Thermal Outages Data Analysis

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Current Thermal Supply Side Uncertainty included in FPR

- Based on sensitivity analysis performed as part of the 2021 Reserve Requirement Study (RRS)
  - Current 2025 Forecast Pool Requirement (FPR) is 1.0894
  - 2025 FPR using perfect capacity is 1.0622. Perfect capacity refers to MW available 100% of the time all year with no outages of any type.
- The FPR difference (0.0272 or ~4,100 MW UCAP) can be allocated to the following supply-side uncertainties:

Uncertainty	FPR Impact	UCAP Impact
Ambient Derates	0.0143	2,150
Maintenance Outages	0.0099	1,500
Outage Variability	0.0003	450
Planned Outages	0	0
Winter-weather Outages	0	0
TOTAL	0.0272	4,100

Current Thermal Supply Side Uncertainty included in FPR

- We estimated the previous values as follows
  - Ambient Derates: sensitivity #16 in 2021 RRS; we eliminate ambient derates, identify the reduction in IRM and then convert the IRM reduction to FPR reduction (by multiplying by 1 – fleet-wide EFORd)
  - Maintenance Outages: sensitivity #14 in 2021 RRS shows the reduction in IRM (which can be converted to FPR reduction) if the study is run using EFORd instead of EEFORd. The difference between EEFORd and EFORd corresponds to maintenance outages because
    - EEFORd = EFORd + ¼ EMOF (where EMOF is Equivalent Maintenance Outage Factor)

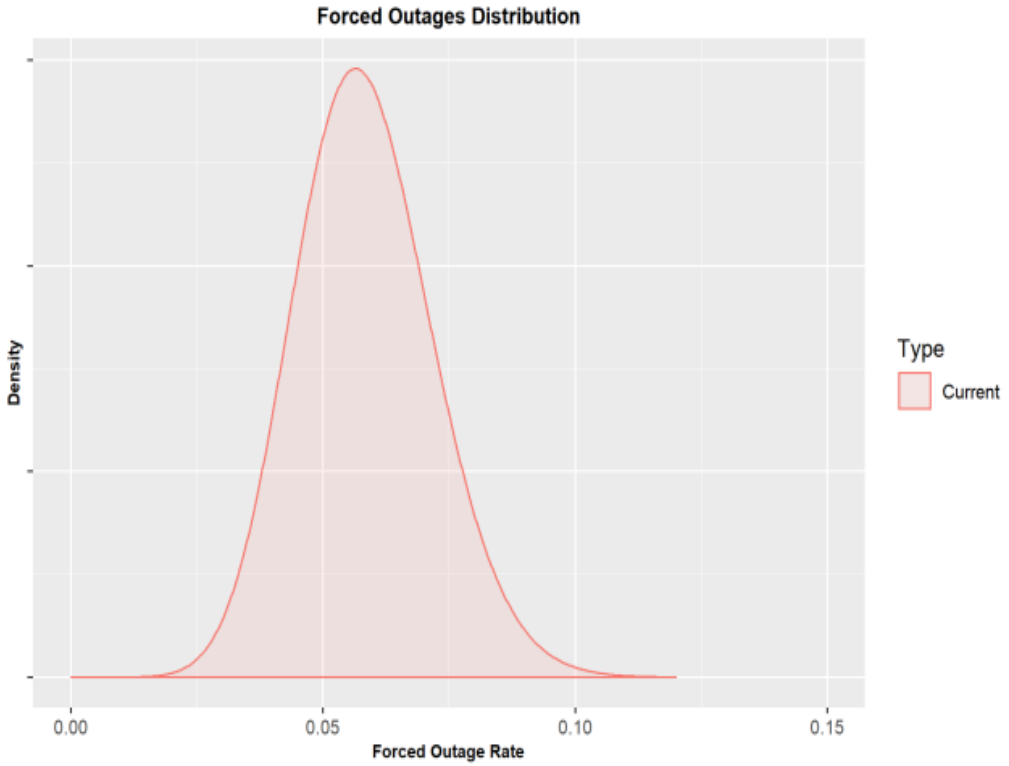
Current Thermal Supply Side Uncertainty included in FPR

- We estimated the previous values as follows
  - Planned Outages: the 2021 RRS shows all the risk in the summer period (and planned outages are not scheduled during the summer period by the model)
  - Winter-weather Outages: the 2021 RRS shows all the risk in the summer period
  - Outage Variability: we know the difference between the FPR and an FPR calculated with perfect units; we also have estimates for the FPR impact of the other uncertainties. Therefore, mathematically, we can get the impact of Outage Variability

Outage Variability

Forced outage distribution in 2021 RRS

This distribution is used in all weeks except for the winter peak week



The concept of outage variability and its impact on the FPR is directly related to the right-hand side tail of the aggregate thermal forced outages distribution.

Given the large number of units in the footprint, this distribution has a pretty narrow right-hand side tail. In fact, the standard deviation is about 1.2% (while the average is around 5%-6%)

Ambient Derates

- In a way, these are correlated hot-weather dependent outages.
- The RRS models 2,500 MW of ambient derates occurring during the summer peak period. This modeling is deterministic (as opposed to probabilistic)
- We decided to model ambient derates in the RRS because:
  - Ambient derates do not impact the ICAP calculation as the ICAP calculation is based on 50/50 weather conditions at the unit site, not more extreme conditions which are those that cause the ambient derates
  - Ambient derates are not recorded as an outage in eGADS

Ambient Derates

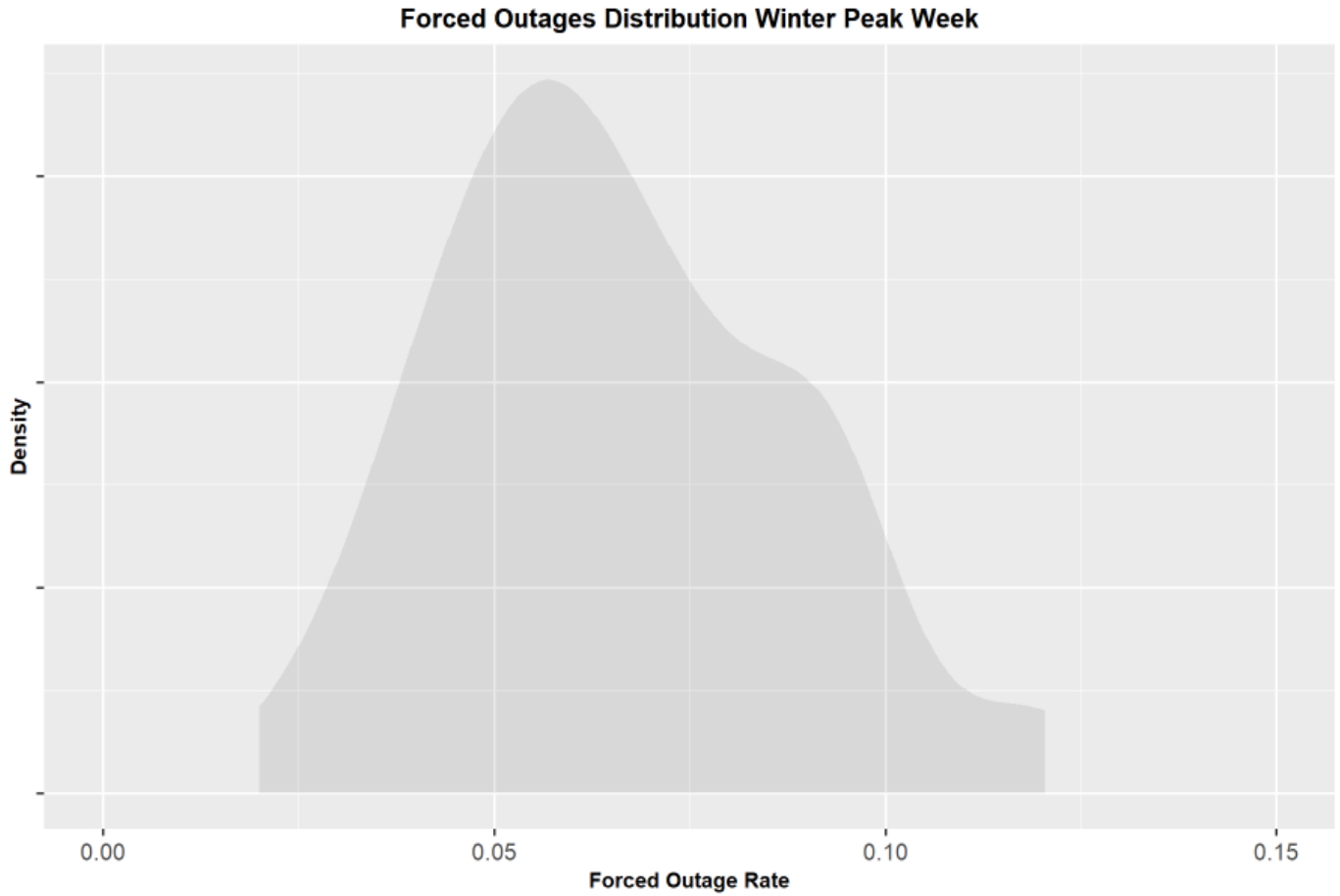
- The last time the 2,500 MW assumption was examined was in 2016. We used summer verification test data for the analysis. We estimated the following share by unit type

Unit Type	Share
Combined Cycle	42.4%
Combustion Turbine	46.8%
Diesel	0.1%
Nuclear	1.1%
Steam	9.6%

- We have recently started to explore other ways to determine an estimate of ambient derates.

Cold-Weather Dependent and Fuel-Related Outages

Winter peak week forced outage distribution in 2021 RRS



We use an empirical forced outage distribution for thermal resources in the RRS for the winter peak week. It is meant to capture **cold-weather** as well as **fuel-related** forced outages.

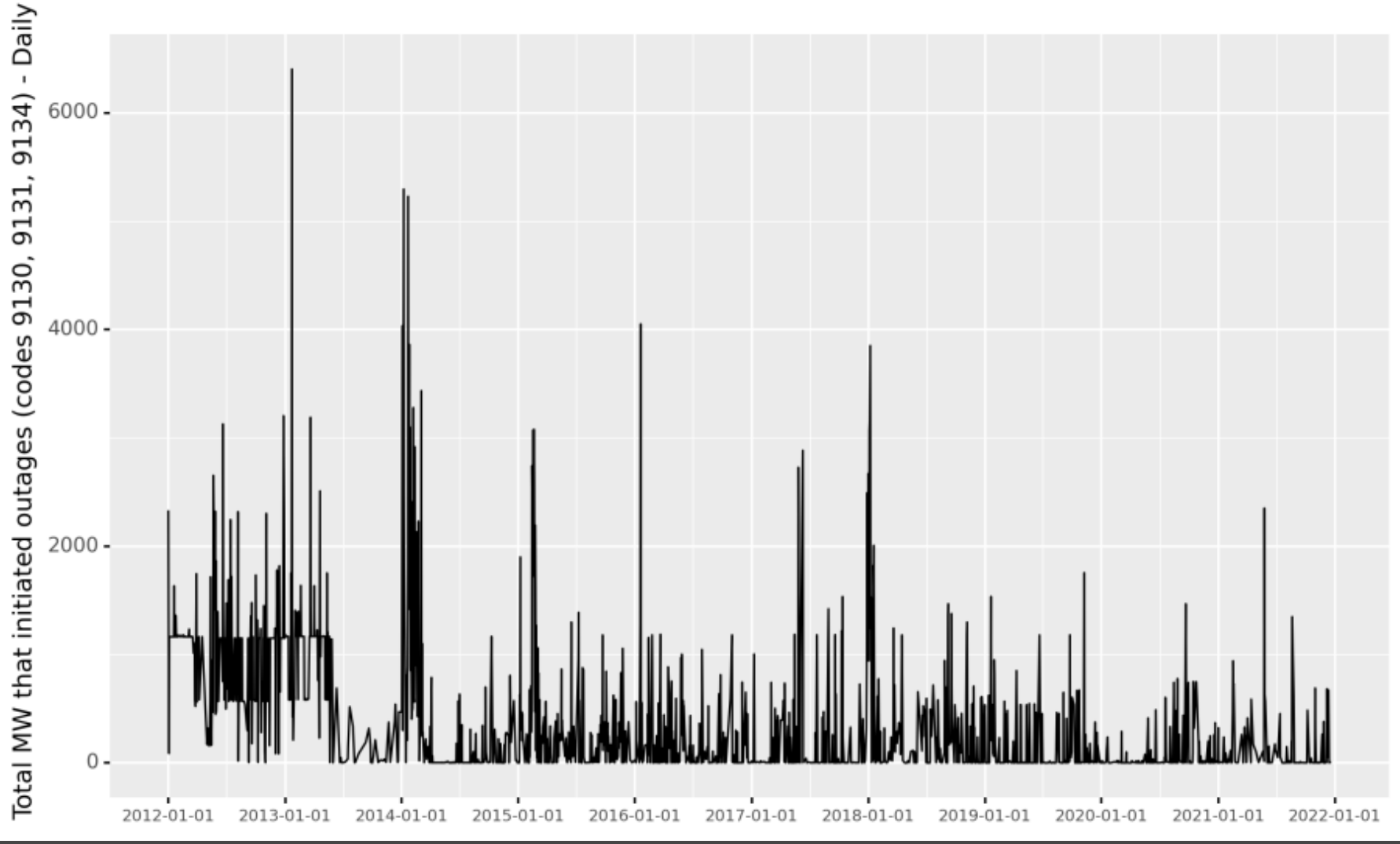
In the 2021 RRS, the distribution was built with aggregate RTO-wide forced outage data from the period 2007/08 – 2020/21, excluding the data from 2013/14, the winter of the first polar vortex.

Cold-Weather Dependent and Fuel-Related Outages

- AEE requested to look at outage data using the following specific cause codes:
  - 9130: “failure of fuel supplier to fulfill contractual obligations…due to physical fuel disruptions or operational impairments…”
  - 9131: “lack of fuel – due to contractual or tariff provisions that allow for service interruption…”
  - 9134: “fuel conservation”

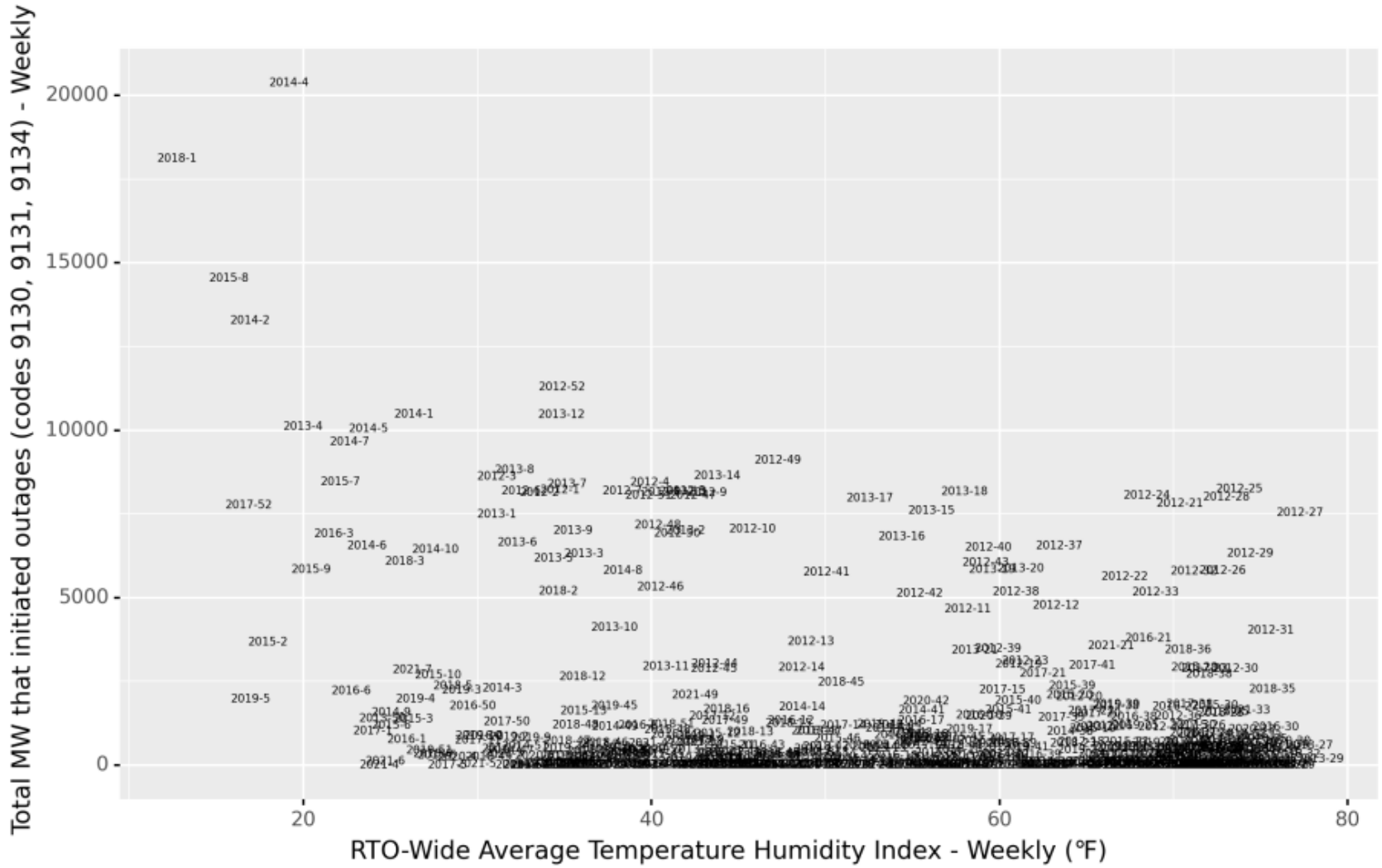
Cold-Weather Dependent and Fuel-Related Outages

Analysis of GADS data in period 2012-2021 (excluding retired units)



Cold-Weather Dependent and Fuel-Related Outages

Analysis of GADS data in period 2012-2021 (excluding retired units)



Labels in graph correspond to Year – Week.

For example, the highest point in the graph corresponds to week 4 of calendar year 2014 (2014-4). In that week, more than 20,000 MW of outages were initiated using the above cause codes.

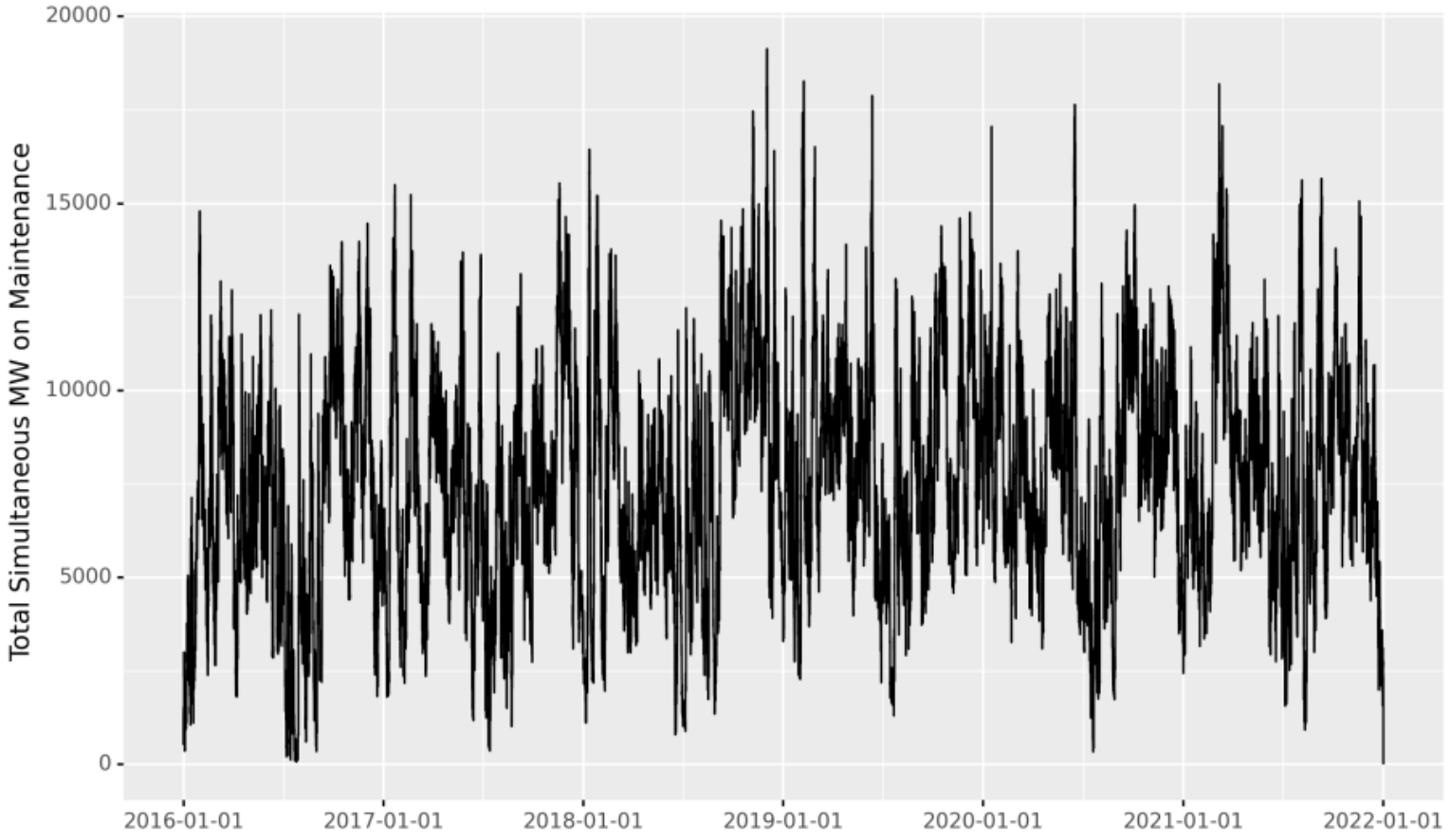
Cold-Weather Dependent and Fuel-Related Outages

- Prior to analyzing any historical data regarding these outages, PJM thinks it is worthwhile to discuss if historical data on these outages is indicative of future performance.
  - Historical reserve levels may be different from those in the future and they are certainly different from reserve levels assumed in the accreditation process (i.e. “1 in 10” reserve levels).
  - On the other hand, the availability of data is limited and historical data may be the only data we have.
- To a certain extent, in the past, PJM has determined that historical data may not be fully indicative
  - Outage data from the polar vortex of January 2014 is removed to develop the forced outage distribution for the winter peak week in the RRS.

Maintenance Outages

- Maintenance outages are reflected in the Reserve Requirement as follows:
  - EEFORd is defined as EFORd + ¼ EMOF, where EMOF is Equivalent Maintenance Outage Factor and it is calculated using GADS data.
  - The remaining ¾ of the EMOF is added to the EPOF (Equivalent Planned Outage Factor)
- Since Planned Outages do no have an impact on the FPR, only the ¼ of the EMOF added to the EFORd has an impact on the FPR

Maintenance Outages



The total MW-weeks of maintenance remain rather constant in each year with an average of 16,250 MW-week.

The share by month in the 2016-2021 period is shown in the table below:

Month	Share
1	8%
2	8%
3	9%
4	8%
5	9%
6	8%
7	5%
8	7%
9	9%
10	11%
11	10%
12	9%

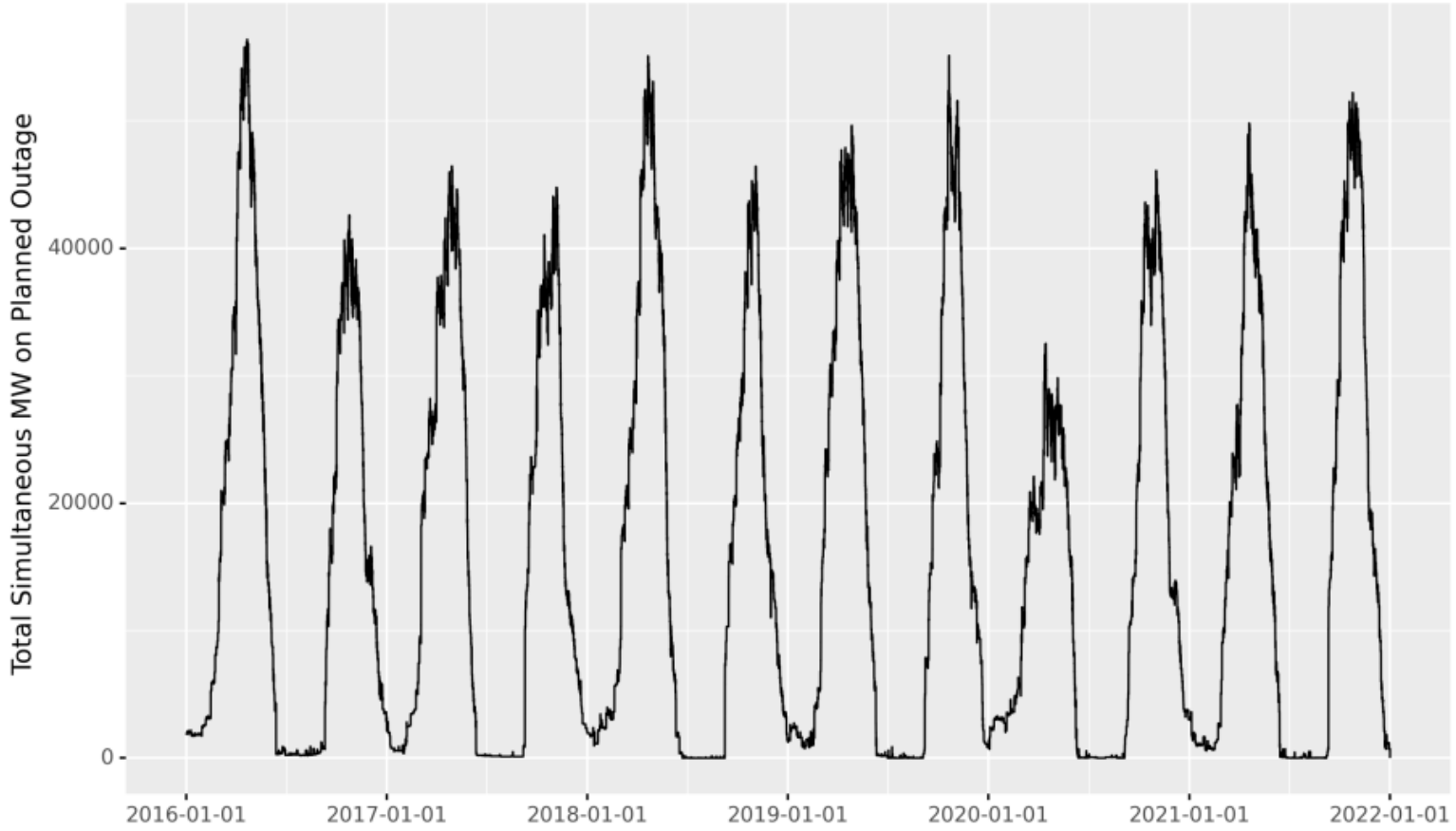
Maintenance Outages

- A question to consider: How relevant are historical maintenance outage patterns relative to future patterns or the patterns considered in the accreditation process?
  - Also, how do we answer the above question considering that the historical maintenance outage patterns may be the only data we have?

Planned Outages

- Planned outages are reflected in the Reserve Requirement by developing a schedule that levelizes reserves across the year.
  - No planned outages are scheduled during the peak summer season.
- As indicated earlier, planned outages have no impact on the FPR today

Planned Outages



The total MW-weeks of planned outages remain rather constant in each year with an average of 34,120 MW-week.

The share by month in the 2016-2021 period is shown in the table below:

Month	Share
1	1%
2	2%
3	12%
4	21%
5	16%
6	1%
7	0%
8	0%
9	6%
10	21%
11	15%
12	4%

Planned Outages

LDA	Estimated 2023 BRA CETO and RelReq Impact (UCAP MW)
AE	0
AEP	1060
APS	80
ATSI	0
BGE	0
CL	0
COMED	0
DAY	**10**
VEPO	280
DPL	20
DPLS	0
DQE	0
DUKE	**220**
EKPC	50
EPJMMA	0
JCPL	0
METED	10
PECO	0
PEPCO	0
PJMWEST	90
PJMMA	0
PLGRP	**230**
PN	180
PS	0
PSN	0
SPJMMA	**40**
WPJMMA	560

While the impact on the Reliability Requirement of the RTO is zero, the impact on the CETOs and Reliability Requirements of LDAs can be non-zero.

The table on the left shows the impact on CETOs and Reliability Requirements for the 2023 BRA.

RPM-modeled LDAs where the impact is greater than zero are highlighted in red.

Planned Outages

- A question to consider: How relevant are historical planned outage patterns relative to future patterns or the patterns considered in the accreditation process?
  - Also, how do we answer the above question considering that the historical planned outage patterns may be the only data we have?

Common Mode Failures

- We have performed the initial phase of this analysis attempting to identify clusters of units that tend to have the majority of their outages simultaneously.
- The analysis showed that we potentially need to change the modeling of some combined cycle units which as of today are modeled in multiple pieces in the resource adequacy studies while the data shows that most of the outages affect all the pieces simultaneously.

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