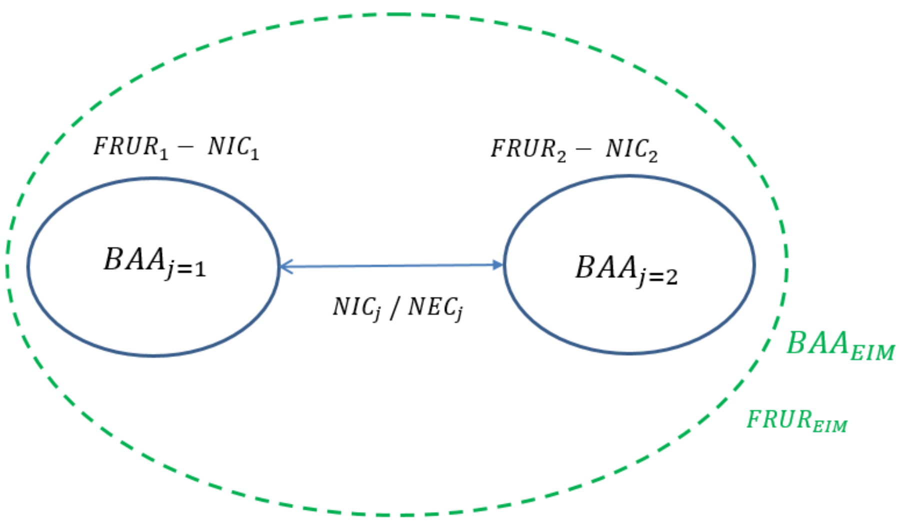
The right-hand side of the constraint stands for the FRP requirements. The term $FRUR_{j,t}$ represents the uncertainty requirement for area *j* in interval t. This is estimated using the histogram calculation that relies on historical net load errors in the real-time market. The term $NIC_{j,t}$ is the net import capability (NIC) for area *j* in interval t. Within the WEIM framework, an individual area will generally be interconnected with other adjacent areas through different interfaces, which will enable transfers among areas. The transfer capability for one area directly depends on the individual transfer capability with each other area directly connected to. Under this construct, the formulation utilizes the concepts of NIC and net export capability (NEC). Figure 2 illustrates the WEIM areas and the transfers among them. The bubbles in red reflect typical sub-regions created by price separations when there are limited transfer capabilities.

Figure 2: Regional separation of WEIM areas



The NIC/NEC concept relies on the premise that a given WEIM area will have certain transfer capability that can be leveraged for imports and exports. This capability considers the nominal transfer capacity made available by each WEIM entity but also on the amount of import or export transfers cleared in the market. With the formulation of the FRP, the NIC is effectively considered in the determination of the final requirement an area needs to procure locally. This is illustrated in Figure 3. There are two individual WEIM areas with an interface that allows transfers between them. The two areas together define the system-wide area. The requirement of each individual area will take into account its net import capability. This concept practically considers that FRP procurement can be done locally but, as part of the wider WEIM area, it can be also met with transfers as long as there is import capability to bring that capacity into the area. Therefore, the effective requirement that needs to be met locally is the uncertainty requirement reduced by the NIC.

Figure 3: Configuration of individual WEIM areas and system-wide area



Additionally, there is one more FRP constraint to enforce a minimum requirement at the system-wide WEIM area. That is, regardless of how each individual WEIM are meets its requirement, this constraint ensure that a minimum requirement is met at the system level. The first term is analogous to the individual area and reflects the contribution to the FRP procurement from all resources from all WEIM areas. The second term reflects the contribution of any surplus variable from the individual WEIM areas. When an individual area relies on the surplus variable ($S_{j,t} > 0$) to meet its local requirements the surplus capacity is carried over for accounting in the system-wide area. This effectively reduces the WEIM area requirements by the amount of relaxation already taking place from individual areas. If an area relaxed the requirement, that capacity cannot be produced locally and, thus, will not be fulfilled from other areas for the system-wide area.

$$\sum_{i \in EIM} FRU_{i,t} + \sum_{j \in EIM} S_{j,t} + S_{EIM,t} \geq FRUR_{EIM,t} \qquad (2)$$

Similar to the individual areas, the term $S_{EIM,t}$ is the surplus variable associated with the system-wide WEIM area at interval t, which can take a value to reflect any relaxation of the WEIM area requirement. The right-hand side of the constraint is composed only of the uncertainty requirement for the WEIM area, $FRUR_{EIM,t}$ There is no NIC component at the WEIM area since this is only a concept when transfers exist for the area of interest relative to other areas.

6.2 Enhancements to initial formulation

After the implementation of the FRP model and as part of standard validation and analysis of market performance, CAISO assessed FRP performance and identified some unintended pricing outcomes. In the original formulation, the total FRP procurement from either local area could take on any value since they were not bounded which could result in local procurements in excess of what was actually deliverable. For this reason, an upper bound was imposed on the local area FRP procurements

$$\sum_{i \in BAA_j} FRU_{i,t} + S_{j,t} \leq FRUR_{j,t} + NEC_{j,t} \ \ \forall\, j \tag{3}$$

Another issue identified through the market performance after implementation was that the surplus variables for FRP had no upper bounds. This resulted in outcomes in which the optimizations took the most economic surplus variable based on the local area demand curve and set the price; this resulted in local areas relaxing excessively to meet the overall requirement and preventing the demand curve for the WEIM area to set the price. CAISO implemented an upper bound constraint on the surplus variables, such that it could be relaxed only up to the amount needed to meet the local requirement,

$$0 \leq S_{j,t} \leq \max\left(0, FRUR_{j,t} - NIC_{j,t}\right) \ \ \forall\, j \tag{4}$$

This upper bound allowed the WEIM surplus variable to take on a value when the overall WEIM requirement could not be met. However, it resulted also in a price formation in which the local area observed negative prices which were offset with a positive price of the WEIM area.

6.3 Current formulation

In April 2018, CAISO improved the FRP formulation to address this price formation concern by using upper bounds that could effectively set the surplus variables as active or not such that they could contribute to the price formation only under specific conditions. The upper bound on the surplus variables defined by Equation (4) was replaced by the following integer-based constraints

$$If\ FRUR_{j,t} - NIC_{j,t} - \sum_{i \in BAA_j} FRU_{i,t} \leq 0 \rightarrow \gamma_{j,t} = 0 \tag{4a}$$

$$If\ FRUR_{j,t} - NIC_{j,t} - \sum_{i \in BAA_j} FRU_{i,t} > 0 \rightarrow \gamma_{j,t} = 1 \tag{4b}$$

When the local area is able to meet its local requirement with its internal resources, there is no need to utilize the surplus variables and thus Equation *4a* makes the surplus variable not active. Otherwise, when the local area cannot meet its local requirements with local FRP capacity, the surplus variable is active as defined with Equation *4b*. These conditions are binary in nature and, therefore, it requires a binary variable $\gamma_{j,t}$ in the mathematical formulation. Equations *4a* and *4b* only define when the surplus variables are active or not but they do not defined the upper bound. These equations need to be complemented with an upper bound imposed on the surplus variables,

$$S_{j,t} \leq FRUR_{j,t} - NIC_{j,t} - \sum_{i \in BAA_j} FRU_{i,t} \tag{5}$$

Equation 5 limits the value on the surplus variable up to the amount needed to meet the local requirement that physical FRP could not satisfy. It prevents the surplus variable to take on a value in excess to satisfy requirements in the WEIM area, which in turn could displace capacity for meeting the WEIM area requirements.

With the binary variables to define if the surplus variables are active or not, the original requirements defined with Equations 1 and 2 can be revised accordingly

$$\sum_{i \in BAA_j} FRU_{i,t} + \gamma_{j,t} S_{j,t} \geq FRUR_{j,t} - NIC_{j,t} \tag{1'}$$

$$\sum_{i \in EIM} FRU_{i,t} + \sum_{j \in EIM} \gamma_{j,t} S_{j,t} + S_{EIM,t} \geq FRUR_{EIM,t} \tag{2'}$$

Through the subsequent market performance of CAISO's pricing, CAISO identified other areas of concerns about FRP performance. One of these areas resulted in an enhancement to enforce a minimum FRP requirement for CAISO area[5]. In the current WEIM footprint the CAISO is the primary driver of the system-wide WEIM requirements because it has the largest share of load and variable energy resources, which leads to the largest share of net load uncertainty. With the consideration of the NIC/NEC, the CAISO FRP requirement that needs to be procured from internal resources is effectively zero. A minimum FRP requirement was introduced in November 2020 for CAISO area since the CAISO has such a large share of the requirement. This ensures that a portion of the FRP requirement is procured within CAISO in order to be available for uncertainty that materializes in the CAISO's area.

$$\sum_{i \in BAA_j} FRU_{i,t} + S_{j,t} \geq DF * FRUR_{j,t} \quad where\ j = CAISO \tag{6}$$

Where *DF* is the diversity factor defined based on the share of the CAISO requirements relative to the overall WEIM requirement. The minimum requirement constraint is enforced when CAISO's share is greater than 60 percent of the overall WEIM area requirement. This constraint was originally activated for the FMM market on November 2020; after further assessment this constraint was also enforced in the real-time dispatch market starting on February 16, 2021[6].

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[5] The minimum FRP requirement was part of the FRP enhancements. Documentation is available at https://stakeholdercenter.caiso.com/StakeholderInitiatives/Flexible-ramping-product-refinements

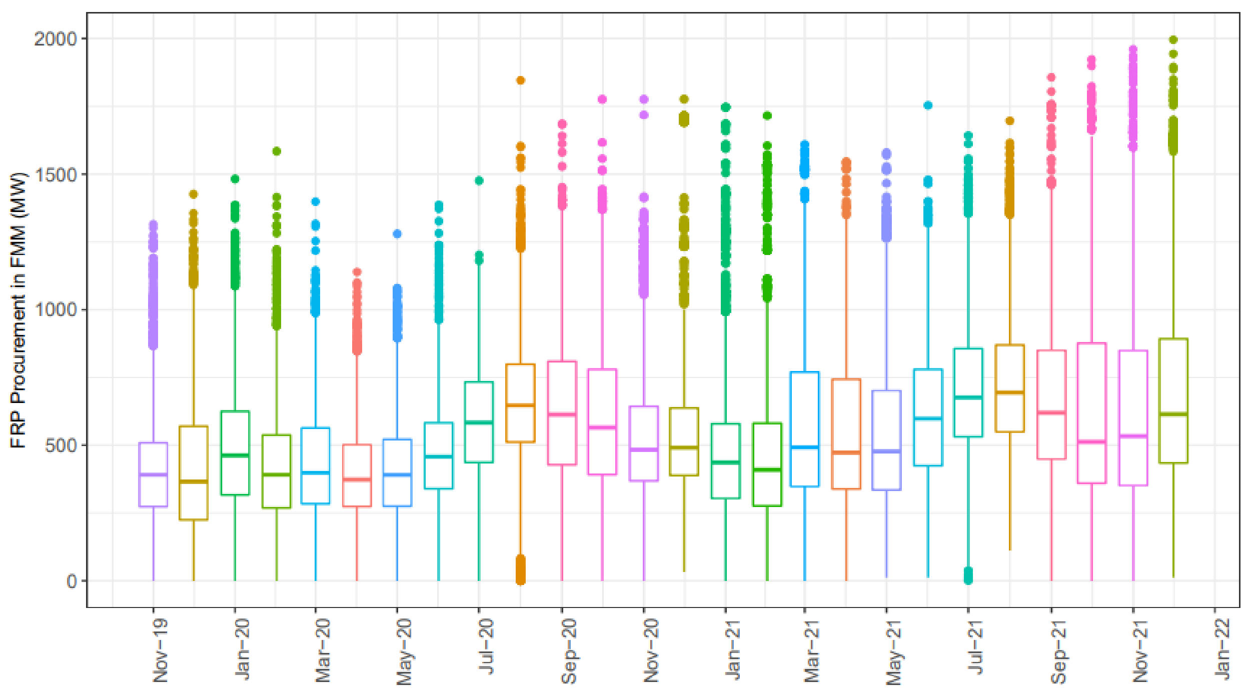
[6] The market notice regarding the activation of the minimum requirement constraint is available at http://www.caiso.com/Documents/Activation-Minimum-Flexible-Ramping-Requirement-Real-time-Dispatch-Market-Effective-021622.html

7 FRP Requirements and Procurement

The FRP capacity procured in the market is guided by the FRP requirements. These requirements reflect the uncertainty associated with each FMM and RTD market. The current methodology relies on a statistical approach to determine the level of requirement to be enforced in the markets. This statistical methodology uses historical uncertainty to estimate a 2.5th and 97.5th percentiles for the downward and upward requirements. The historical uncertainty is calculated as the net load errors between FMM and RTD markets for the FMM requirements and as the net load error between binding and advisory intervals for the RTD requirements. The requirement is calculated individually for each WEIM area as well as for the system-wide WEIM area. Currently, CAISO is in the process of implementing an enhanced methodology to estimate FRP requirements. In addition to relying on historical net load errors, this methodology will factor in forecasted values for load, wind and solar. This will allow FRP requirements to reflect expected net load conditions for the time being assessed[7].

Figure 4 and Figure 5 show the trend of FRP procurement per month over the last two years for CAISO area.

Figure 4: FRP procurement in FMM

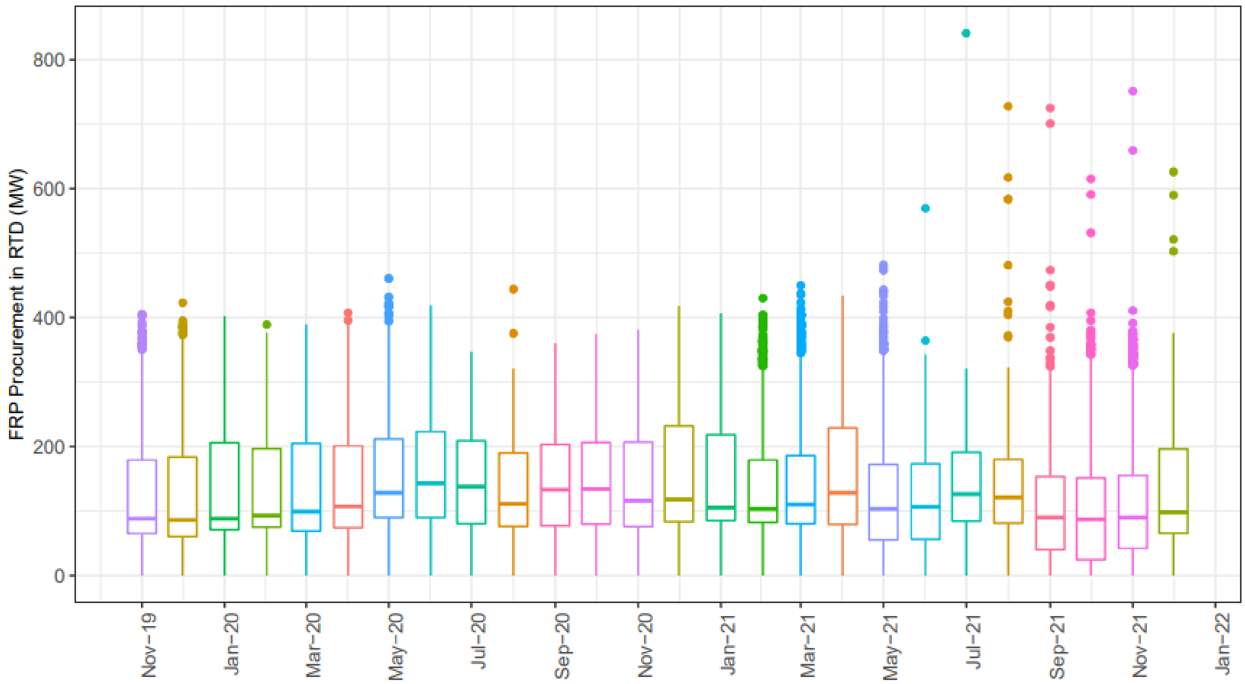


Overall, there is an expected increase on the maximum level of FRP requirement which will lead to a higher level of FRP procurement given the ongoing addition of renewable resources into the system. Seasonal weather conditions are also expected to impact the level of FRP requirements. The FMM procurement will naturally tend to be higher than the RTD requirements since they are based on 15- and

[7] The FRP enhancement initiative describes this methodology in the companion Appendix C of the initiative https://stakeholdercenter.caiso.com/StakeholderInitiatives/Flexible-ramping-product-refinements

5-minute timeframes. As explained in the previous section, the FRP procured in the CAISO area is largely driven by the system-wide WEIM requirements since CAISO's effective requirements tend to be zero.

Figure 5: FRP procurement in RTD



Under typical conditions, all balancing authority areas generally have larger import or export limits than their flexible ramping up or flexible ramping down requirement. As described in previous sections, when accounting for the net import/export capability of a given balancing area, they typically are greater than the local FRP requirements, resulting in the balancing authority area's flexible ramping product requirement to be effectively 0 MW. The practical consequence of this is that the balancing authority area's upward flexible ramping product does not need to be procured from internal resources.

Figure 6 and Figure 7 show the distribution of gross versus effective requirements for CAISO area for the last two years for both FMM and RTD markets. The distribution on the right hand side shows the gross requirement are largely nonzero. Once the NIC is considered, the effectively requirements shown in the left-hand side subplot reflects the distribution of lower, and quite frequently 0 MW, requirements. For instance, the first quantile (25^{th}) as denoted with the lower bound of the box is most of the time greater than 500MW but becomes 0MW for the effective requirements.

Figure 6: Nominal and effective FRP requirement in FMM

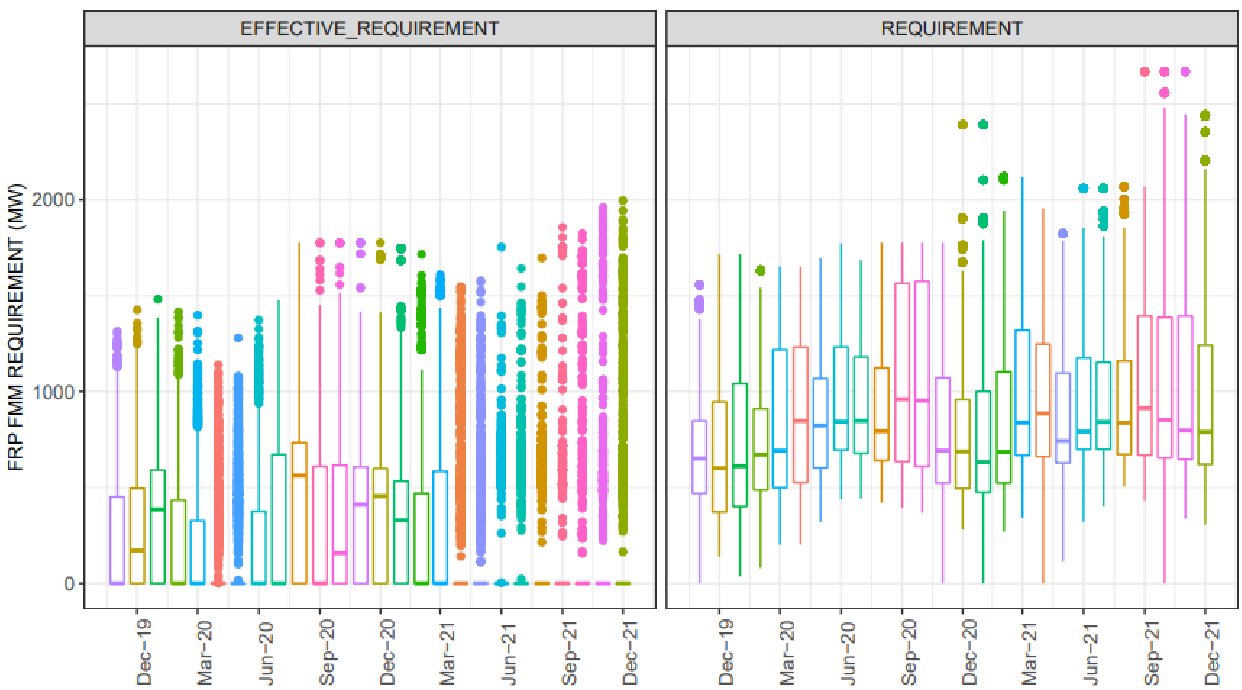
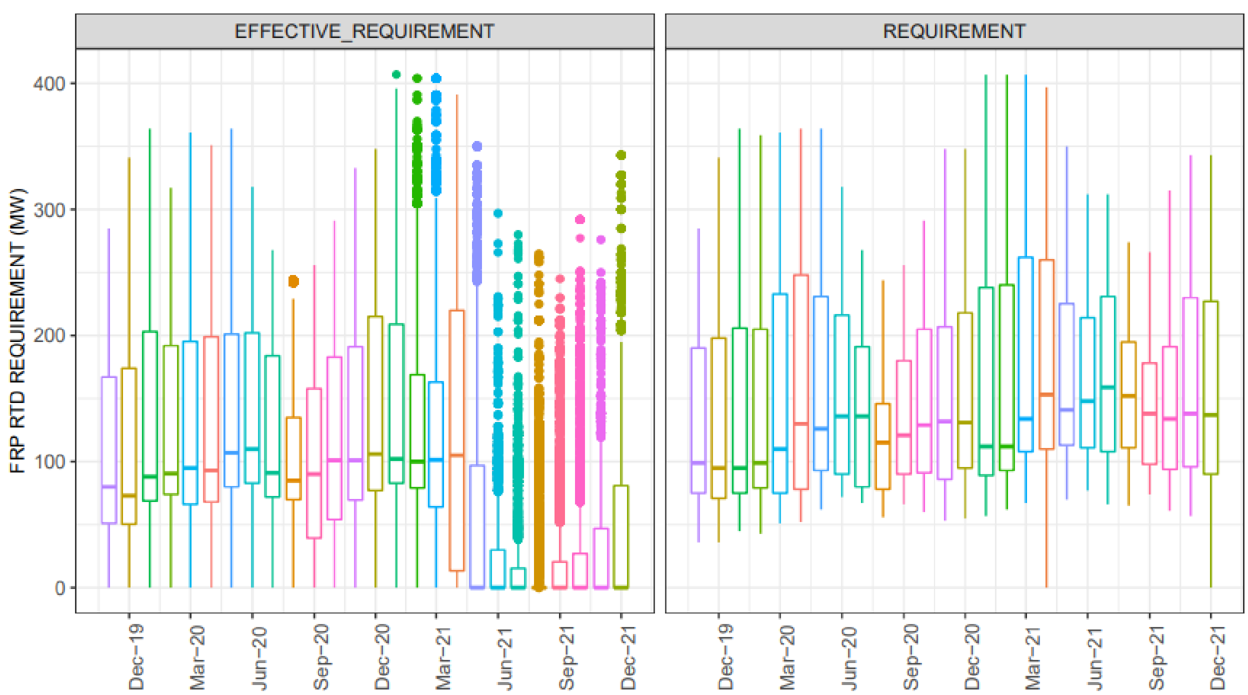


Figure 7: Nominal and effective FRP requirement in RTD



There is a marked pattern change starting in April 2021 in both FMM and RTD markets, where the effective requirements become 0 MW more frequently. This coincides with the onboarding of additional entities in the WEIM, which resulted in additional transfer capability available in the overall WEIM market. Since some of the new WEIM entities are directly connected to the CAISO area, like in the case of LADWP and TID areas, the net import capability for the CAISO area increases. This additional import capacity will tend to offset more frequently the nominal FRP requirements.

This condition is applicable to all WEIM areas at different degrees depending on their corresponding transfer capability. Table 1 provides the frequency when the effective requirements are nonzero. This is shown for all areas and for the FMM market. The red color highlights the instances with a low frequency, while blue colors reflects a higher frequency.

There are several trends to highlight. First, prior to November 2020, CAISO area observed a frequency lower than 50 percent of the time with nonzero requirements. Starting on November 2020 and with the introduction of the minimum requirement constraint, the frequency of nonzero effective requirements increased significantly to over 90 percent of the time. Second, historically only Idaho and PAC have seen a high frequency of nonzero effective requirements given the transfer capabilities associated with them. Third, with the onboarding of addional WEIM areas, the transfer capabilities reference changes for other areas and this can represent a change in pattern in either direction, increasing or decreasing the frequency of nonzero requirements.

Table 1: Frequency of 0MW effective requirements in the WEIM

Month	AZPS	BANC	CISO	IPCO	LADWP	NEVP	NWMT	PACE	PACW	PGE	PNM	PSEI	PWRX	SCL	SRP	TIDC
Feb-20	46.7	60.1	47.1	80.9		2.5		27.5	65.1	62.7		57.9	40.2			
Mar-20	38.1	61.3	29.7	86.2		0.9		22.6	69.9	74.3		58.8	19.8			
Apr-20	41.8	95.2	21.5	89.1		5.9		42.8	88.4	39.8		73.7	20.5	31.3	56.6	
May-20	11	95.2	24.4	86.6		8.3		49.5	90	34.9		88.7	15	35.1	9	
Jun-20	11.7	97	29.4	69.5		6.8		40.9	98.8	15.6		97.6	14.5	22.9	5	
Jul-20	19.6	98.9	49.5	73.6		5.8		29.3	99.2	14.9		96.6	3.8	23.8	10.2	
Aug-20	8.5	95.7	66.3	72.3		11.6		12.7	95.8	13.4		96	7.7	30.2	3.8	
Sep-20	5.9	98.9	44.7	91.2		4.8		11.8	91.6	30.3		95.2	24.2	27.7	4.5	
Oct-20	9.5	92.3	50.3	92.2		3.4		8.1	92.8	41		92	37.1	33.3	4	
Nov-20	2.8	86.6	93.4	83.3		3.8		16.7	86.4	62.2		91.8	36.3	38.8	3.7	
Dec-20	3.8	92.5	98.6	95.9		4.5		20	91.6	79.3		96.6	17.9	39.2	3.6	
Jan-21	3.3	92	93.6	95.3		2.9		25.3	90.8	85.4		92.5	34.3	41.9	2.1	
Feb-21	10.1	79.4	96.9	81.5		3.5		33.4	89.9	87.4		86.7	31.8	40.6	18.5	
Mar-21	2.9	82	99.5	92.5		4		34.6	88.9	81.4		93.5	25.5	27.1	3.7	33.7
Apr-21	1.8	22.1	96.1	98.9	3.7	2.6		25.8	93.2	61.6	36.4	95.6	14.2	11.5	3.4	83.2
May-21	3	3.9	89.2	98.4	1.3	2.2		18.2	87.1	67.7	71.8	90.9	29.8	8.5	1.4	90
Jun-21	3.3	4.3	92.7	98.1	1.5	2.6	5	10.3	91.3	36.6	51	73.2	25.1	14	13.8	84.9
Jul-21	7	10.7	88.2	98.6	2.1	3	8.3	13.3	71.8	24.5	23.2	46	19.3	5.7	17.3	89.6
Aug-21	4.6	7.6	81.7	99.5	1.8	2.2	12.9	6.4	84.6	30.5	23	43.2	26.3	5.3	30.2	91.3
Sep-21	4.2	9	89.2	99	1.7	1.1	49.2	5.3	44.3	22.4	31.3	30.9	20.1	1.9	7	89.8
Oct-21	1.2	13.1	90.5	96.5	3	1.4	86.7	23.5	76.7	31.1	53.4	34.4	33.5	6.6	4.3	81.1
Nov-21	1.5	12.6	92.2	96.1	1.5	1.1	13.1	12	85.8	51	54.1	56.9	56.3	8.7	7.6	74
Dec-21	2.5	7.2	93.5	98.9	3.8	2.3	8.3	15.6	94.5	37.7	37.3	52.5	17.5	7.1	11.1	81.9
Jan-22	2.8	10.2	89.3	97.3	3.1	3	3.2	20.6	90.9	33.3	51.1	54	20.2	5.4	4.7	78.2

8 FRP Prices

Similar to other market products, the market clearing process provides FRP awards and prices. Awards and prices are at the resource level, even though FRP prices are derived from the individual WEIM areas the system-wide area. The price of a given area reflects the value to procure FRP. Unlike other market products, such as energy and ancillary services, the FRP product is fully based on an opportunity cost construct and there are no explicit bids to express the willingness and value assessed for resources with the capability to procure FRP.

Figure 8 and Figure 9 illustrate the monthly frequency of nonzero FRP prices for FMM and RTD markets, respectively, for the CAISO area. For FMM, the nonzero prices happened less than 2 percent of the time prior to November 2020. Afterwards, the frequency of nonzero prices has increase fairly, reaching up to 15 percent of the time in March 2021. This change in pattern was driven by the enforcement of the minimum requirement. By enforcing the minimum requirement, the market optimization needs to procure FRP within CAISO area and when there is no sufficient capacity, it will relax the requirements by using the surplus variables of the demand curve for FRP, setting a nonzero price.

The frequency of nonzero prices for RTD is much lower and represents only a fraction of a percent for the study period. There is no marked trend change in RTD for before and after November 2020 because the minimum requirement was originally enforced only in FMM. As explained throughout this document, there are three main reasons for which these FRP prices are frequently clearing at zero, such as zero effective requirements, utilization of non-deliverable capacity and pricing based on opportunity cost.

Figure 8: Monthly frequency of nonzero FRP prices in CAISO area. FMM market

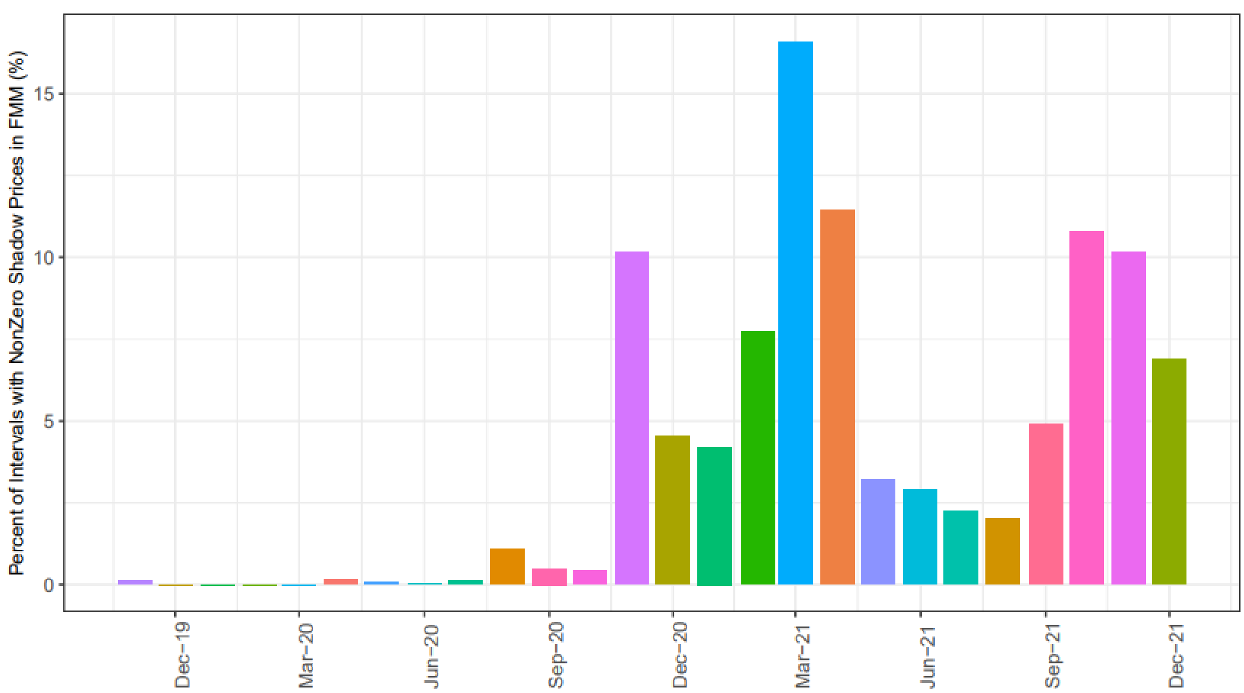


Figure 9: Monthly frequency of nonzero FRP prices in CAISO area. RTD market

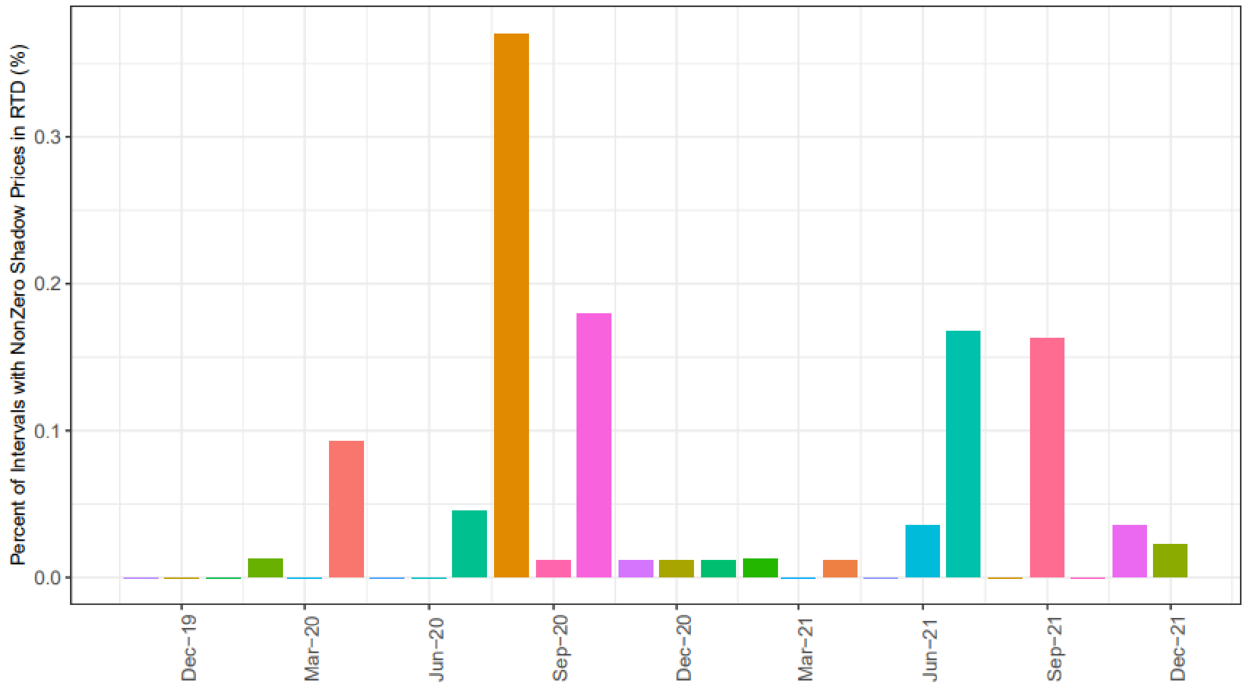


Figure 10 and Figure 11 show the nonzero prices for the WEIM area in both FMM and RTD markets, respectively. These plots show a very low frequency of nonzero prices too.

Figure 10: Monthly frequency of nonzero FRP prices in system-wide WEIM area. FMM market

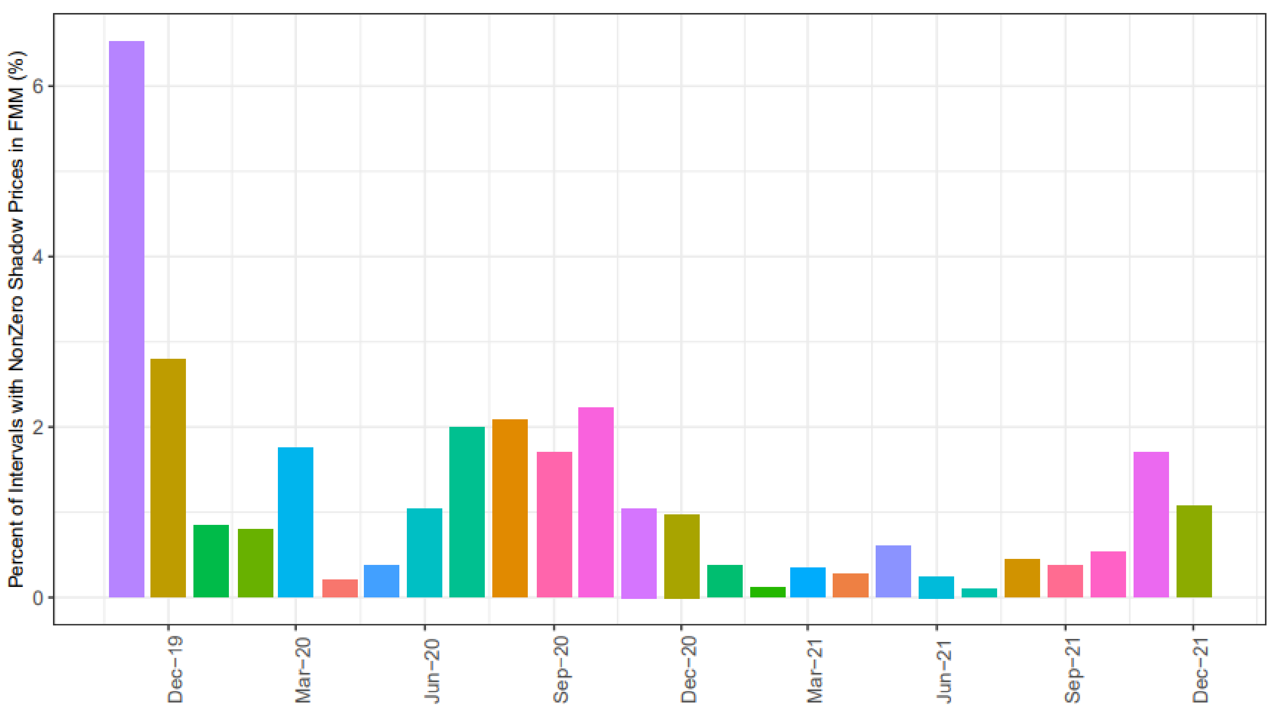


Figure 11: Monthly frequency of nonzero FRP prices in system-wide WEIM area. RTD market

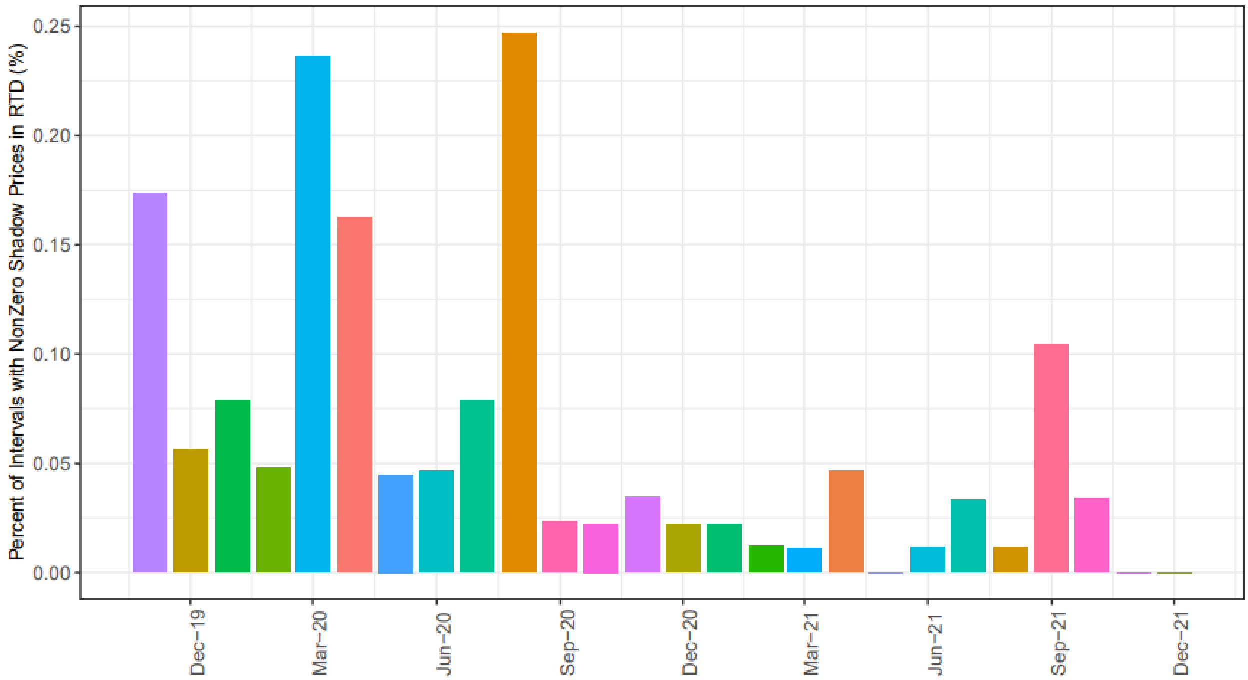


Figure 12 and Figure 13 show the monthly distribution of nonzero prices for CAISO area in both FMM and RTD markets, respectively. FMM exhibit a larger and broader distribution of prices after the implementation of the minimum requirement. RTD shows no trend over time. In both trends, the distribution shows prices are largely in the low-price range.

Figure 12: Monthly distribution of nonzero FRP prices in CAISO area. FMM market

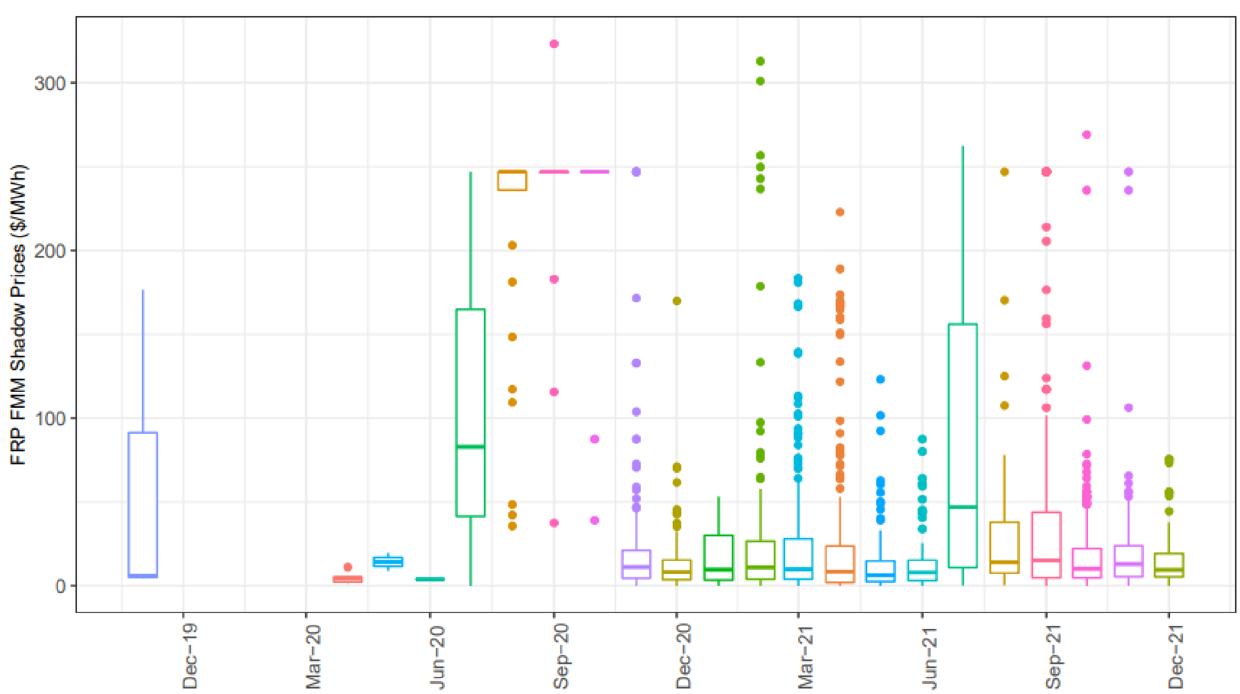


Figure 13: Monthly distribution of nonzero FRP prices in CAISO area. RTD market

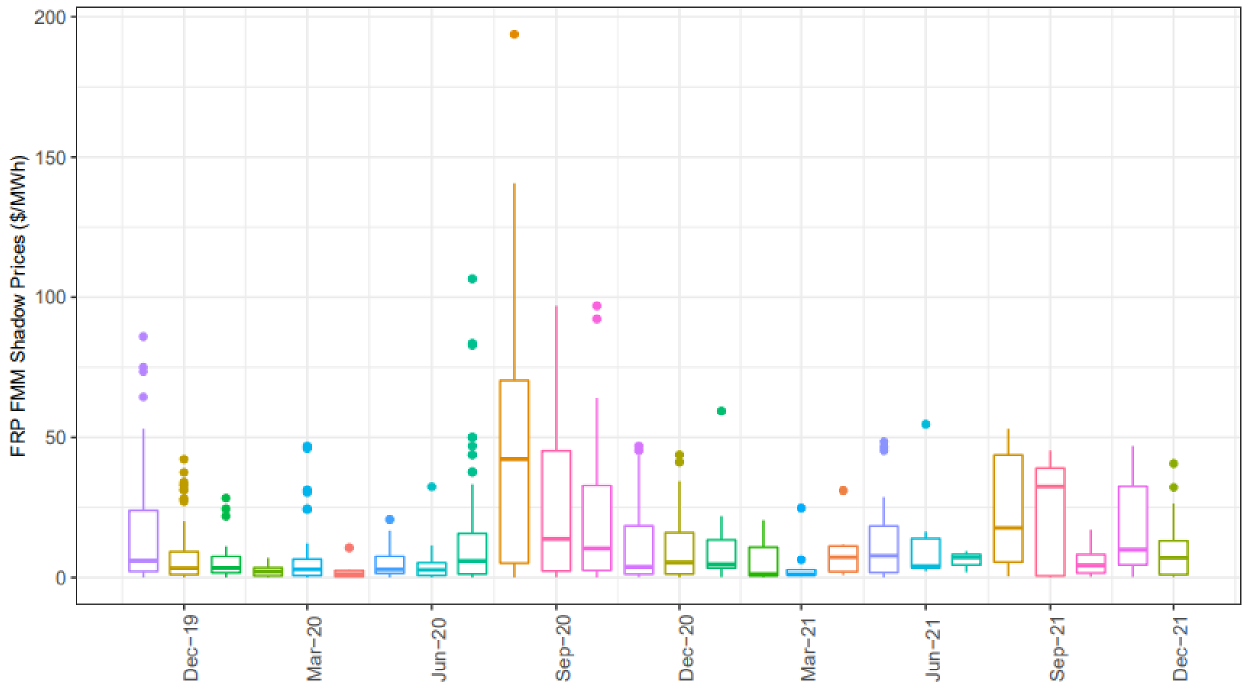


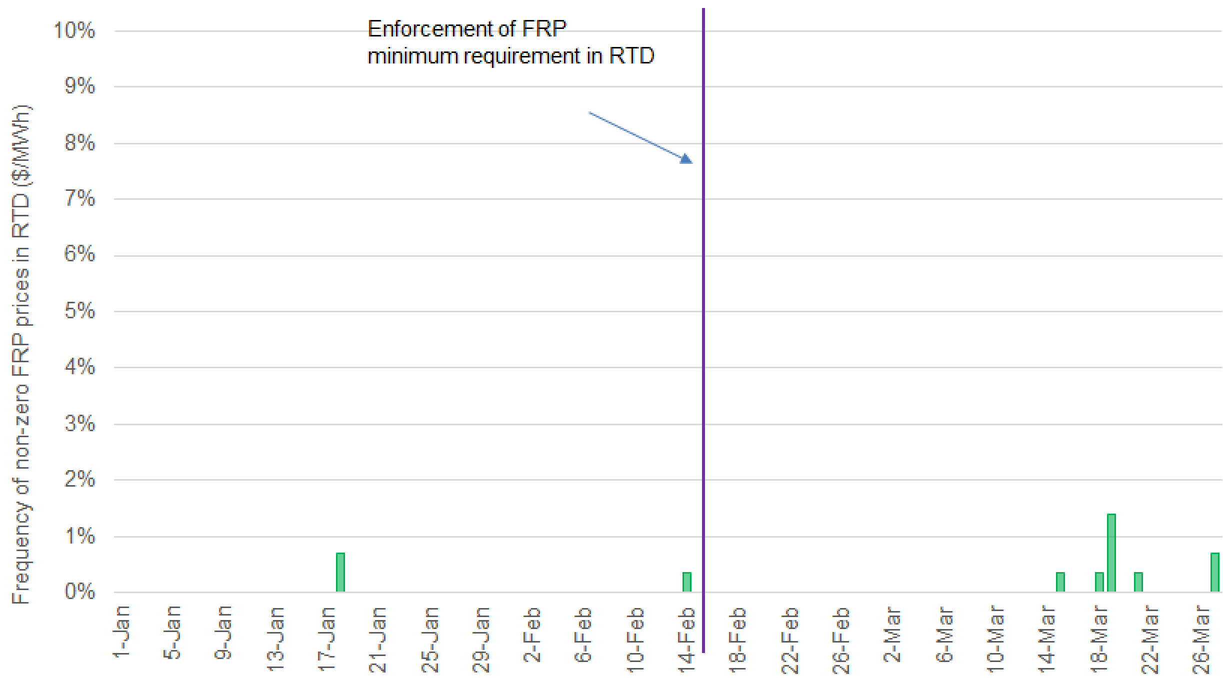
Table 2 below summarizes the frequency of nonzero FRP prices in the FMM market for all WEIM areas. FRP prices have been largely zero across all areas.

Table 2: Frequency in percentage of nonzero FRP prices

Month	AZPS	BANC	CISO	EIM	IPCO	LADWP	NEVP	NWMT	PACE	PACW	PGE	PNM	PSEI	PWRX	SCL	SRP	TIDC
Feb-20	1	0	0	0.8	0		0.5		0	0.1	0.1		0.6	0.5			
Mar-20	1.4	0	0	1.8	0		0.2		0.1	0.2	0.2		0	1.4			
Apr-20	0.1	0	0.2	0.2	0		0.8		0	0	0		0.1	0.2	0	4.9	
May-20	0.8	0	0.1	0.4	0.1		2.4		0.1	0	0.2		0	0.7	0	0.1	
Jun-20	0.2	0	0	1	0.3		2.4		0.1	0.1	0.6		0.4	1.1	0	0.5	
Jul-20	0	0	0.1	2	0.1		4.4		0.2	0.1	4.2		0.6	1.8	0.1	0.7	
Aug-20	0.1	0.4	1.1	2	0.2		7.3		0.4	0.2	1.5		0.7	2	0	1.6	
Sep-20	0.2	0.2	0.5	1.7	0		2.5		0.2	0.3	1.4		0.2	0.6	0.1	1	
Oct-20	1.2	0.2	0.4	2.2	0		1.6		0.5	0.2	0.7		0.3	0.9	0.1	1.8	
Nov-20	0.5	0	10.2	1	0.1		0.8		0	0.1	1.5		0.1	0.5	0.2	0.7	
Dec-20	0.3	0.1	4.5	1	0		0		0	0.1	0.2		0	0.4	0.2	0.3	
Jan-21	0.3	0	4.2	0.4	0		0.1		0.1	0.1	0.3		0	0.3	0	0.2	
Feb-21	0.6	0	7.7	0.1	0.1		0.3		0.1	0.1	0.4		0.1	0.1	0.1	8.9	
Mar-21	0.3	0.1	16.6	0.3	0.1		0.7		0.2	0.2	0.3		0.4	0.3	0.1	0.5	0.7
Apr-21	0	0	11.4	0.3	0	0.1	0.3		0.1	0.1	0.4	6.8	0.1	0.1	0	0.5	0.3
May-21	0.7	0	3.3	0.6	0	0.1	0.9		0.1	0.3	0.3	0.1	0.5	0.5	0	0.2	0.2
Jun-21	0	0	2.9	0.2	0	0.1	1.3	0.8	0.4	0	1.5	0.4	0.9	0.3	0	1	0
Jul-21	0.1	0.1	2.3	0.1	0.3	0.1	0.8	3	0.3	0.1	1.1	0.5	0.2	0.2	0.1	2.9	0.1
Aug-21	0.2	0	2	0.4	0.6	0	0.6	1.2	0.1	0.1	1.5	0.1	0.2	0.5	0	2.8	0.2
Sep-21	0.3	0	4.9	0.4	0.1	0	0.4	23.8	0.3	0.1	0.8	0.2	0	0.4	0.2	1.8	0.1
Oct-21	0	0	10.8	0.5	0	0.3	0.5	44.3	0.1	0	0.8	0.3	0.2	0.9	0.1	0.3	0.3
Nov-21	0.5	0	10.2	1.7	0	0.1	0	1.4	0.1	0.6	0.2	0.3	0.2	1.7	0.1	1.7	0
Dec-21	0	0	6.9	1.1	0	0.3	0.1	1.9	0.6	0.1	0.4	0.3	0.2	1.4	0.1	0.2	0
Jan-22	0	0	9.3	1.2	0.2	0	0	0.5	1.8	0.3	0.3	0.2	0	1.4	0	0.2	0.1

On February 16, 2022 CAISO activated the minimum requirement constraint in the RTD market. As shown in Figure 14, the enforcement of this constraints has not had a major change in pricing patterns for CAISO area.

Figure 14: Frequency of nonzero prices in RTD after enforcement of minimum constraint



9 FRP Pricing on July 9, 2021

Since its implementation, the FRP has exhibit weak price signals as shown in previous section. In instances where plenty of capacity is available, FRP procurement may result in zero prices since there is no opportunity costs to procure it. However, during tighter supply conditions a stronger price signal is expected due to the natural condition for opportunity costs to arise when procuring FRP and its trade off with procuring for energy. This also depends on the level of FRP requirements which depend on the net load uncertainty. During summer 2021 conditions, in spite of CAISO experiencing limited supplies and forecasting resource deficiency after the Malin and NOB intertie derates due to the Bootleg fire, FRP pricing was weak with multiple intervals priced at zero. Given high temperatures across the western part of the United States, supply was limited not only in CAISO but in other areas of the WEIM footprint[8].

Figure 15 shows the FRP prices for all WEIM areas, including CAISO's and the system-wide WEIM area prices. CAISO's prices in FMM were nonzero for several intervals in peak hours, reaching the maximum prices of $247 in intervals of hour ending 19 and 21. Prices in SRP and NEVP were sporadically nonzero during peak hours. Several of these prices indeed happened in intervals when WEIM areas failed either

[8] CAISO provided detailed analysis on the system conditions and market performance during summer months. July's report is available at http://www.caiso.com/Documents/SummerMarketPerformanceReportforJuly2021.pdf

the capacity or flexible ramp test, which imposed a cap on the transfers in the real-time market. The price for the system-wide WEIM area remained largely at $0 throughout peak hours of July 9 in spite of the tight supply conditions in the West.

Figure 15: FRP prices in FMM for July 9, 2021 peak hours

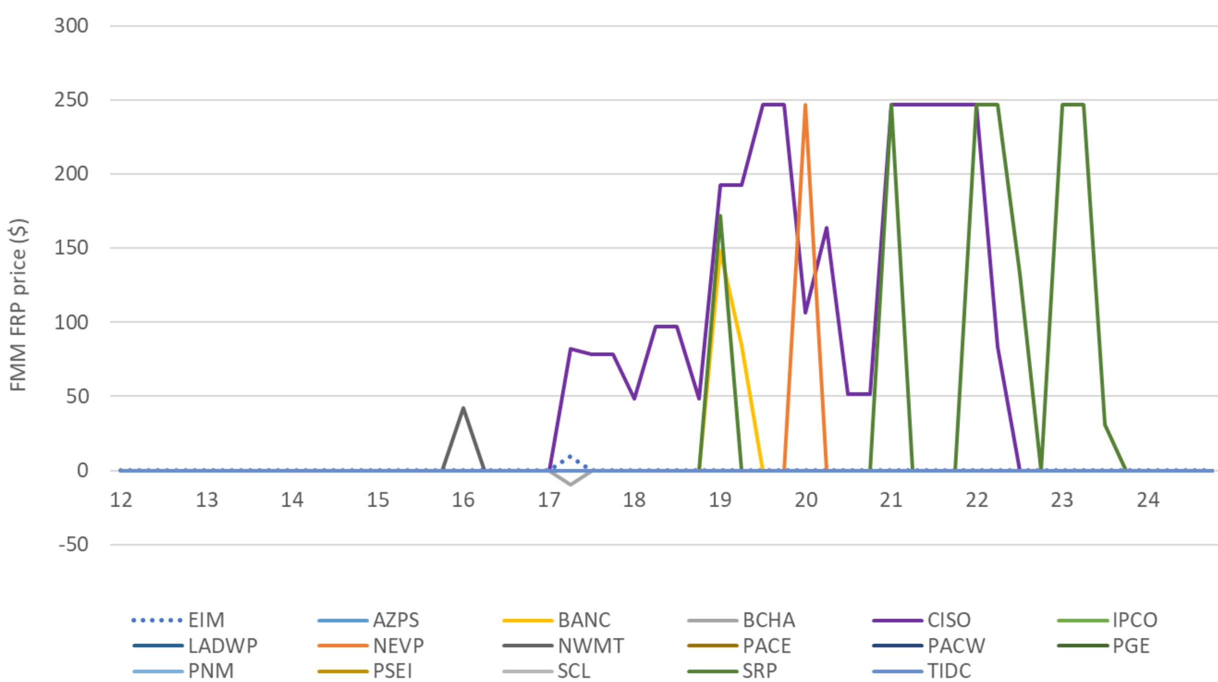
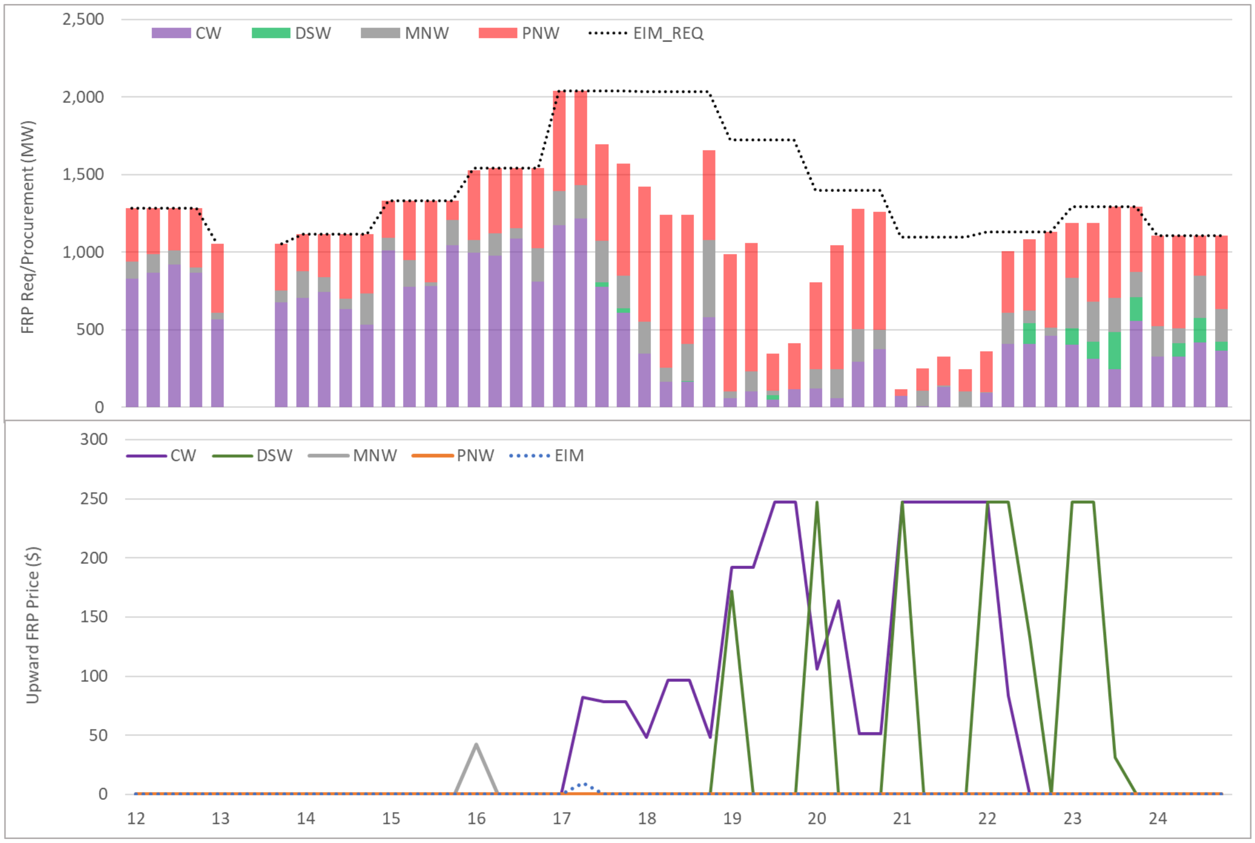


Figure 16 shows an aggregated trend of FRP prices at the regional zones of the WEIM footprint and how they tracked relative to the amount of FRP requirement and procurement for the system-wide WEIM area. As the system reach peak hours and FRP requirements reached 2,000MW, the WEIM market was unable to meet all FRP requirement; in the most critical time of hour ending 19 and 21, only a small portion of the requirement was procured. Across the peak hours the procurement was mainly from CAISO and Pacific Northwest areas. Figure 17 complements the comparison by showing the trend of the FRP procurement relative to the FMM energy prices for the WEIM areas. This show that FRP relaxation concurs when energy prices are relatively high. This is an expected relationship since FRP procurement is price sensitive based on the demand curves[9]. The high energy prices reflect the tight supply condition in the CAISO and the Desert Southwest. The Pacific Northwest prices tracked low reflecting a condition of sufficient supply. This pricing outcome still raises the question about the weak price signal for FRP across the WEIM footprint.

[9] The flexible ramping product framework uses a procurement demand price curve that is calculated based on the probability of a power balance constraint occurring if the flexible ramping product is not met. If the upward flexible ramping product requirement is relaxed, the demand curve value would increase the energy price above last economic energy bid. There is a demand curve for the upward and also for the downward FRP.

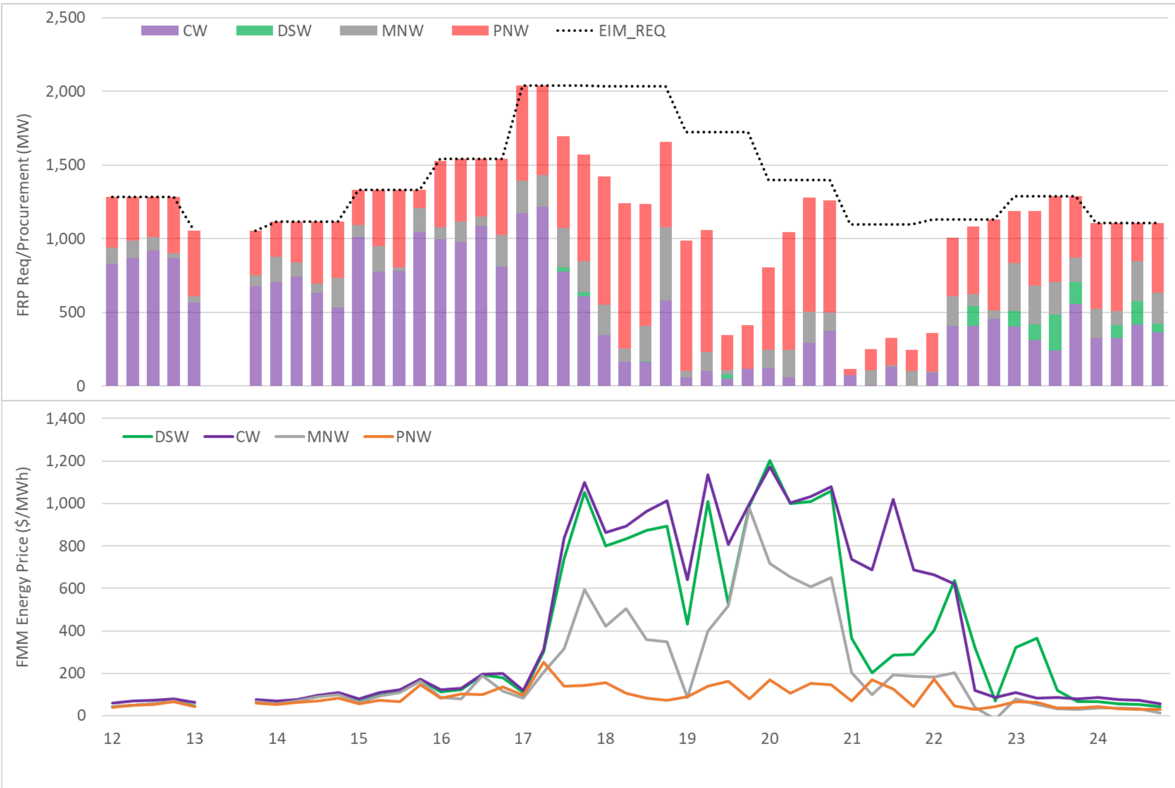
Figure 16: FRP procurement and prices in FMM for July 9, 2021



This outcome can be further explained by focusing in a specific real-time interval. For reference this explanation relies on July 9 2021, hour ending 17, interval 3. In this interval there were no test failures, which allows us to explore a typical scenario of FRP at work.

Table 3 summarizes the FRP solution. It includes the nominal (uncertainty) requirement and the effective FRP requirement once the NIC is considered. Since the NIC component is sufficiently large, the effective requirement is 0 MW for all areas.

Figure 17: FRP procurement and energy prices in FMM for July 9, 2021



Since CAISO area also has a minimum requirement, this constraint is the one that forces CAISO to have a nonzero effective requirement. The system-wide area is also nonzero and reflects the nominal uncertainty requirement since there is no NIC applicable to the system-wide area. With zero effective requirements for all areas but CAISO, the system-wide WEIM are requirement set the constraint effectively driving the overall procurement. Multiple areas in the WEIM footprint provide FRP capacity to meet the WEIM area requirement. For all areas that have a 0 MW effective requirement, the optimal solution can result in zero or nonzero procurement, but under either scenario their FRP price will be zero because they can meet a 0 MW requirement. There were six WEIM areas that did not procure any FRP capacity to meet the WEIM area requirement, including AZPS, IPCO, LADWP, PNM, SRP and TIDC. These WEIM areas could not procure any FRP capacity because they had no supply available. With procuring 0 MW, these areas indeed meet the requirement constraint and the requirement is not relaxed, therefore the demand curve does not set a nonzero price. For the other areas that had nonzero effective requirement but procured nonzero capacity, it reflects procurement above the requirement and thus its price will be zero reflecting that there is sufficient capacity and no opportunity cost.

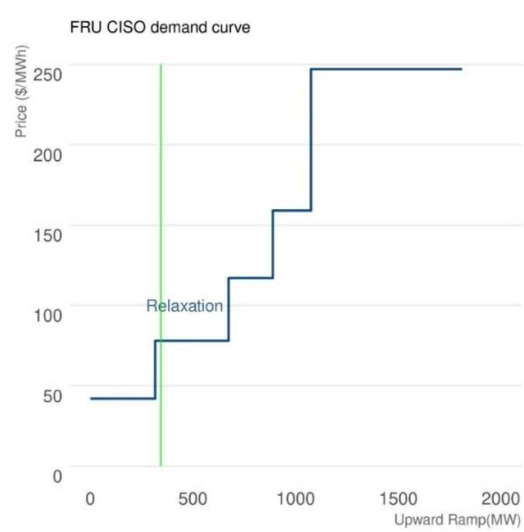
For CAISO area, there was a minimum requirement of 925 MW, which could not be procured fully from its internal resources. Therefore, the requirement was relaxed by 344 MW; this is the value of the surplus variable which will determine the FRP clearing price for CAISO area. Figure 18 shows the actual demand curve for upward FRP of CAISO area for hour ending 17. The surplus variable has a price of $78 for the MW segment where 344 MW is contained, which is what sets the CAISO price.

Table 3: FRP market solution for July 9, HE17. FMM market

BAA	Uncertainty Req (MW)	Effective Req (MW)	Min Req (MW)	Procurement (MW)	Relaxation (MW)	Flex Price ($)	Energy Price ($)
AZPS	169	0	0	0	0	0	762
BANC	51	51	0	196	0	0	1,000
CISO	1,810	925	925	581	344	78	855
IPCO	149	0	0	0	0	0	312
LADWP	191	0	0	0	0	0	751
NEVP	303	0	0	30	0	0	731
NWMT	78	0	0	19	0	0	192
PACE	377	0	0	250	0	0	442
PACW	117	0	0	102	0	0	335
PGE	158	0	0	148	0	0	85
PNM	183	0	0	0	0	0	714
PSEI	91	0	0	130	0	0	113
PWRX	161	0	0	161	0	0	53
SCL	19	0	0	78	0	0	116
SRP	124	0	0	0	0	0	761
TIDC	9	0	0	0	0	0	960
EIM	2,038	2,038	0	1,694	344	0	

The system-wide WEIM area has a requirement of 2,038 MW, which is met partially with 1,694 MW of FRP capacity procured in multiple WEIM areas. The rest is met with the relaxation already set for CAISO area of 344 MW. This is based on the current formulation of the requirement for the system-wide area as described by Equation *2'*, in which any relaxation realized in an individual area is counted towards the procurement of the system-wide area. Since all the requirement is met at the system-wide area, there is no relaxation needed for the WEIM requirement and, consequently, the FRP price for the system-wide area is also $0.

Figure 18: FRP demand curve for CAISO area for July 9, 2021 HE17



Similar market outcome and interplay occurred for the RTD market. Figure 19 shows the trend of RTD for FRP requirement at the system-wide area, the FRP and energy prices. Along instances of FRP requirements being relaxed, FRP prices are nonzero for CAISO and the Desert Southwest while energy prices reach the $1,000 level. Table 4 provides similar summary of the FRP results. The effective requirements for most of the areas is zero and thus the FRP procurement will be largely driven by the system-wide WEIM area. Since the requirements are zero, the resulting FRP prices for these areas will be zero because the demand curve will not require the surplus variables to take on a nonzero value. Unlike FMM case, the CAISO area has also an effective requirement of zero because there was no minimum requirement imposed for CAISO in July 2021. The minimum requirement for CAISO started to be enforced on February 16, 2022. Likewise, the system-wide WEIM requirement is fully met with procurement from CAISO, Powerex and Seattle City Light areas. Consequently, the price for the overall WEIM area is also zero.

Figure 19: FRP procurement vs FRP and energy prices in RTD for July 9, 2021 HE19

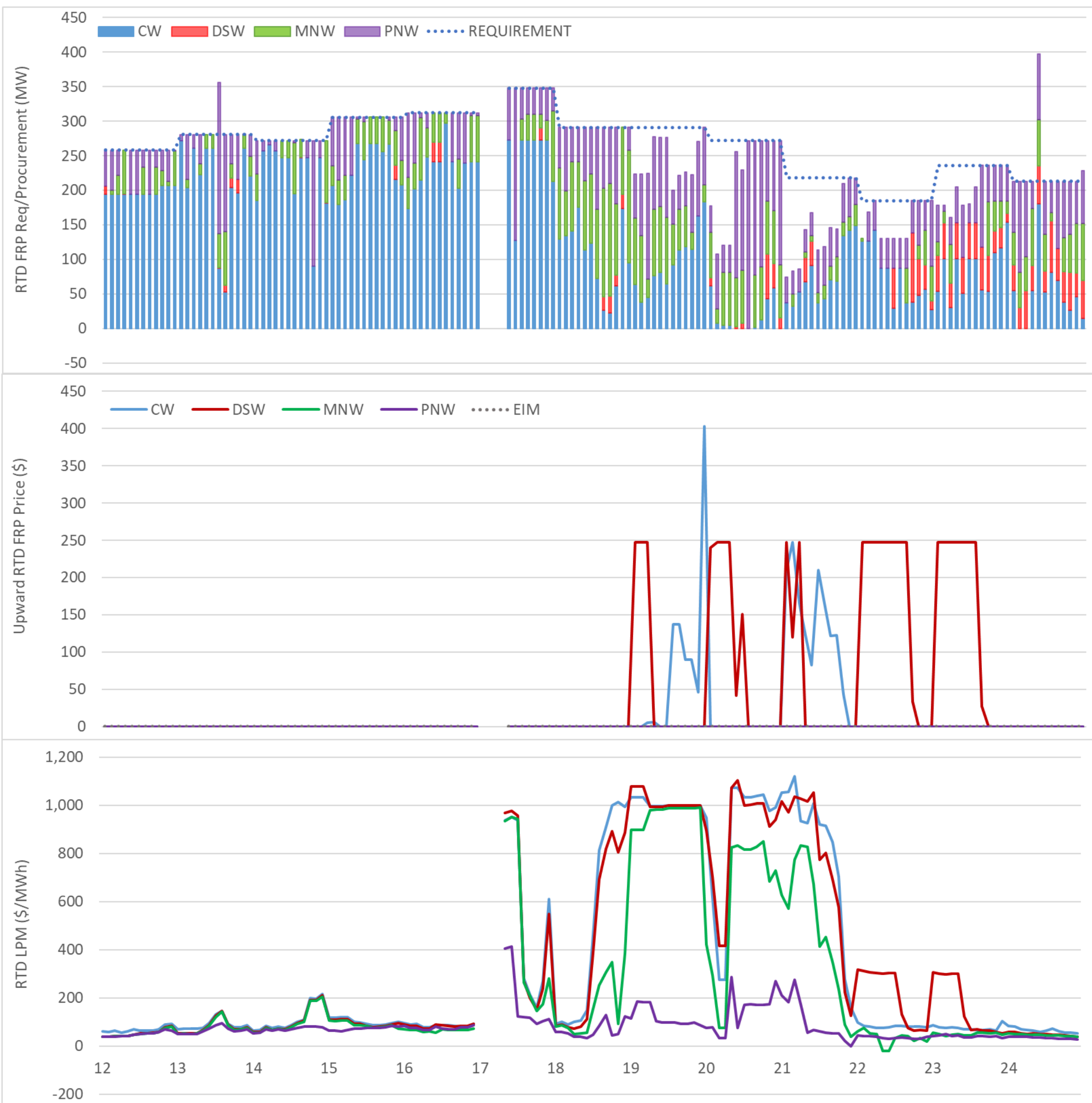


Table 4: Summary of FRP solution for July 9, HE17. RTD market

BAA	Uncertainty Req (MW)	Effective req (MW)	Procurement (MW)	Relaxation (MW)	FRP Price ($)	Energy Price ($)
AZPS	45	0	0	0	0	994
BANC	14	0	0	0	0	1001
CISO	273	0	127	0	0	994
IPCO	37	0	0	0	0	994
LADWP	69	0	0	0	0	994
NEVP	99	0	0	0	0	994
NWMT	23	0	0	0	0	994
PACE	86	0	0	0	0	960
PACW	30	0	0	0	0	151
PGE	28	0	0	0	0	151
PNM	53	0	0	0	0	994
PSEI	21	0	0	0	0	65
PWRX	47	38	143	0	0	65
SCL	5	5	78	0	0	65
SRP	36	0	0	0	0	994
TIDC	3	0	0	0	0	997
EIM	348	348	348	0	0	

10 FRP Utilization and Deliverability

The goal of having flexible ramp capacity is to ensure that such ramp-able capability is available for use when uncertainty materializes in the market. One way to measure how effective the product performs is by measuring how the flexible ramp is utilized and delivered. In the pricing performance analysis, CAISO found that one of the major issues in the FRP performance was the FRP could not be fully deliverable due to congestion and economics. For instance, FRP was awarded to high bid-price resources, such as those resource bidding close to the bid cap. It also found that FRP was awarded to resources impacted by congestion such that the room available on these resources was created by decremental dispatches of energy driven by internal constraint congestion. The current formulation as described in previous sections does not consider congestion management in the market clearing process for FRP. Procurement of the flexible ramping product is based on opportunity costs, which arise from the tradeoffs between the need for energy and the need for ramping capability.

Figure 20 illustrates the utilization and deliverability of FRP for peak hours of July 9, 2021. There are different groups. One group of the metrics is to differentiate between CAISO or other EIM areas. Another group is for the type of resources, whether they are variable energy resources (VER), limited energy resources (LES), PDR or any other. There is also a group for the three major types of drivers, namely congestion, economics or resource constraints. Congestion is when a resource was awarded FRP based on capacity created by decremental dispatches due to congestion. As a result, the market can procure upward flexible ramping capacity from resources that are dispatched down for congestion management, which in the next market run when uncertainty materializes cannot be deployed due to congestion. This interplay between congestion and flexible ramping product procurement can be further exacerbated because the market may find it optimal to allocate upward flexible ramping product capacity precisely to resources dispatched decrementally for congestion management. The other driver is related to economics of the market; this more about utilization rather than deliverability. In certain conditions, FRP awards are not utilized in the market because the price for energy was not high enough. On July 9, there were FRP awards to resources that had energy bids close to the bid cap; however, the energy prices were not sufficiently high to make this resources to be in merit for energy dispatch. The last driver is resource constraints, in which certain limitations, like energy limits, may prevent the use of the FRP awards. Overall, a significant portion of FRP capacity for the peak hours on July 9 was of no use in the real-time market. Figure 21 shows the total average FRP capacity that could not be utilized or delivered, and shows that this is a persistent outcome in the FRP performance. The CAISO is currently implementing an FRP enhancement to address this issue of deliverability with a new FRP formulation based on nodal FRP procurement[10].

[10] The nodal procurement is part of the second phase of FRP enhancement initiative that is currently scheduled for implementation in fall 2022. The enhancement is described at http://www.caiso.com/InitiativeDocuments/FinalProposal-FlexibleRampingProductRefinements.pdf

Figure 20: Classification of non-deliverable FRP capacity

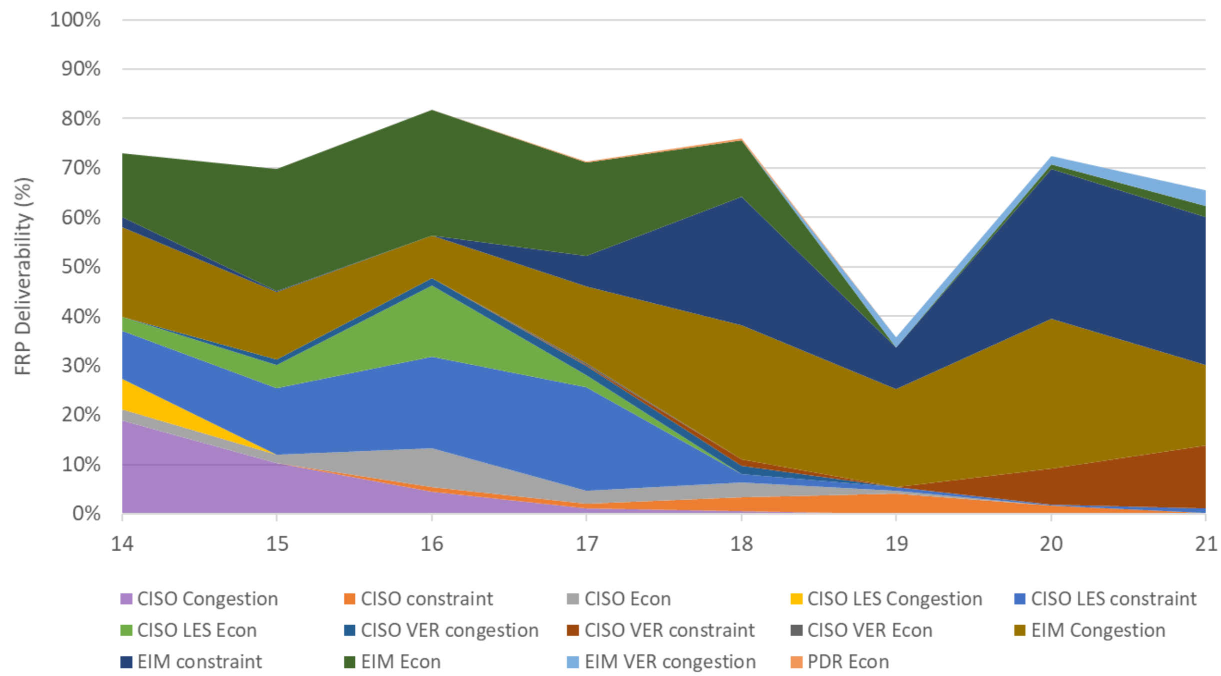


Figure 21: Monthly trend of undeliverable FRP