Hourly Carbon Free Energy Matching in CAPSTF Modeling

Constellation

April 25, 2023

Hourly CFE Scores Provide Critical Insights into PJM CAPSTF Modeling

- Hourly matching of carbon free energy and load supports the diverse portfolio of resources needed to decarbonize the grid reliably and affordably
- PJM has provided a wealth of hourly data as part of the CAPSTF modeling; we use this information to demonstrate how the resources procured under each mechanism align with hourly demand

Carbon-Free Generation

Identify firm, dispatchable, and non-dispatchable generation options

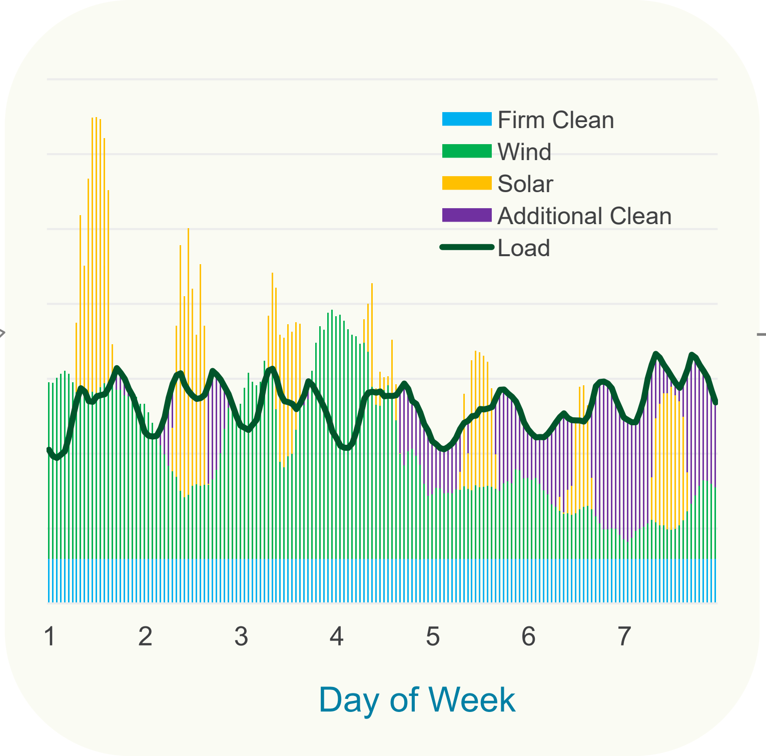
Load

Incorporate load date – either from individual customers or system-wide

Carbon Emissions

Capture data on grid emissions intensity

24/7 Hourly CFE Match



Auditing

Hourly digital certificates verify load matching

Reporting

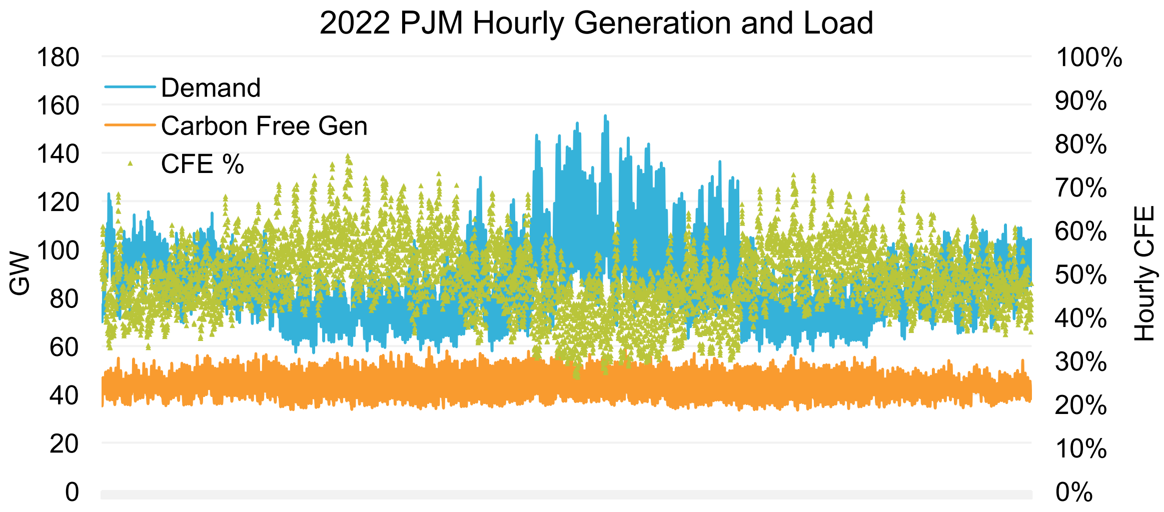
Our customers can see the CFE match achieved in every hour as well as key emissions impacts such as avoided CO_2

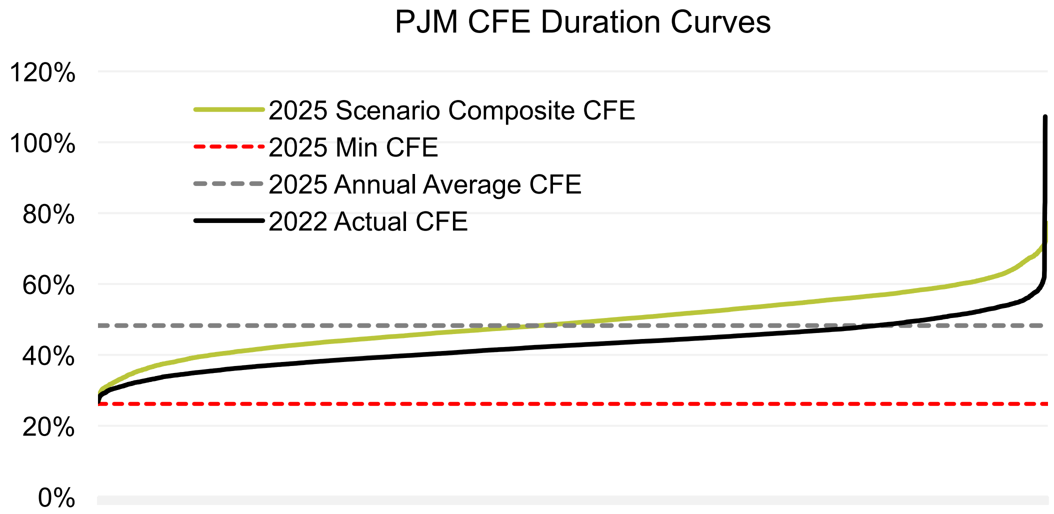
Flexibility

Ultimately, customers will be able to respond to gid conditions to better align load with gen portfolio

Calculating Hourly Carbon Free Energy (CFE) Scores

- **Central question:** How do procured renewable resources align with hourly load?
- To measure alignment, we calculate the Carbon Free Energy (CFE) score
  - In each hour, **CFE Score = Carbon-Free Generation ÷ Demand**
    - Carbon-free generation includes LFG, biomass, nuclear, wind, solar (including BTM), and conventional hydro. All other resource types are excluded
  - Here, we use ISO demand as the denominator
    - Individual customers would use the hourly CFE in their portfolio and their hourly load to calculate their hourly CFE score
- Using hourly data, we examine:
  - Timing of high and low periods of CFE
  - Duration of low-CFE periods
  - Marginal emissions rates
- We also use annual summary metrics
  - Annual min CFE
  - Low-CFE periods (defined as annual min + 10 percentage points)
  - Average CFE: load-weighted annual average where hourly CFE limited to 100%





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Scenario Groupings

Scenario	Group	2030 Total Wind/Solar Generation (GWh)
Status Quo (CPAWG; 1)	Status Quo	174
Status Quo (WEE)	Status Quo	182
FCEM, states' RECs (2A)	2A	178
ICCM, states' RECs (2B)	2B	181
FCEM, states' RECs, rational (2A)	2A	181
FCEM, regional REC (2C)	2C	173
ICCM, regional REC	Not included	177
FCEM, regional REC, rational (2C)	2C	177
RPM followed by FCEM, states' RECs (IMM)	IMM	186
RPM followed by FCEM, states' RECs, rational (IMM)	IMM	183
FCEM, 10% voluntary REC demand (2D)	2D 10	275
FCEM, 20% voluntary REC demand (2D)	2D 20	353
FCEM, 30% voluntary REC demand (2D)	2D 30	423
FCEM, 10% voluntary CEAC demand (2E)	2E 10	176
FCEM, 20% voluntary CEAC demand (2E)	2E 20	176
FCEM, 30% voluntary CEAC demand (2E)	2E 30	187
Status Quo, low clean capacity targets (3)	Clean Capacity Low	171
Status Quo, mid clean capacity targets (3)	Clean Capacity Mid	172
Status Quo, high clean capacity targets (3)	Clean Capacity High	180
FCEM+RPM, low clean capacity targets (4)	Clean Capacity Low	176
FCEM+RPM, mid clean capacity targets (4)	Clean Capacity Mid	173

Where multiple scenarios are mapped to the same group, results are calculated as an average across the group

These (2D) scenarios include substantially higher procurement targets

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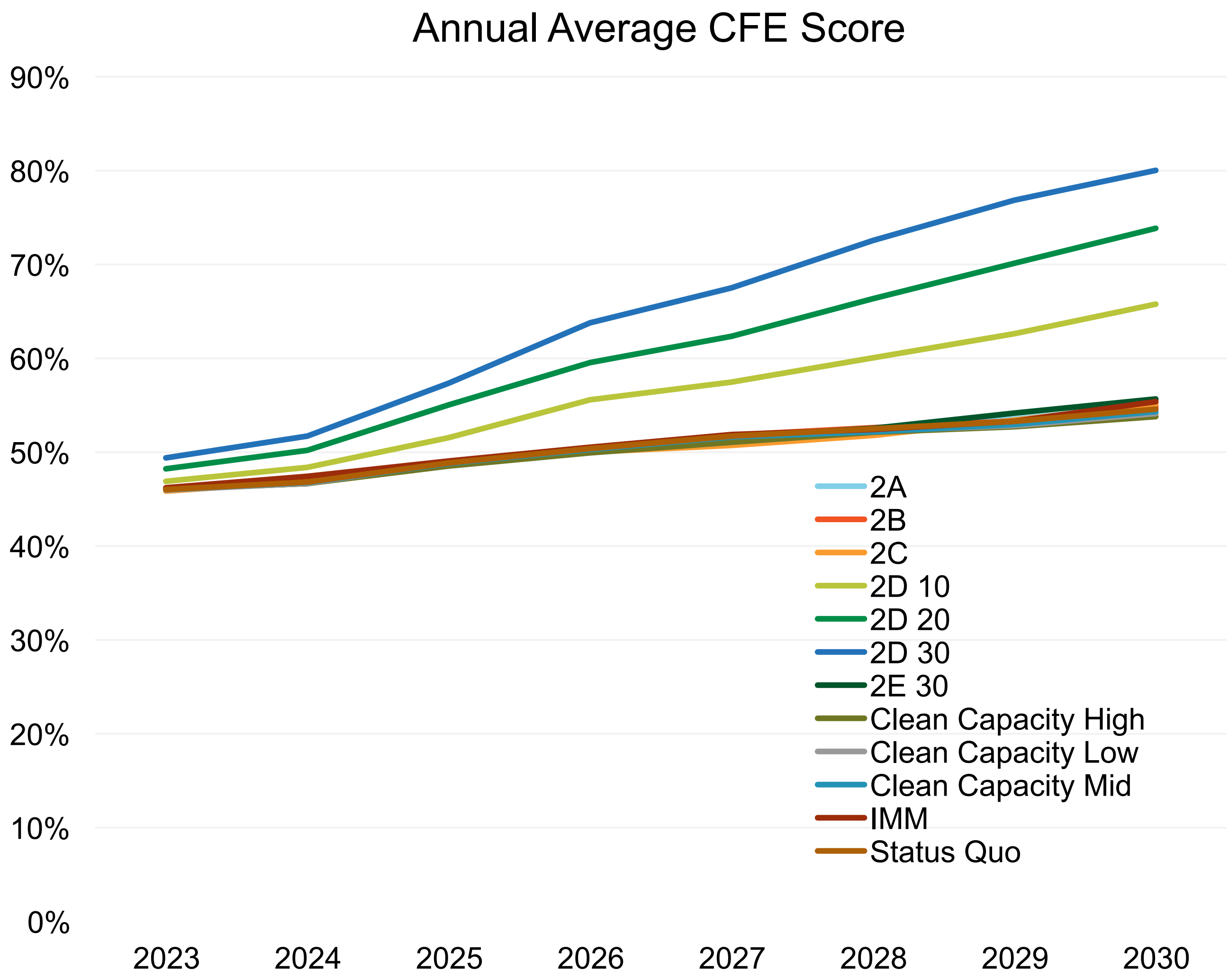
Annual Average CFE Scores

- At the ISO level, the various procurement methods produce only minor differences in annual average CFE through 2030
  - Most scenarios cluster at roughly 55% by 2030
- The annual average CFE does increase in scenarios that include additional voluntary demand
  - The highest CFE scores occur in FCEM, 30% voluntary demand scenario (2D), reaching 81% by 2030
  - We expect that CFE scores the CEAC scenarios (2E) would have been equivalent to the 2D scenarios if initial demand levels had been set at a level commensurate with total existing clean gen
- Nuclear generation constitutes the largest proportion of the CFE match: in 2023, the renewable-only CFE score is 10 percent



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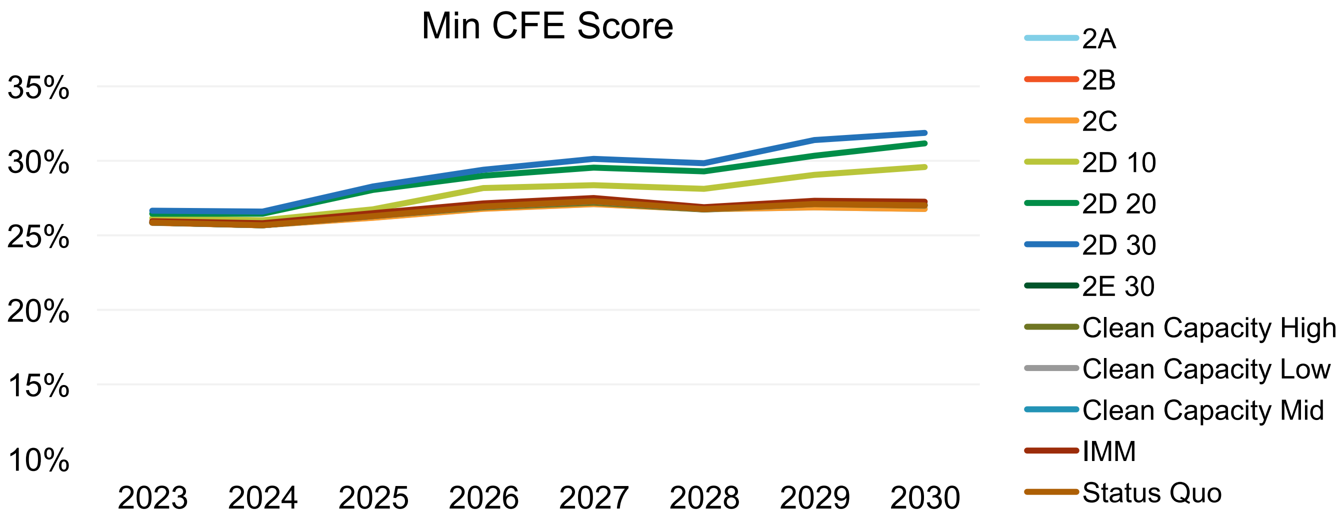
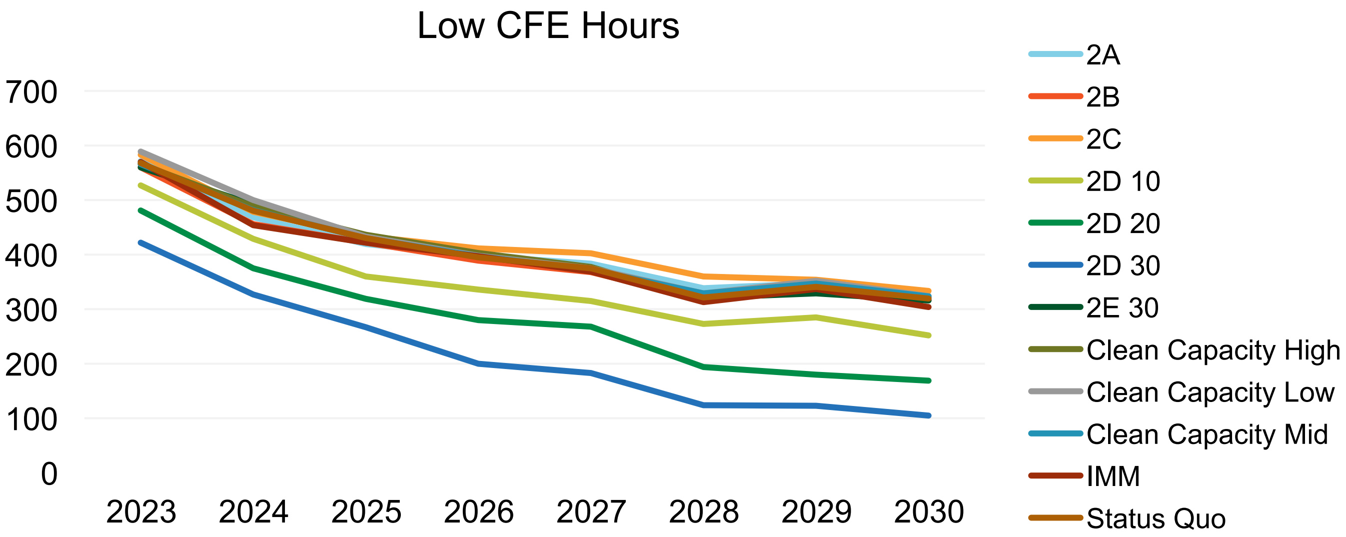
Minimum CFE Scores and Low-CFE Periods

- Annual minimum CFE scores are roughly 26%; again, without substantial differentiation among scenarios, except in those where procurement targets are increased
  - Further, the minimum CFE increases only marginally from 2023 to 2030
  - The tight clustering of minimum CFE scores indicates that there are persistent time periods of low CFE across all scenarios
- We define “low-CFE” periods as those in which the CFE score is within 10 percentage points of the annual minimum
- Across most of the scenarios, under 10% of the hours are low-CFE in 2023
  - By 2030, low-CFE hours constitute less than 5% of total hours
  - In 2022 nearly 1,500 hours were low-CFE (17% of total hours)





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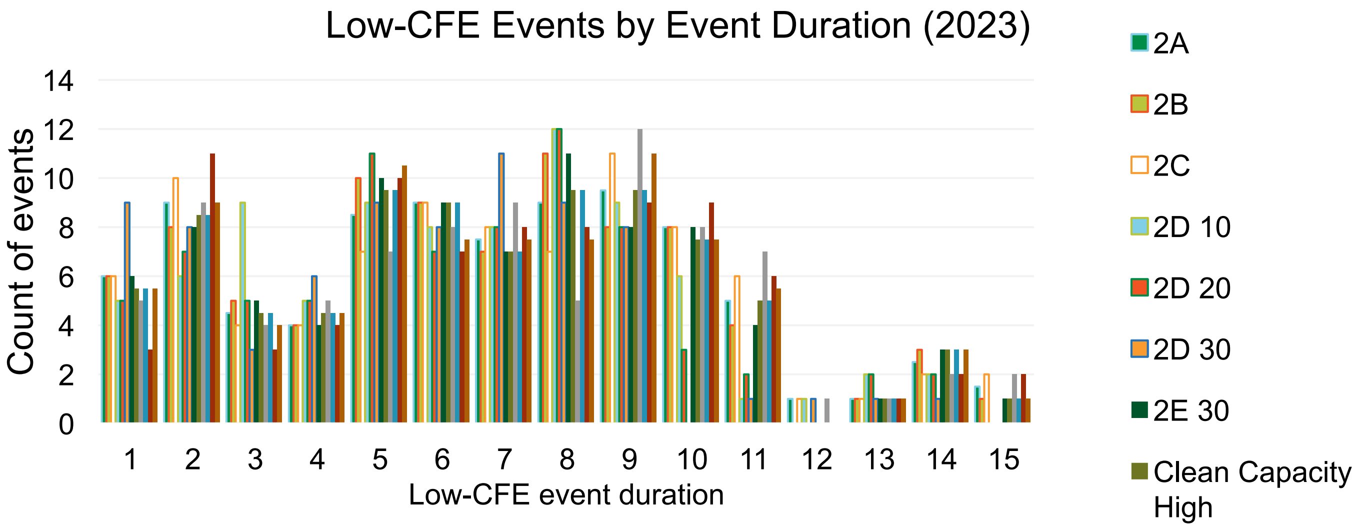
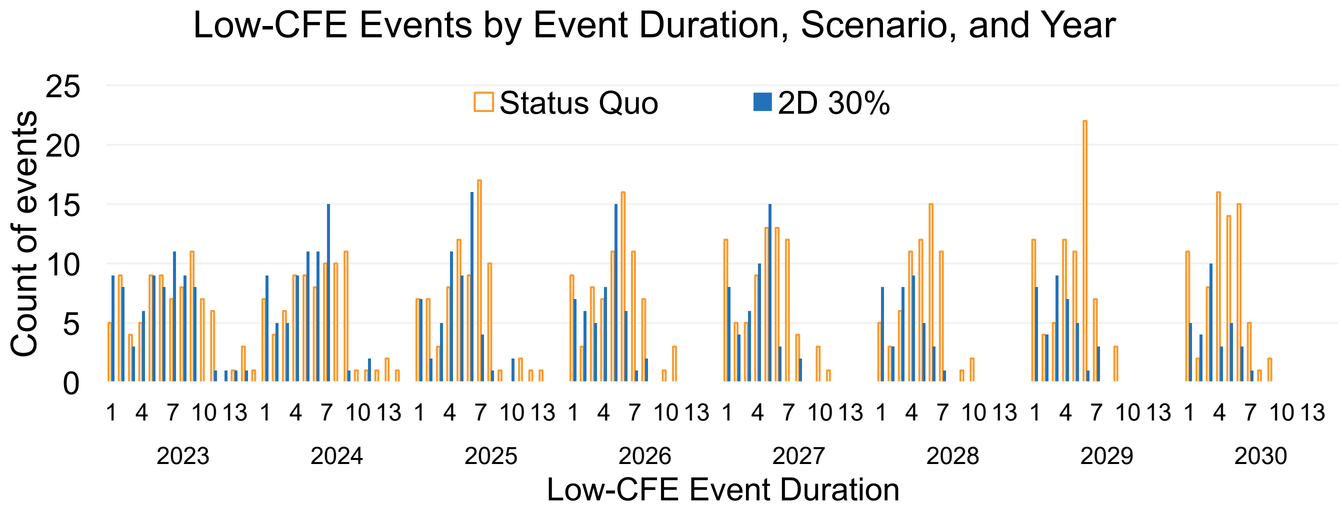
Low-CFE Event Frequency and Duration

- A “low-CFE event” is a discrete period of 1-hour or more during which the average CFE score is within 10 percentage points of the annual minimum CFE
  - The longest low-CFE event across all scenarios and years is 15 hours
  - 25-30% of low-CFE events are 4 hours or less
- Scenarios exhibit roughly similar patterns on low-CFE event duration, with most events lasting 5-10 hours
- Over the forecast period, the frequency of the longest duration low-CFE events drops, but middle-duration low-CFE event frequency increases
- In the 30% 2D scenario, the long-duration events attenuate more quickly, but shorter-duration events persist





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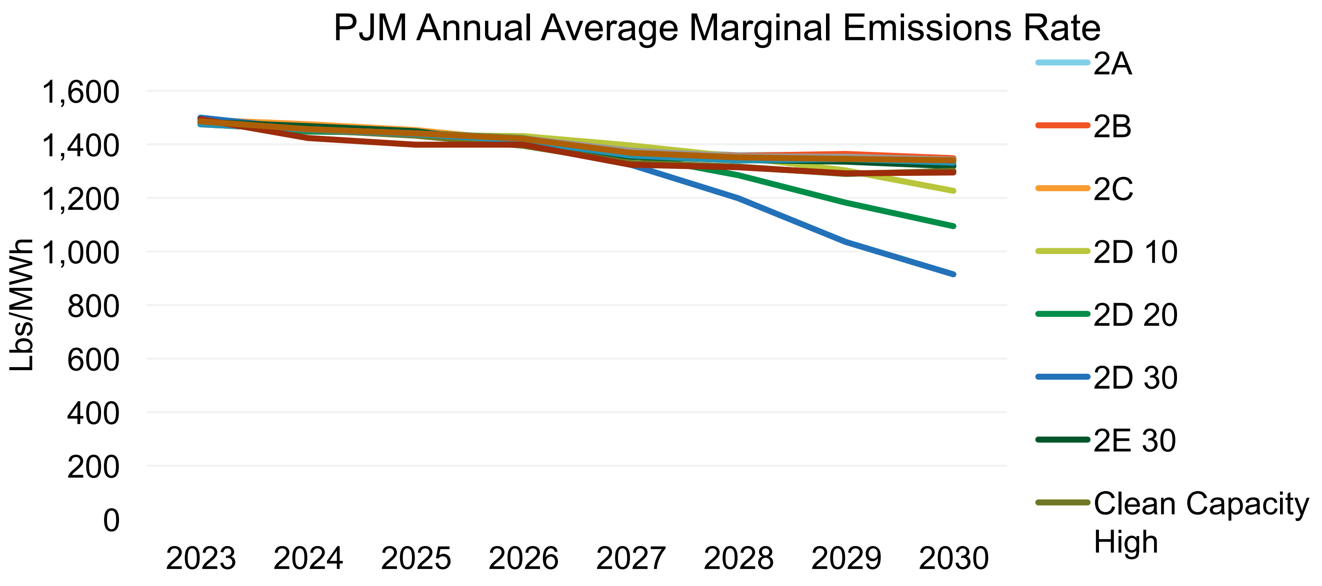
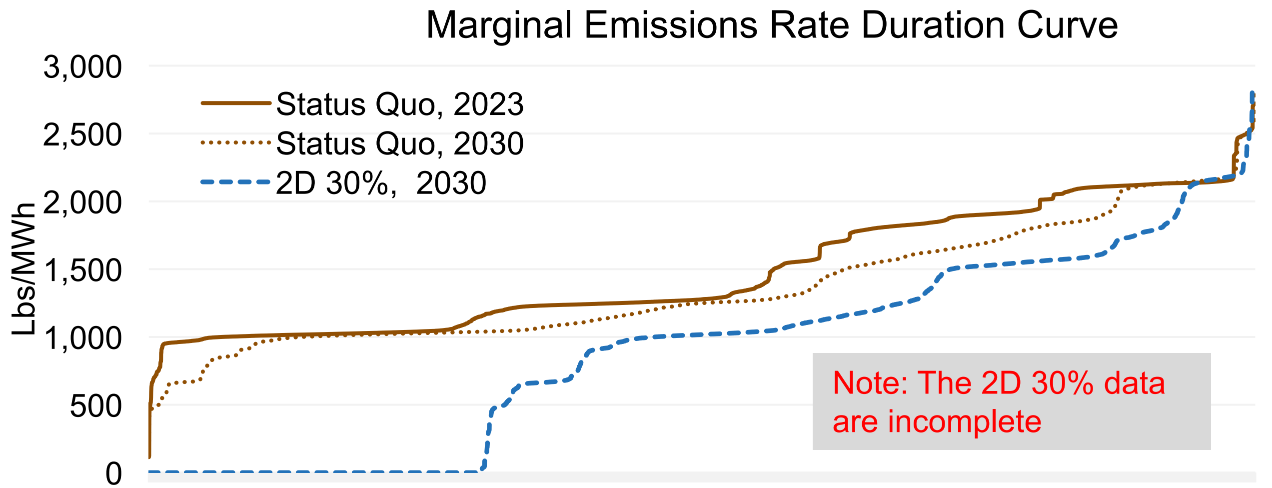
Marginal Emissions Rates

- The annual average marginal emissions rates* decline over time in all scenarios, though generally modestly
- In most scenarios, the rate falls roughly 11% from 2023 by 2030, while the rate in 2D 30% scenario drops 40% over the same time period
- As expected, the rate declines the most in the 2D scenarios, though results in these scenarios only separate from the others towards the end of the forecast period
- Note that in the 2D 30% scenario, there are roughly 2,600 hours where the marginal emissions rate is either zero or data are missing in 2030
  - From the available data, we can see that PJM is a net exporter of carbon free generation in at least 500 hours

*To calculate the PJM marginal emission rate, we use the load-weighted average of the zonal marginal emissions rates.





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