Scenario Identification

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FSSTF
09/20/2019

Goals of Scenario Analysis

Inform stakeholders about:	Phase 1	Phase 2: Phase 1 sensitivities based on stakeholder feedback	Phase 2: Additional scenarios using Relevant Risk data from historical cold snaps
1. Potential impacts of fuel/energy/resource risk events	✓	✓	✓
2. Factors that contribute to fuel/energy/resource security	✓	✓	✓
3. Risk of occurrence of selected scenarios			✓
4. Analysis framework that could be applied to **risks in other seasons** and **other resource portfolios**	✓	✓	✓

Phase 1 Sensitivities based on Stakeholder Feedback

Scenario Analysis Approach

Approach	Winter Load	Renewable Profiles	Relevant Risk Forced Outages	Other Forced Outages
Phase 1 & Phase 1 Sensitivities based on Stakeholder Feedback **(Phase 2)**	Typical • 50/50 peak (134,976 MW) • 2011/12 load profile Extreme Winter • 95/5 peak (147,721 MW) • 2017/18 load profile 14 day study period	2017/18 winter profiles, scaled to nameplate capacity in portfolio	Modeled sensitivities for fuel delivery risks: oil refueling, non-firm gas availability, pipeline disruptions	Forced outage rates using GADS cause codes not used in relevant risks or sensitivities
Historical Relevant Risk Events **(Phase 2)**	Load shapes consistent with selected cold snaps	Profile from cold snap, scaled to nameplate capacity in portfolio	Relevant Risk Forced Outages Rates from cold snap scaled to portfolio	
			Sensitivities for discrete occurrences of risks outside of historical forced outage dataset	

Portfolios: Announced (25.8% IRM), Escalated 1 (15.8% IRM), Escalated 2 (15.8% IRM), Escalated 3 (15.8% IRM)

Review: Phase 1 Scenarios

Dispatch	Retirement	Winter Load	Non-Firm Gas	Refueling	Pipeline Disruption (med. impact)	Pipeline Disruption (high impact)	Forced Outages
Economic	Announced	Typical 50/50 134,976 MW	62.5% Avail.	Moderate	Looped 1	Looped 1	Five-Year Avg.
Max. Emergency	Escalated 1	Extreme 95/5 147,721 MW	0% Avail.	Limited	Looped 2	Looped 2	Modeled Outages
	Escalated 2				Single 1	Single 1	
					Single 2	Single 2	

324
combinations

Phase 1 Sensitivities based on Stakeholder Feedback

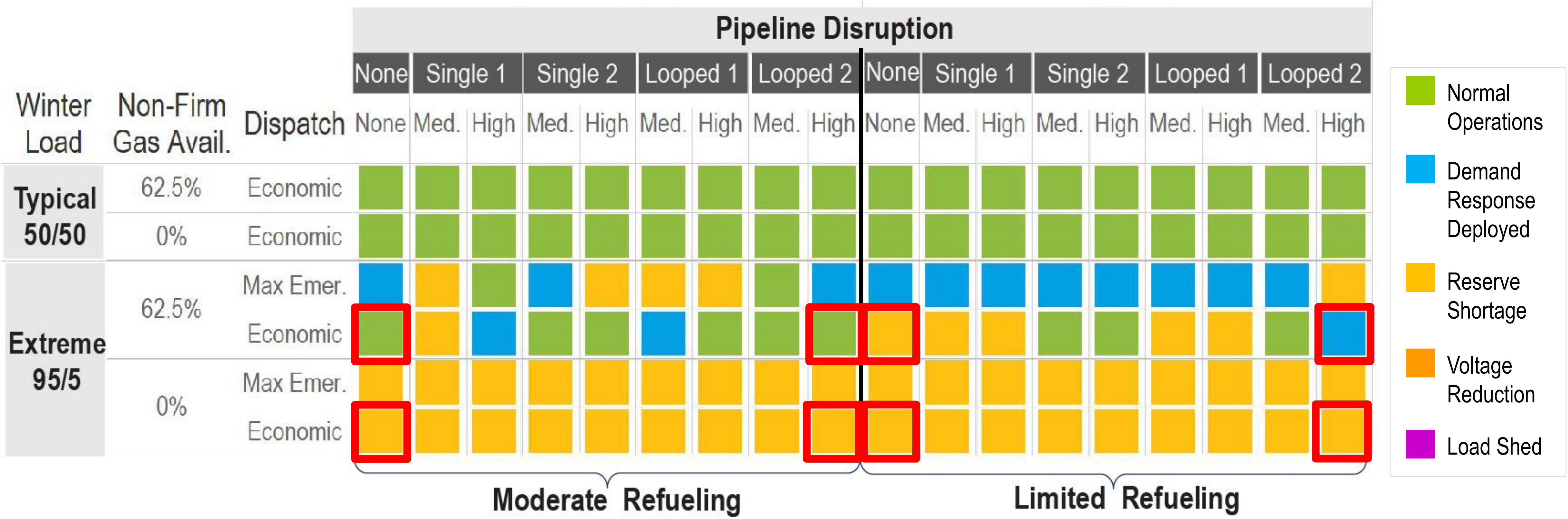
Adjust following **input assumptions**, one at a time, for selected scenarios:

1. Pipeline disruption concurrent with event peak load
2. 14-day pipeline disruption
3. Initial oil inventory level at 50%
4. Portfolio sensitivity with additional renewable replacement of retirements (Escalated 3)

Outputs consistent with Phase 1 results presented for each scenario:

Normal Operations	**No Emergency Procedures** Normal economic dispatch
Demand Response Deployed	**Pre-Emergency Action** Demand response deployment
Reserve Shortage	**Emergency Warning** An operational reserve shortage is triggered when 10-minute Synchronized Reserves are less than the largest generator in PJM. Depending on system conditions, a reserve shortage will trigger additional emergency procedures such as voltage reduction warnings and manual load shed warnings.
Voltage Reduction	**Emergency Action** Voltage reduction action enables load reductions by reducing voltages at the distribution level. PJM estimates a 1-2% load reduction resulting from a 5% load reduction in transmission zones capable of performing a voltage reduction.
Load Shed	**Emergency Action** Manual load shed action enables zonal or system-wide load shed. This is the last step of all emergency procedure actions.

Announced Retirement Models for Sensitivities



Escalated Retirement Models for Sensitivities

Pipeline Disruption

Winter Load	Retirement	Non-Firm Gas Avail.	Dispatch	Moderate Refueling									Limited Refueling								
				None	Single 1		Single 2		Looped 1		Looped 2		None	Single 1		Single 2		Looped 1		Looped 2	
				None	Med.	High	Med.	High	Med.	High	Med.	High	None	Med.	High	Med.	High	Med.	High	Med.	High
Typical 50/50	Escalated 1	62.5%	Economic																		
		0%	Economic																		
	Escalated 2	62.5%	Economic																		
		0%	Economic																		
Extreme 95/5	Escalated 1	62.5%	Max Emer.																		
			Economic																		3
		0%	Max Emer.	4	4	5	4	6	5	7	4	14	37	41	48	37	41	46	62	49	78
			Economic	9	10	11	9	10	9	13	9	22	43	44	56	42	46	47	63	53	83
	Escalated 2	62.5%	Max Emer.																		
			Economic																		
		0%	Max Emer.	4	3	5	4	4	4	4	3	4	11	12	13	13	14	14	15	14	22
			Economic	7	7	7	7	7	6	8	7	7	19	19	20	19	20	19	26	21	34

- Normal Operations
- Demand Response Deployed
- Reserve Shortage
- Voltage Reduction
- Load Shed

Phase 1 Sensitivities based on Stakeholder Feedback:
Pipeline Disruption Concurrent with Peak Load*

Sensitivity	Related Phase 1 Scenario #	Portfolio	IRM	Dispatch	Winter Load	Non-Firm Gas Availability	Infrastructure Disruption	Disruption Severity	Disruption Duration	Refueling	Initial Oil Inventory Level
1	45	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Moderate	85%
2	54	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Limited	85%
3	63	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Moderate	85%
4	72	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Limited	85%
5	153	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Moderate	85%
6	162	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Limited	85%
7	171	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Moderate	85%
8	180	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Limited	85%
9	261	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Moderate	85%
10	270	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D6-10	Limited	85%
11	279	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Moderate	85%
12	288	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D6-10	Limited	85%

*Peak of 147,721 MW occurs on Day 10 with Extreme Winter load shape

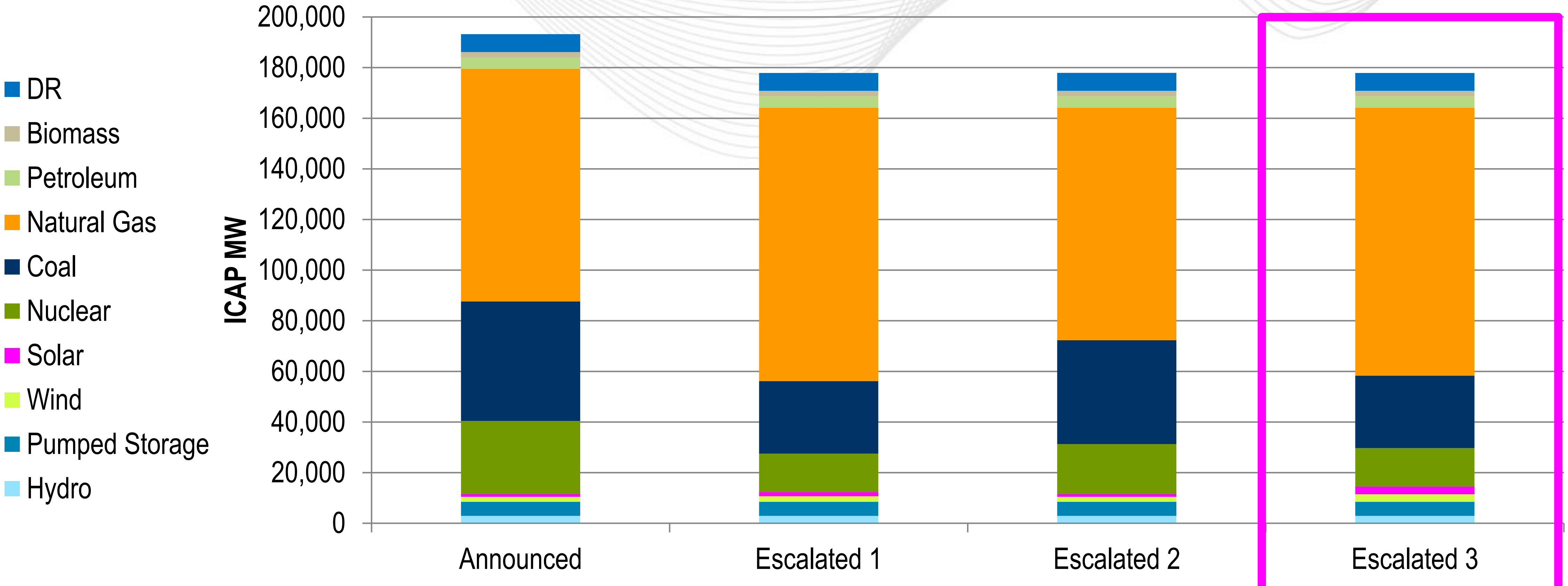
Phase 1 Sensitivities based on Stakeholder Feedback: **14-day Pipeline Disruption**

Sensitivity	Related Phase 1 Scenario #	Portfolio	IRM	Dispatch	Winter Load	Non-Firm Gas Availability	Infrastructure Disruption	Disruption Severity	Disruption Duration	Refueling	Initial Oil Inventory Level
13	45	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Moderate	85%
14	54	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Limited	85%
15	63	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Moderate	85%
16	72	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Limited	85%
17	153	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Moderate	85%
18	162	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Limited	85%
19	171	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Moderate	85%
20	180	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Limited	85%
21	261	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Moderate	85%
22	270	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-14	Limited	85%
23	279	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Moderate	85%
24	288	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-14	Limited	85%

Phase 1 Sensitivities based on Stakeholder Feedback: **Initial Oil Inventory Level at 50%**

Sensitivity	Related Phase 1 Scenario #	Portfolio	IRM	Dispatch	Winter Load	Non-Firm Gas Availability	Infrastructure Disruption	Disruption Severity	Disruption Duration	Refueling	Initial Oil Inventory Level
25	37	Announced	28.5%	Economic	Extreme	62.5%	None	None	None	Moderate	50%
26	46	Announced	28.5%	Economic	Extreme	62.5%	None	None	None	Limited	50%
27	55	Announced	28.5%	Economic	Extreme	0%	None	None	None	Moderate	50%
28	64	Announced	28.5%	Economic	Extreme	0%	None	None	None	Limited	50%
29	145	Escalated 1	15.8%	Economic	Extreme	62.5%	None	None	None	Moderate	50%
30	154	Escalated 1	15.8%	Economic	Extreme	62.5%	None	None	None	Limited	50%
31	163	Escalated 1	15.8%	Economic	Extreme	0%	None	None	None	Moderate	50%
32	172	Escalated 1	15.8%	Economic	Extreme	0%	None	None	None	Limited	50%
33	253	Escalated 2	15.8%	Economic	Extreme	62.5%	None	None	None	Moderate	50%
34	262	Escalated 2	15.8%	Economic	Extreme	62.5%	None	None	None	Limited	50%
35	271	Escalated 2	15.8%	Economic	Extreme	0%	None	None	None	Moderate	50%
36	280	Escalated 2	15.8%	Economic	Extreme	0%	None	None	None	Limited	50%
37	45	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Moderate	50%
38	54	Announced	28.5%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Limited	50%
39	63	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Moderate	50%
40	72	Announced	28.5%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Limited	50%
41	153	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Moderate	50%
42	162	Escalated 1	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Limited	50%
43	171	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Moderate	50%
44	180	Escalated 1	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Limited	50%
45	261	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Moderate	50%
46	270	Escalated 2	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Limited	50%
47	279	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Moderate	50%
48	288	Escalated 2	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Limited	50%

Addition of Escalated 3 Portfolio for Sensitivity



	Announced	Escalated 1	Escalated 2	Escalated 3
Wind (ICAP / nameplate)	1,945 / 14,962	2,163 / 16,638	1,945 / 14,962	2,940 / 22,613
Solar (ICAP / nameplate)	1,153 / 3,034	1,613 / 4,245	1,153 / 3,034	3,023 / 7,956

Phase 1 Sensitivities based on Stakeholder Feedback: **"Escalated 3" Portfolio**

Sensitivity	Related Phase 1 Scenario #	Portfolio	IRM	Dispatch	Winter Load	Non-Firm Gas Availability	Infrastructure Disruption	Disruption Severity	Disruption Duration	Refueling	Initial Oil Inventory Level
53	145	Escalated 3	15.8%	Economic	Extreme	62.5%	None	None	None	Moderate	85%
54	154	Escalated 3	15.8%	Economic	Extreme	62.5%	None	None	None	Limited	85%
55	163	Escalated 3	15.8%	Economic	Extreme	0%	None	None	None	Moderate	85%
56	172	Escalated 3	15.8%	Economic	Extreme	0%	None	None	None	Limited	85%
61	153	Escalated 3	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Moderate	85%
62	162	Escalated 3	15.8%	Economic	Extreme	62.5%	Pipeline (L2)	High	D1-5	Limited	85%
63	171	Escalated 3	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Moderate	85%
64	180	Escalated 3	15.8%	Economic	Extreme	0%	Pipeline (L2)	High	D1-5	Limited	85%

Scenarios using Relevant Risk data from Historical Cold Snap Events

Risk Assessment Review

June
- Why current focus on winter?
- Relevant Risk filtering and identification

July
- Historical Cold Snap data
- Historical Pipeline Disruption frequency data

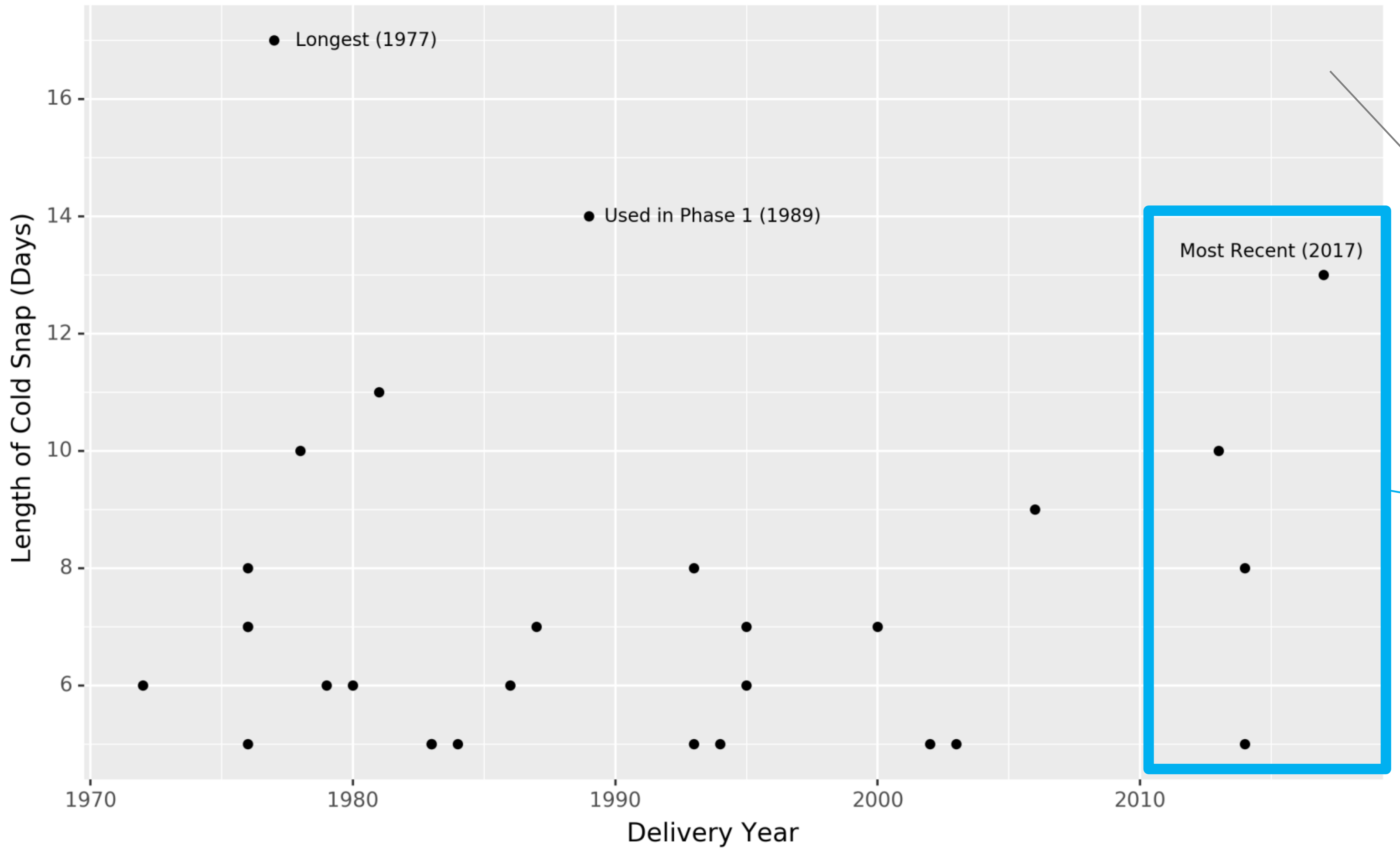
August
- Historical Pipeline Disruption impact data
- Historical Wind and Solar Intermittency
- Historical Relevant Risk data
- Discussion of scenario analysis approach

September
- Review of Relevant Risk data as input to scenario analysis

Relevant Risks for Winter Scenarios

Relevant Risks	Coverage
Long Duration Cold Snap	Covered in July
Short Duration Cold Snap	Covered in July
Natural Gas Pipeline Disruptions	Covered in July / August
Solar Intermittency	Covered in August
Wind Intermittency	Covered in August
Coal Refueling (Bridge Failure)	Covered in August
Coal Refueling (Lock and Dam Failure)	Covered in August
Coal Refueling (Rail Failure)	Covered in August
Coal Refueling (River Freezing)	Covered in August
Coal Unavailability (Coal Quality)	Covered in August
Natural Gas Unavailability Non-Firm Units	Covered in August
Oil Refueling (Oil Terminal)	Covered in August
Oil Refueling (Truck Restrictions)	Covered in August
Nuclear Regulatory Shutdown (Fuel Related)	Covered in August
Nuclear Regulatory Shutdown (Non-Fuel Related)	Covered in August
Nuclear Unavailability (High Winds)	Covered in August
Hydro Unavailability (Freezing Rivers)	Covered in August
River Freezing (Cooling Water Impacts)	Covered in August
Ice Storm (Transportation Impacts)	Covered in August

Cold Snaps



29 identified cold snaps in 47 winter periods (1972 – 2018)

- Definition: 5 or more contiguous days where average RTO wind-adjusted temperature (WWP) in each day is less than 21.5°F
- Average occurrence: 0.6 Cold Snaps per Delivery Year (Winter)
- Average Length: 7.5 days

4 Cold Snaps with available data for calculating:

- Fuel specific Relevant Risk Forced Outage Rates (RR-FOR)
- Wind & Solar capacity factor profiles

Cold Snaps Analyzed:

Cold Snap	Start	Stop	Duration
1	Jan. 21, 2014	Jan. 30 2014	10 Days
2	Jan. 6, 2015	Jan. 10, 2015	5 Days
3	Feb. 13, 2015	Feb. 20, 2015	8 Days
4	Dec. 26, 2017	Jan. 7, 2018	13 Days

Winter Peak Hours:

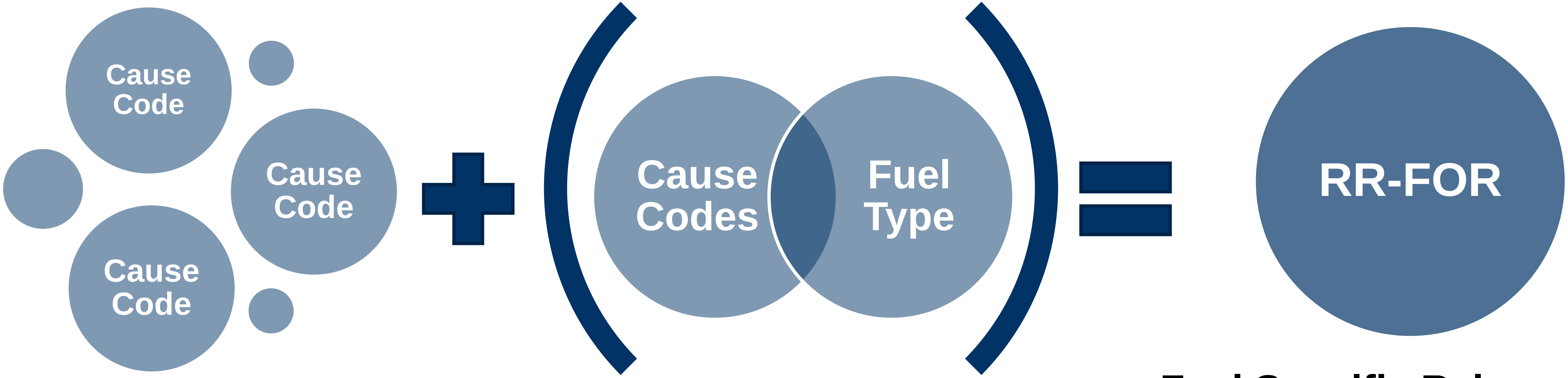
AM Peak	PM Peak
HE08 & HE09	HE19 & HE20

Forced Outage Rate:

$$\text{FOR} = \frac{\text{MW Forced Out}}{\text{Total Installed Nameplate}}$$

For coal, natural gas, nuclear, hydro, and oil resources, the forced outage rate serves as an indicator of the degree of unavailability for a set of resources

Fuel Specific Relevant Risk Forced Outage Rate (RR-FOR)



Fuel Specific Cause Codes

Common Cause Codes

Fuel Specific Relevant Risk Forced Outage Rate

Cold Snaps Analyzed:

Cold Snap	Start	Stop	Duration
1	Jan. 21, 2014	Jan. 30 2014	10 Days
2	Jan. 6, 2015	Jan. 10, 2015	5 Days
3	Feb. 13, 2015	Feb. 20, 2015	8 Days
4	Dec. 26, 2017	Jan. 7, 2018	13 Days

Winter Peak Hours:

AM Peak	PM Peak
HE08 & HE09	HE19 & HE20

Capacity Factor:

$$\mathrm{CF} = \frac{\text{Actual Hourly Output}}{\text{Total Installed Nameplate}}$$

For solar and wind resources, capacity factor serves as an indicator of how effectively the resources are performing

Scenario Analysis Approach

Approach	Winter Load	Renewable Profiles	Relevant Risk Forced Outages	Other Forced Outages
Phase 1 & Phase 1 Sensitivities based on Stakeholder Feedback **(Phase 2)**	Typical • 50/50 peak (134,976 MW) • 2011/12 load profile Extreme Winter • 95/5 peak (147,721 MW) • 2017/18 load profile 14 day study period	2017/18 winter profiles, scaled to nameplate capacity in portfolio	Explicitly modeled sensitivities for fuel delivery risks: oil refueling, non-firm gas availability, pipeline disruptions	Forced outage rates using GADS cause codes not used in relevant risks or sensitivities
Historical Relevant Risk Events **(Phase 2)**	Load shapes consistent with selected cold snaps	Profile from cold snap, scaled to nameplate capacity in portfolio	Relevant Risk Forced Outages Rates from cold snap scaled to portfolio Sensitivities for discrete occurrences of risks outside of historical forced outage dataset	

Portfolios: Announced (25.8% IRM), Escalated 1 (15.8% IRM), Escalated 2 (15.8% IRM), Escalated 3 (15.8% IRM)

Approach to Historical Cold Snap + Relevant Risk Scenarios

Set 1: Four most recent cold snaps with related RR-FOR and wind/solar capacity factor profiles from same period

Set 2: Scenarios for remaining 25 cold snaps paired with RR-FOR and wind/solar capacity factor profiles from each of the four cold snaps

		Fuel Specific RR-FOR				Wind & Solar Capacity Factor Profiles			
		CS-1	CS-2	CS-3	CS-4	CS-1	CS-2	CS-3	CS-4
Cold Snap	CS-1	Set 1				Set 1			
	CS-2		Set 1				Set 1		
	CS-3			Set 1				Set 1	
	CS-4				Set 1				Set 1
	Remaining 25	Set 2	Set 2	Set 2	Set 2	Set 2	Set 2	Set 2	Set 2

- Monte Carlo for other forced outages (non RR-FOR) in each scenario
- Approach could be applied to any portfolio – in this case will be using Phase 1 & Phase 1 sensitivity portfolios
- Results: Loss of load metrics

Goals of Scenario Analysis

Inform stakeholders about:	Phase 1	Phase 2	
		Phase 1 sensitivities based on stakeholder feedback	Additional scenarios using Relevant Risk data from historical cold snaps
1. Potential impacts of fuel/energy/resource risk events	✓	✓	✓
2. Factors that contribute to fuel/energy/resource security	✓	✓	✓
3. Risk of occurrence of selected scenarios			✓
4. Analysis framework that could be applied to **risks in other seasons** and **other resource portfolios**	✓	✓	✓

APPENDIX

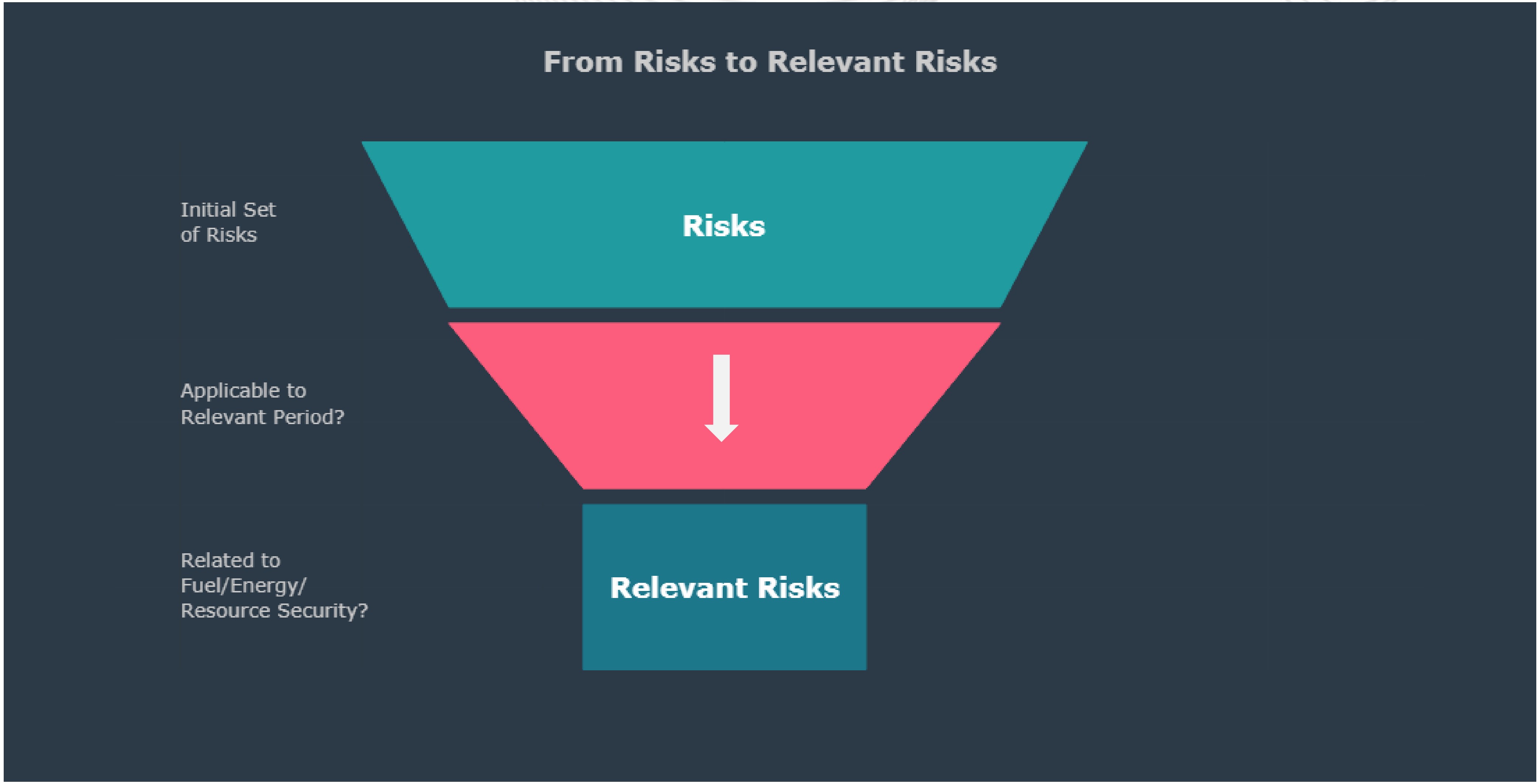
Education

FSSTF

June 26, 2019

Patricio Rocha Garrido, Resource Adequacy Planning
Daniel Bennett, Generation
Natalie Tacka, Applied Innovation
Patrick Bruno, Capacity Market Operations

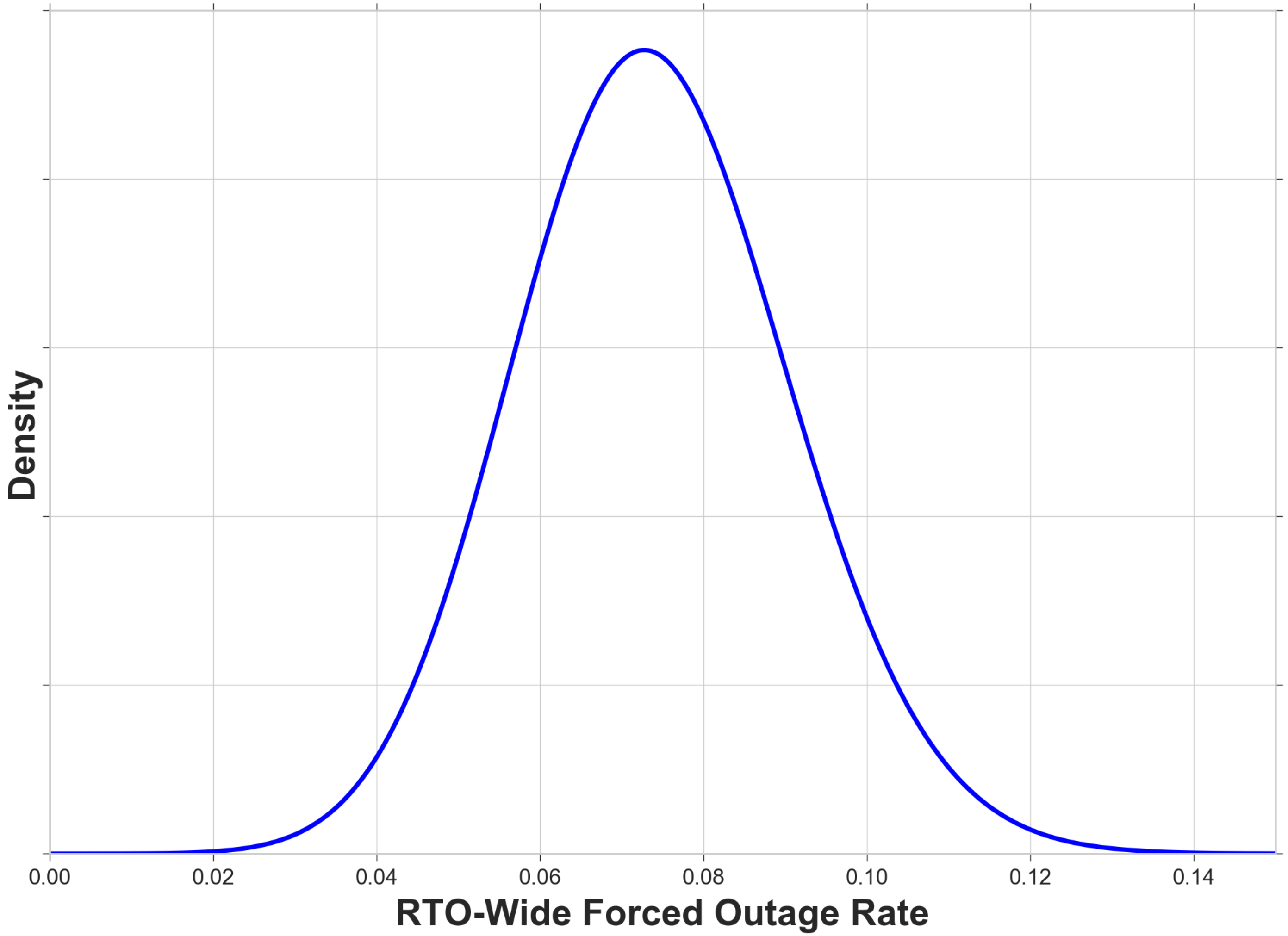
- At the previous FSSTF, PJM presented the approach to filter the Relevant Risks
  - This entailed determining a Relevant Period


From Risks to Relevant Risks
Initial Set of Risks
Risks
Applicable to Relevant Period?
Related to Fuel/Energy/ Resource Security?
Relevant Risks

- At today's FSSTF, PJM will make presentations
  - Supporting Winter as the Relevant Period
  - Showing a preliminary version of the Relevant Risks filtering process
  - Showing more information about current Products/Mechanisms that address the most typical uncertainties/risks
- At the July FSSTF, as part of the Gap Analysis, PJM will examine if the identified Relevant Risks are addressed by the current Products/Mechanisms

Relevant Period Identification and Methodology

Theoretical RTO-wide Forced Outage Rate



If individual forced outages are random and independent

Mean: ~7.0%
StDev: ~1.4%
90th Perc: ~9.2%

- For the last 11 years, the top 3 peak-load weeks of each season are identified
- The RTO-wide Forced Outage Rate at the peak hour of each weekday within each of the above weeks is recorded
- Therefore, for instance, for Winter Week 1
  - There are 11 winter peak weeks (one for each year)
  - There are 5 peak hours within each of the above weeks (one for each weekday)
  - We end up with 55 RTO-wide forced outage observations

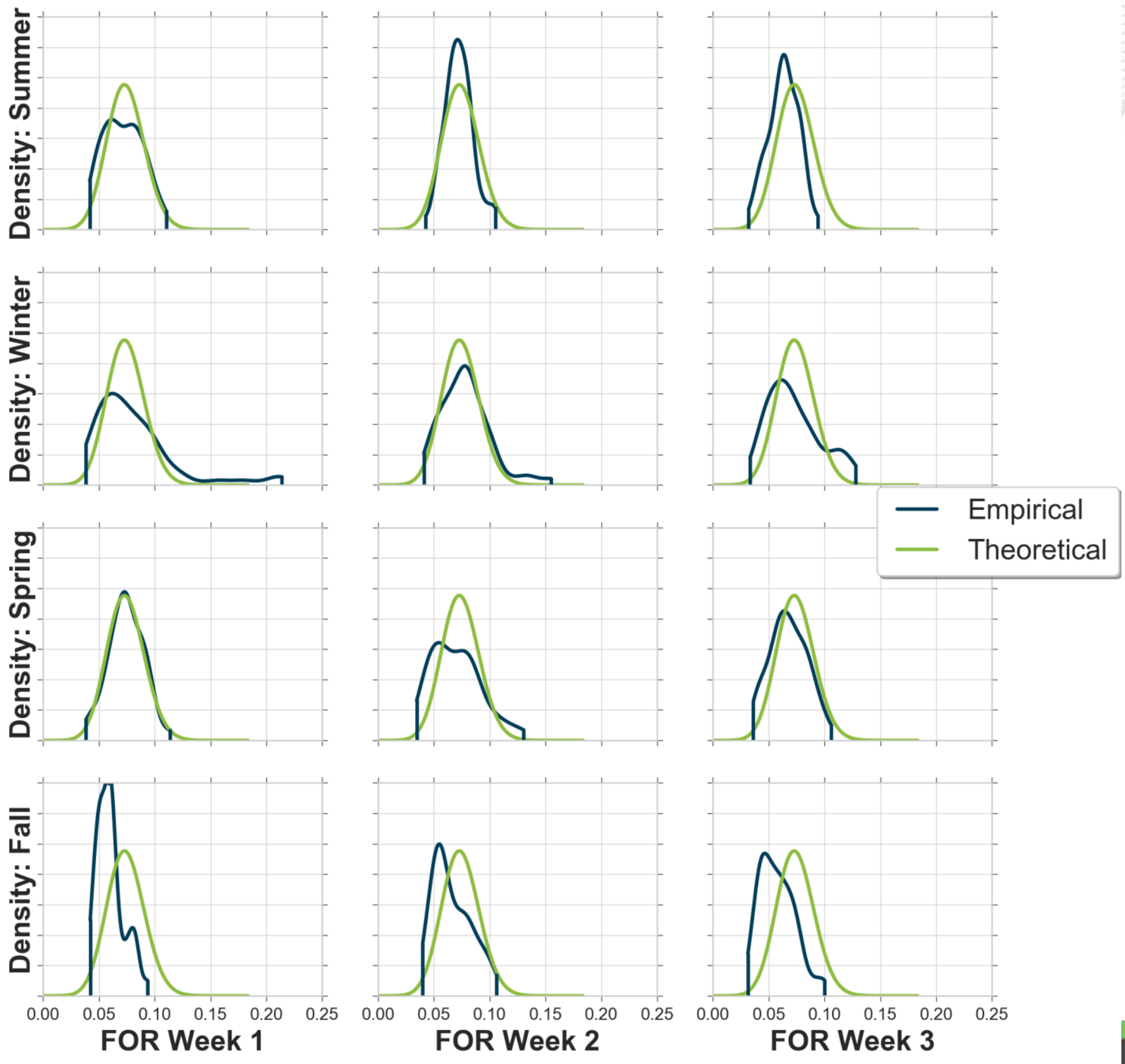
Empirical RTO-wide Forced Outage Rates

Season	Load-Magnitude Ordered Week	RTO-Wide Forced Outage Rate Mean	StDev	90th perc
Summer	1	7.1%	1.8%	9.3%
Summer	2	7.2%	1.3%	8.5%
Summer	3	6.3%	1.3%	7.9%
Winter	1	8.2%	3.8%	11.8%
Winter	2	7.8%	2.3%	10.2%
Winter	3	7.3%	2.4%	11.3%
Spring	1	7.4%	1.6%	9.2%
Spring	2	7.0%	2.3%	10.1%
Spring	3	6.7%	1.7%	8.8%
Fall	1	6.0%	1.2%	8.0%
Fall	2	6.6%	1.7%	9.3%
Fall	3	5.8%	1.6%	7.6%

For comparison, the Theoretical distribution has the following statistics:

Mean: ~7.0%
StDev: ~1.4%
90th Perc: ~9.2%

Empirical vs Theoretical Distributions



Height of line represents how often forced outage rates in x-axis have occurred in the last 11 years for each of the season-week combinations.

In the Top 3 winter weeks, the empirical forced outage distribution (blue line) has a longer right-hand side tail than the theoretical forced outage distribution (green line).

Observations

- The previous slide shows that historical RTO-wide Forced Outage Rates during the Top 3 Winter weeks do not comport with the independence assumption
  - For the Top 3 weeks of the rest of the seasons the independence assumption seems to hold
- Why have RTO-wide forced outage rates been historically greater during the Top 3 Winter weeks?

Forced Outages due to Lack Of Fuel

- Using the Empirical RTO-wide Forced Outage Rate data, but only considering those forced outages with cause codes related to lack of fuel yields the following table

		RTO-Wide Forced Outage MW due to Lack of Fuel		
Season	**Load-Magnitude Ordered Week**	**Mean**	**StDev**	**90th perc**
Winter	1	2,310	2,670	6,649
Winter	3	1,744	2,307	4,572
Winter	2	1,600	1,640	3,404
Spring	2	794	1,448	1,648
Spring	1	570	651	1,284
Spring	3	563	516	1,351
Fall	3	476	497	1,219
Fall	2	307	486	1,170
Summer	3	194	368	871
Fall	1	172	307	654
Summer	1	131	300	339
Summer	2	113	308	317

The weeks showing the highest volume of forced outages due to lack of fuel (Winter 1, Winter 3, Winter 2, Spring 2) are the same weeks showing a longer right-hand side tail for the empirical forced outage distribution in Slide 5.

The top 3 Winter weeks are by far the weeks with the highest volume of forced outages due to lack of fuel

Seasonal Peak Load Consideration

- In addition, Winter is the season with the second highest peak loads. For instance, according to the 2019 PJM Load Forecast for Delivery Year 2023

  Forecasted 50/50 Seasonal Peaks:
  - Summer: 152,854 MW
  - Winter: 133,882 MW
  - Spring: 120,617 MW
  - Fall: 130,255 MW

Conclusion

- Putting together the above Forced Outages and Seasonal Peak Load considerations, the Winter Peak Period is the most concerning period from a Fuel/Resource Security perspective given the potential for high forced outage levels and high peak loads that may result in loss-of-load events
  - This supports the approach taken in Phase 1 whose results show loss-of-load events during a Winter cold snap under a high volume of forced outages

Risk Filtering Process and Scenario Review

Definitions

Risk

- Any event that may pose a resource adequacy issue for the PJM system

Relevant Period(s)

- Period(s) of the year in which Fuel/Energy/Resource Security issues may result in potential resource adequacy issues

Relevant Risk

- A subset of the identified Risks relevant to Fuel/Energy/Resource Security scope and that may occur during the determined Relevant Period

Relevant Scenarios

- Combination of potential realizations of Relevant Risks that create a set of conditions to be evaluated

Objectives and Process

Identify Risks

- Review historical data and solicit input from stakeholders and area experts to list Risks to the PJM system

Narrow to Relevant Risks

- Analyze the Risks identified to develop a list of risks within the Fuel/Energy/Resource Security scope and the identified Relevant Period

Collect Data on Study Risks

- Collect data on the frequency of occurrence, generation impact, locational nature, and other factors necessary to model the Study Risks and their affect of Fuel/Energy/Resource Security

Define Relevant Scenarios

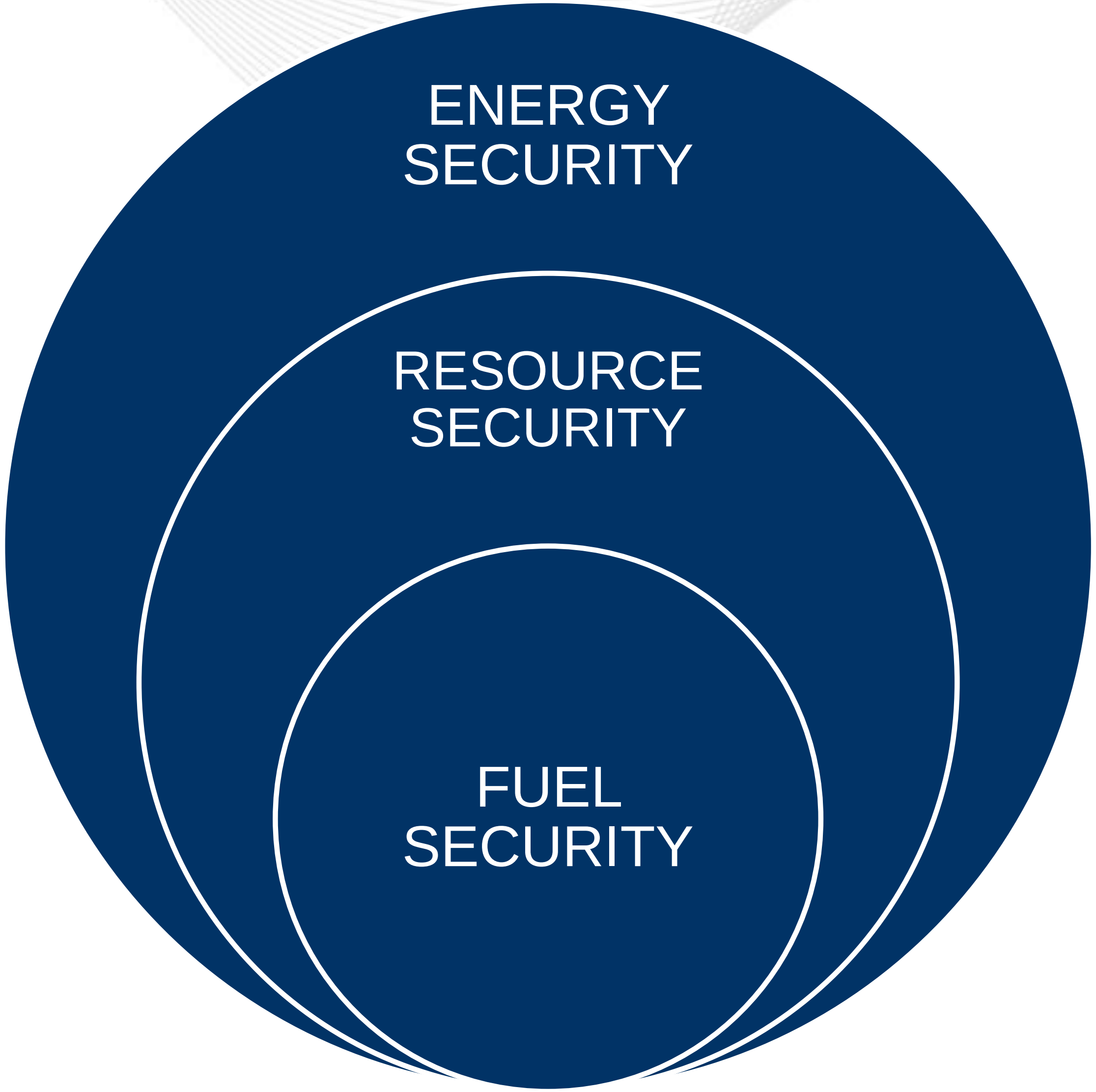
- Combine the Relevant Risks into event scenarios and identify any significant gaps from Phase 1 scenarios

Evaluate Relevant Scenarios

- Identify Relevant Scenarios with high loss of load impact to the PJM system

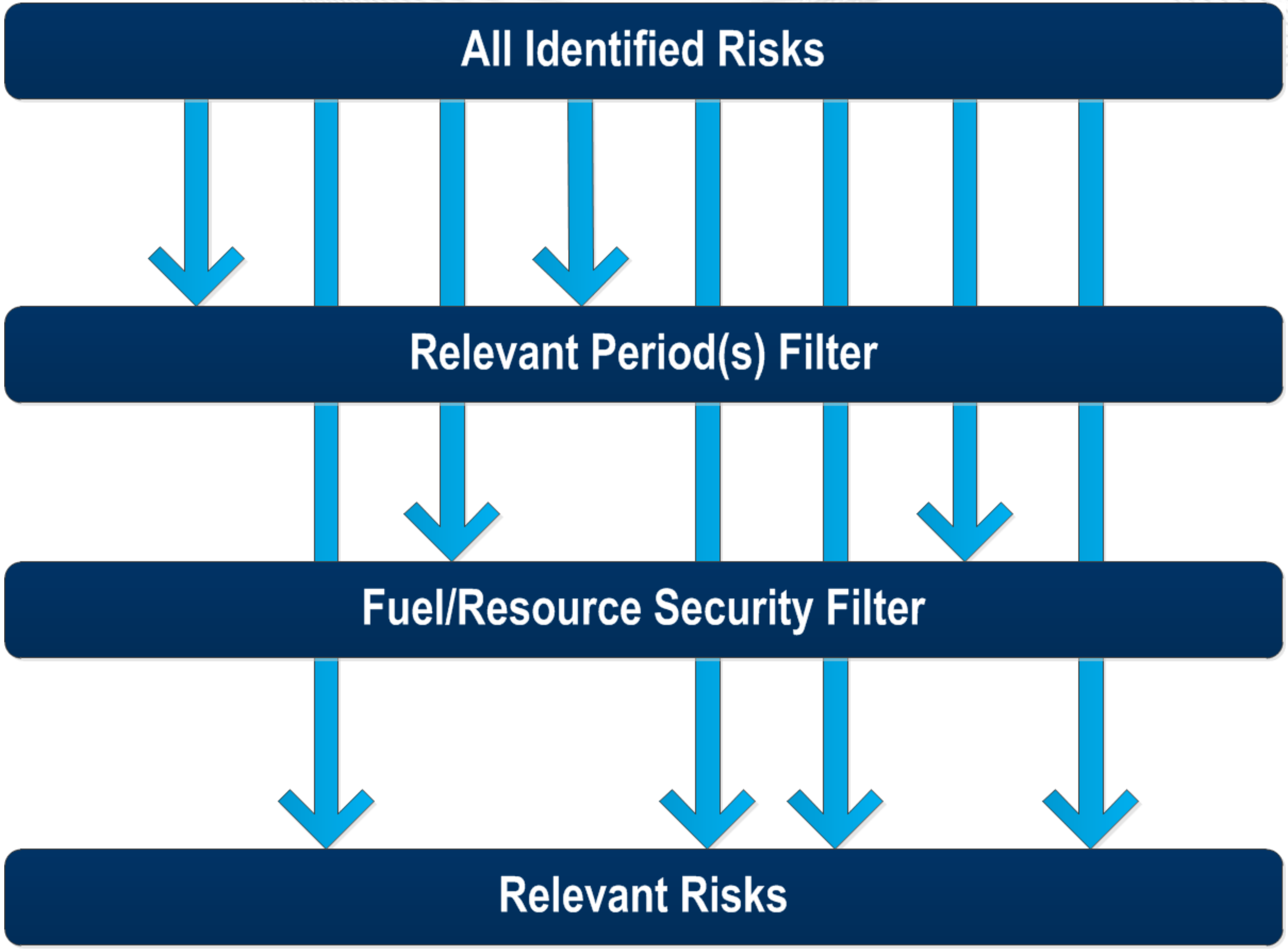
Senior Task Force Charter Terms

<u>Fuel Security</u>:
This can be categorized as the availability of fuel both on-site and assessed from delivery systems required for a unit to generate consistent with dispatch signals or operating instructions. This includes all resource types



<u>Resource Security</u>:
Availability of a set of resources with the same fuel type associated with different types of common vulnerabilities. Includes all resource types.

Relevant Risk Identification



Identified Risks (1 of 3)

INDEX	RISK	DESCRIPTION
1	Long Duration Cold Snap	Consecutive days below a temperature threshold greater than a set duration
2	Short Duration Cold Snap	Consecutive days below a temperature threshold less than a set duration
3	Long Duration Heat Wave	Consecutive days above a temperature threshold greater than a set duration
4	Short Duration Heat Wave	Consecutive days above a temperature threshold less than a set duration
5	Coal Refueling (Bridge Failure)	Reduced coal refueling capacity due to a bridge failure
6	Coal Refueling (Lock and Dam Failure)	Reduced coal refueling capacity due to a lock and dam failure
7	Coal Refueling (Rail Failure)	Reduced coal refueling capacity due to a failure of the rail infrastructure
8	Coal Refueling (River Freezing)	Reduced coal refueling capacity due to freezing rivers impacting barge traffic
9	Coal Unavailability (Coal Quality)	The unavailability of coal fired units due to poor fuel quality (wet coal, low quality coal, etc.)

Identified Risks (2 of 3)

INDEX	RISK	DESCRIPTION
10	Natural Gas Pipeline Disruptions	Any disruption to the natural gas pipeline infrastructure (pipe, gas compressor, etc.) that impacts the ability to transport natural gas, excluding malicious causes (to be included in Phase 3)
11	Natural Gas Unavailability Non-Firm Units	The curtailment or unavailability of natural gas delivery to units with interruptible transportation for any reason
12	Oil Refueling (Oil Terminal)	Reduced oil refueling capacity due to limitations at oil terminals or other oil supply centers
13	Oil Refueling (Truck Restrictions)	Reduced oil refueling capacity due to truck transportation limitations
14	Nuclear Regulatory Shutdown (Fuel Related)	A mandated shutdown or power reduction of nuclear units for reasons related to fuel issues
15	Nuclear Regulatory Shutdown (Non-Fuel Related)	A mandated shutdown or power reduction of nuclear units for reasons not related to fuel issues
16	Nuclear Unavailability (High Winds)	The preemptive shutdown or power reduction of nuclear units due to high wind speeds

Identified Risks (3 of 3)

INDEX	RISK	DESCRIPTION
17	Hydro Unavailability (Drought / Low Water Level)	Reduced hydro availability due to low water levels or droughts
18	Hydro Unavailability (Freezing Rivers)	Reduced hydro availability due to river freezing
19	Solar Intermittency	The inherent intermittency of solar resources throughout the year
20	Wind Intermittency	The inherent intermittency of wind resources throughout the year; Temperature-triggered shutdown based on turbine settings
21	High River Temperatures / Drought (Cooling Water Impacts)	Plant efficiency impacts caused high river water temperatures reducing cooling capabilities
22	River Freezing (Cooling Water Impacts)	Plant efficiency impacts caused by river freezing (ice on screens, reduced water intake capabilities, etc.)
23	Earthquake	An earthquake that affects the PJM footprint
24	Hurricane / Tropical Storms	A hurricane or tropical storm that affects the PJM footprint
25	Ice Storm (Transportation Impacts)	An ice storm that affects the PJM footprint and adversely impacts the transportation of fuel or other commodities

INDEX	RISK	SPRING	SUMMER	FALL	WINTER
1	Long Duration Cold Snap				
2	Short Duration Cold Snap				
3	Long Duration Heat Wave				
4	Short Duration Heat Wave				
5	Coal Refueling (Bridge Failure)				
6	Coal Refueling (Lock and Dam Failure)				
7	Coal Refueling (Rail Failure)				
8	Coal Refueling (River Freezing)				
9	Coal Unavailability (Coal Quality)				
10	Natural Gas Pipeline Disruptions				
11	Natural Gas Unavailability Non-Firm Units				
12	Oil Refueling (Oil Terminal)				
13	Oil Refueling (Truck Restrictions)				
14	Nuclear Regulatory Shutdown (Fuel Related)				
15	Nuclear Regulatory Shutdown (Non-Fuel Related)				
16	Nuclear Unavailability (High Winds)				
17	Hydro Unavailability (Drought / Low Water Level)				
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19	Solar Intermittency				
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23	Earthquake				
25	Ice Storm (Transportation Impacts)				

INDEX	RISK	FUEL SECURITY	RESOURCE SECURITY	Explicitly Modeled PHASE 1
1	Long Duration Cold Snap			
2	Short Duration Cold Snap			
5	Coal Refueling (Bridge Failure)			
6	Coal Refueling (Lock and Dam Failure)			
7	Coal Refueling (Rail Failure)			
8	Coal Refueling (River Freezing)			
9	Coal Unavailability (Coal Quality)			
10	Natural Gas Pipeline Disruptions			
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22	River Freezing (Cooling Water Impacts)			
25	Ice Storm (Transportation Impacts)			

Scenario Feedback Mapped to Identified Risks

- A matrix combining feedback on risks/scenarios submitted by stakeholders with a mapping to the identified risks is located on the FSSTF webpage:
  - https://www.pjm.com/committees-and-groups/task-forces/fsstf.aspx

Next Steps

Identify Risks

- Review historical data and solicit input from stakeholders and area experts to list Risks to the PJM system

Narrow to Relevant Risks

- Analyze the Risks identified to develop a list of risks within the Fuel/Energy/Resource Security scope and the identified Relevant Period

Collect Data on Study Risks

- Collect data on the frequency of occurrence, generation impact, locational nature, and other factors necessary to model the Study Risks and their affect of Fuel/Energy/Resource Security

Define Relevant Scenarios

- Combine the Relevant Risks into event scenarios and identify any significant gaps from Phase 1 scenarios

Evaluate Relevant Scenarios

- Identify Relevant Scenarios with high loss of load impact to the PJM system

Cold Snaps and Pipeline Disruptions – Historical Data

Patricio Rocha Garrido
FSSTF
07/16/2019

- At the May FSSTF, PJM presented the Risk Assessment Approach which included:
  - Identifying the Relevant Risks (this was covered at the June FSSTF meeting)
  - Identifying the potential realizations of each Relevant Risk.
    - To accomplish this, historical data on each Relevant Risk will be analyzed
- At today's FSSTF, PJM will present historical data on two such Relevant Risks: Cold Snap and Pipeline Disruptions
- At the August FSSTF, PJM will present historical data on the remaining Relevant Risks as well as the impact of the Relevant Risks on PJM generation

Relevant Risks Identified at June FSSTF Meeting

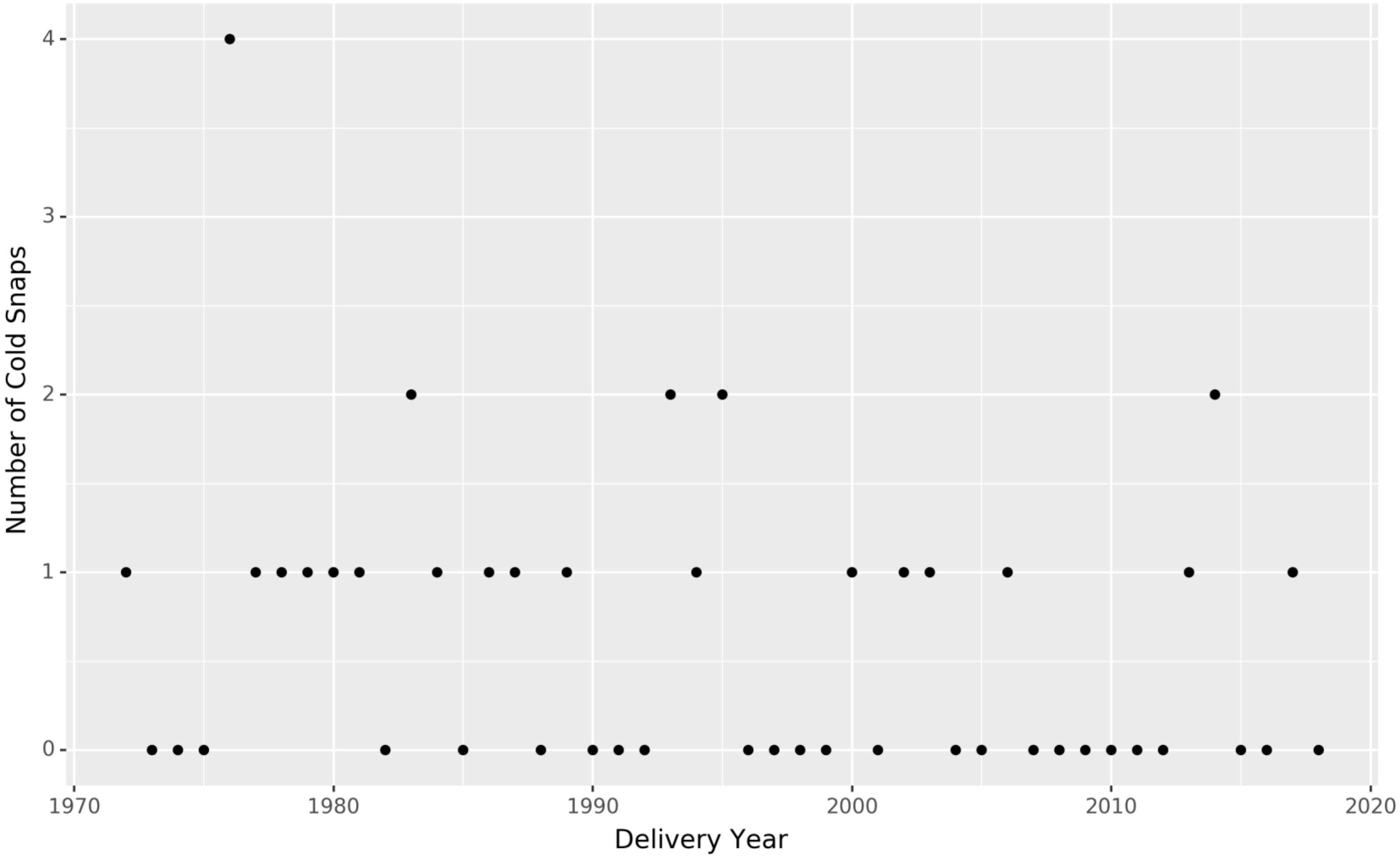
Relevant Risks
Long Duration Cold Snap
Short Duration Cold Snap
Natural Gas Pipeline Disruptions
Solar Intermittency
Wind Intermittency
Coal Refueling (Bridge Failure)
Coal Refueling (Lock and Dam Failure)
Coal Refueling (Rail Failure)
Coal Refueling (River Freezing)
Coal Unavailability (Coal Quality)
Natural Gas Unavailability Non-Firm Units
Oil Refueling (Oil Terminal)
Oil Refueling (Truck Restrictions)
Nuclear Regulatory Shutdown (Fuel Related)
Nuclear Regulatory Shutdown (Non-Fuel Related)
Nuclear Unavailability (High Winds)
Hydro Unavailability (Freezing Rivers)
River Freezing (Cooling Water Impacts)
Ice Storm (Transportation Impacts)

Cold Snap – Definition

- A series of 5 or more contiguous days where the average RTO wind-adjusted temperature (WWP) in each of such days is less than 21.5°F
  - The RTO WWP for a given day is calculated as a load-weighted average across 30+ weather stations in the current PJM footprint, and across the 24 hour readings of each day
  - The 21.5°F threshold corresponds to an estimate of the 90th percentile value of historical daily RTO average WWP values

- Weather data from period DY1972 - DY2018 (47 winter periods)
- Average RTO wind-adjusted temperature (WWP) is calculated for each of the winter days

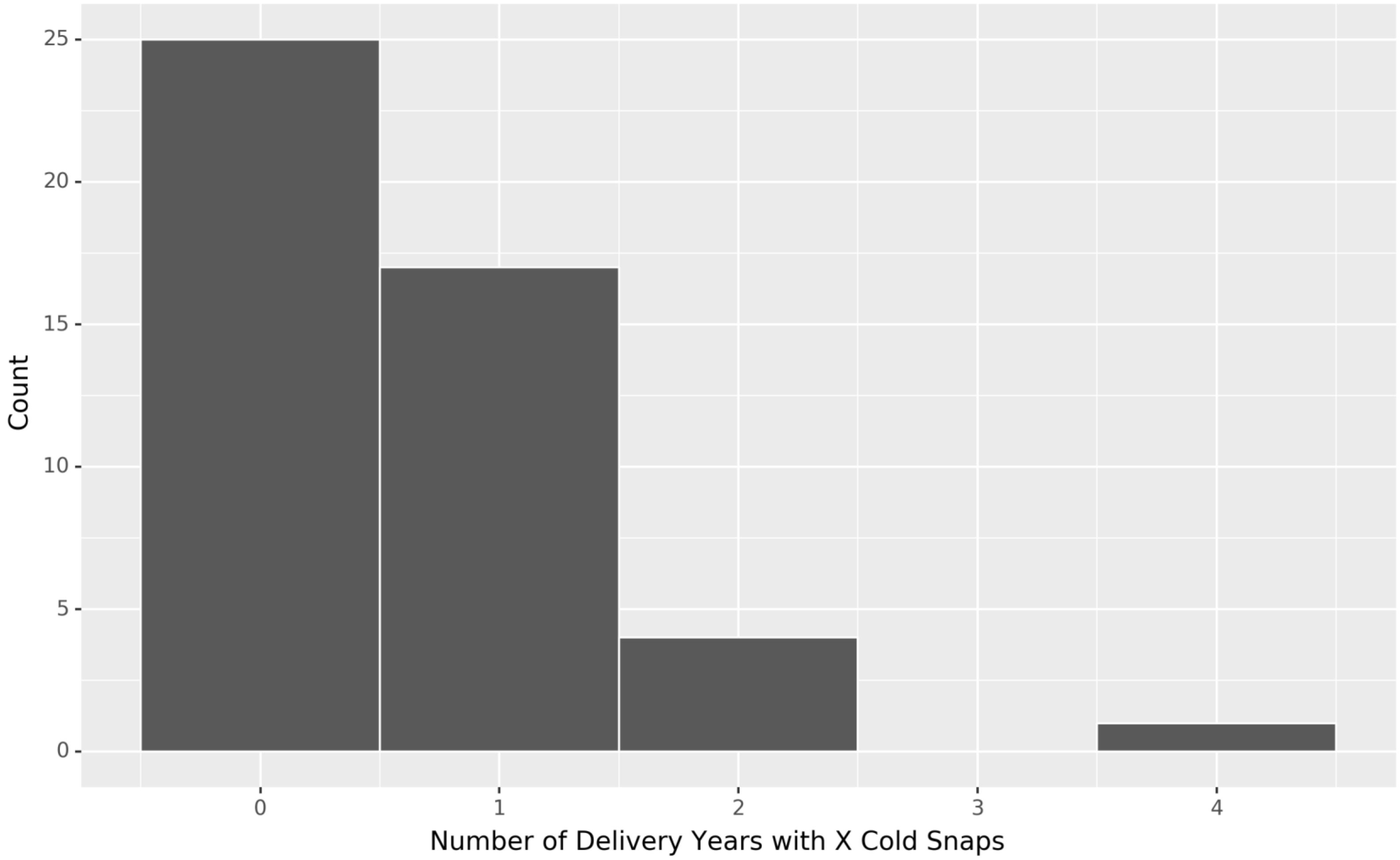
Cold Snaps – Delivery Year vs Number of Cold Snaps



A total of 29 cold snaps
in 47 winter periods
are identified

Average: 0.6 Cold Snaps
per Delivery Year (Winter)

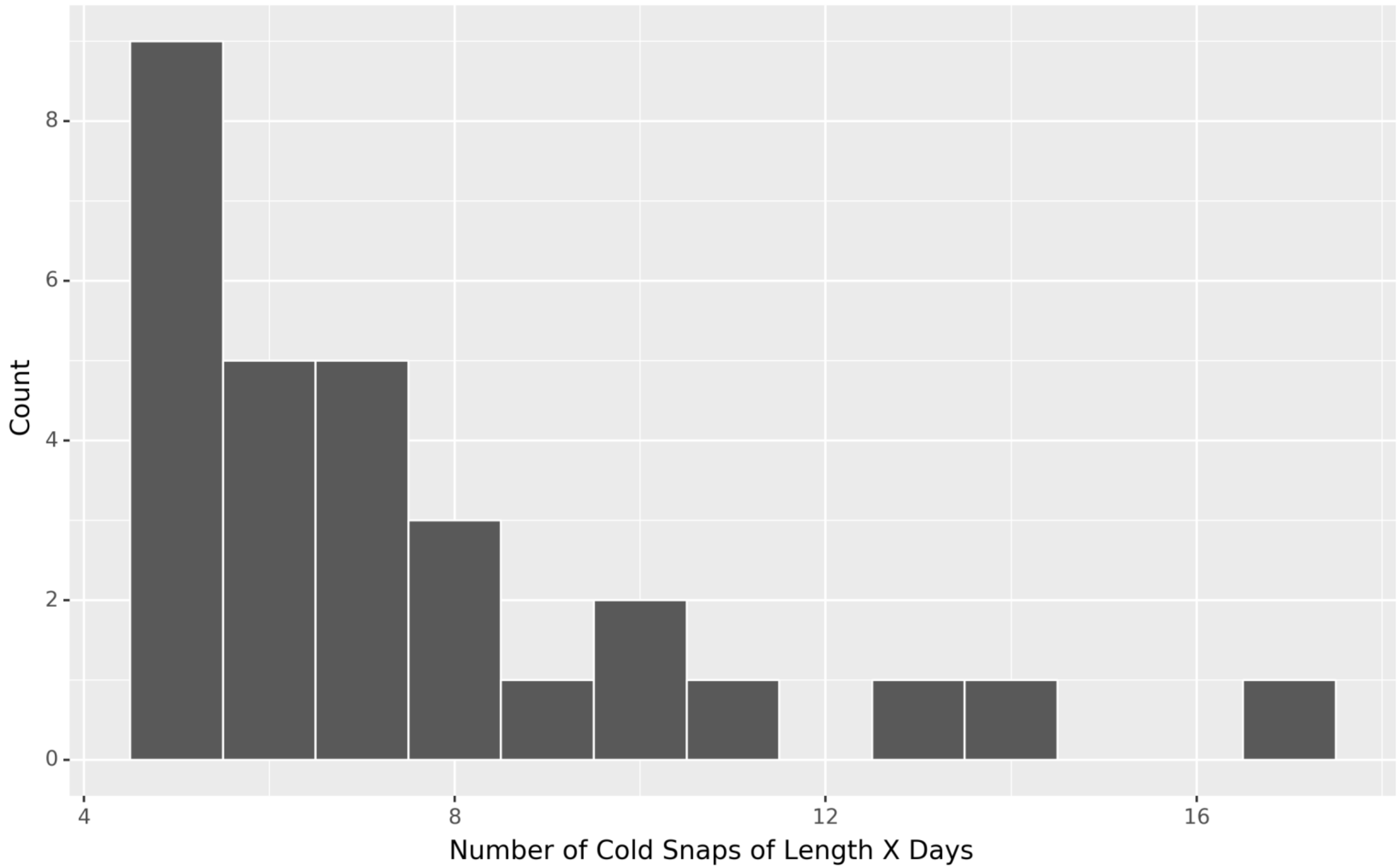
Cold Snaps – Number of DYs with X Cold Snaps



A total of 29 cold snaps in 47 winter periods are identified

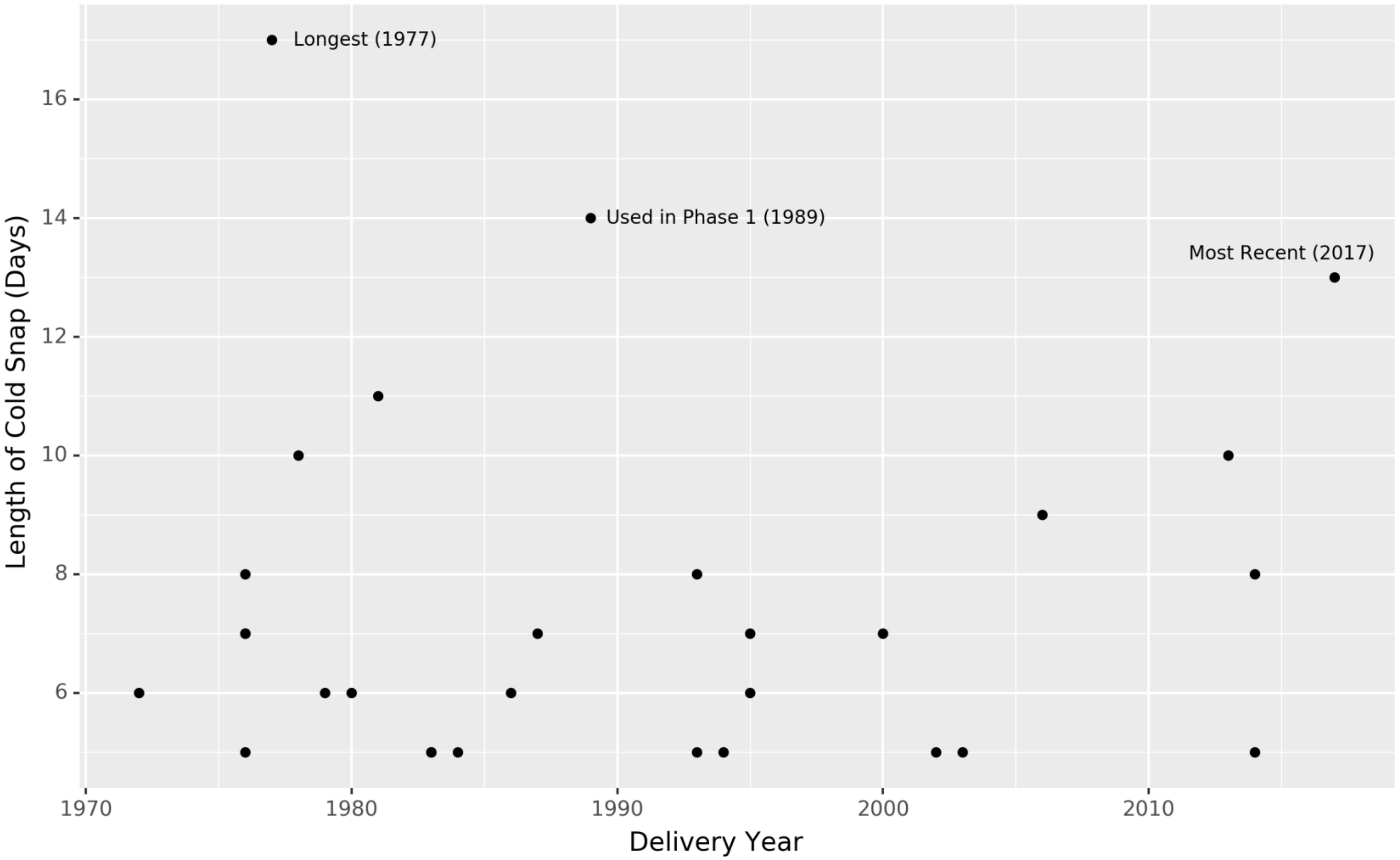
Average: 0.6 Cold Snaps per Delivery Year (Winter)

Cold Snaps – Number of Cold Snaps of Length X Days

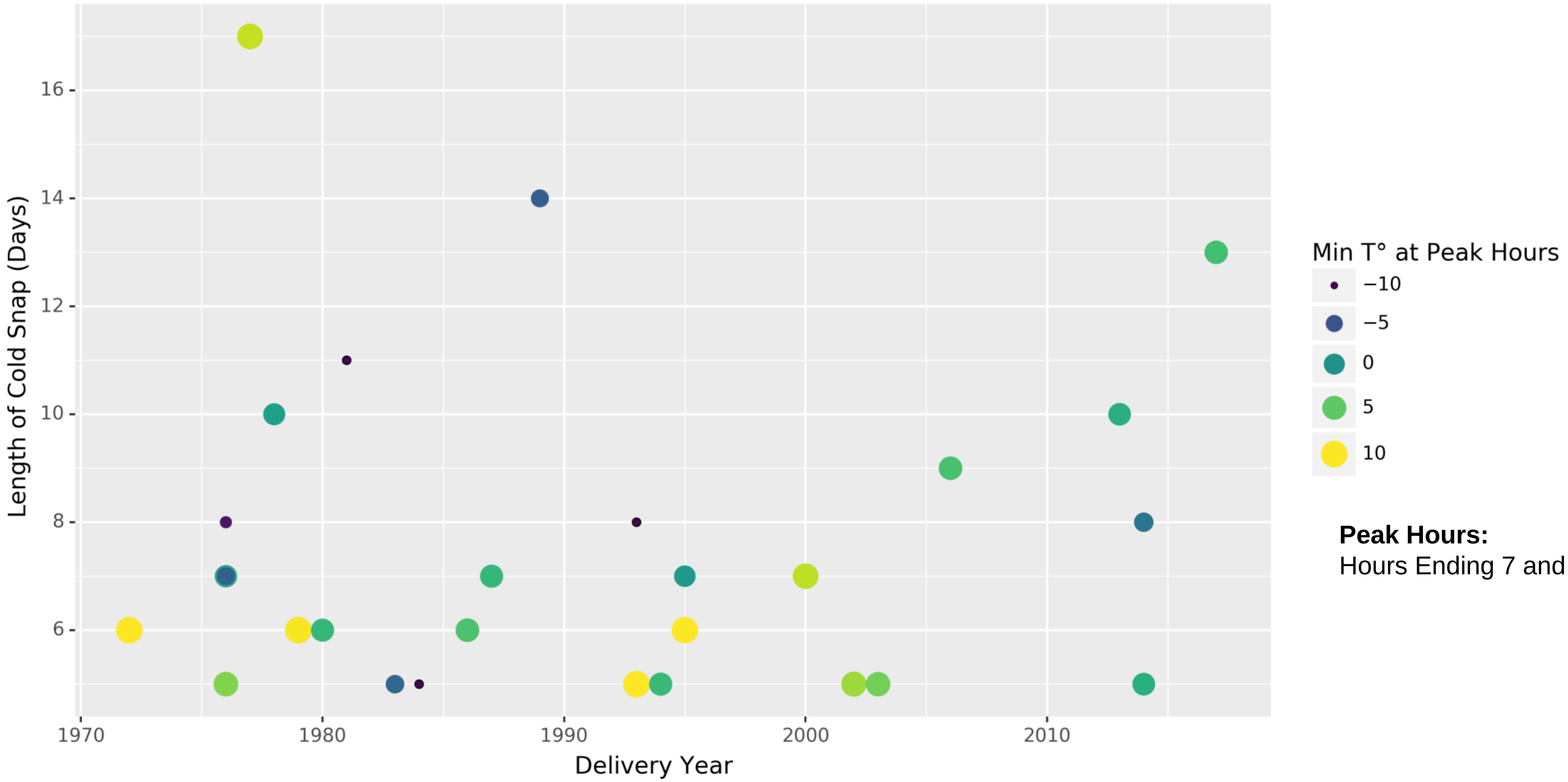


Average Length: 7.5 days

Cold Snaps – Delivery Year vs Length of Cold Snap



Cold Snaps – Delivery Year vs Length of Cold Snap (and Min T at Peak Hours)



Peak Hours:
Hours Ending 7 and 19

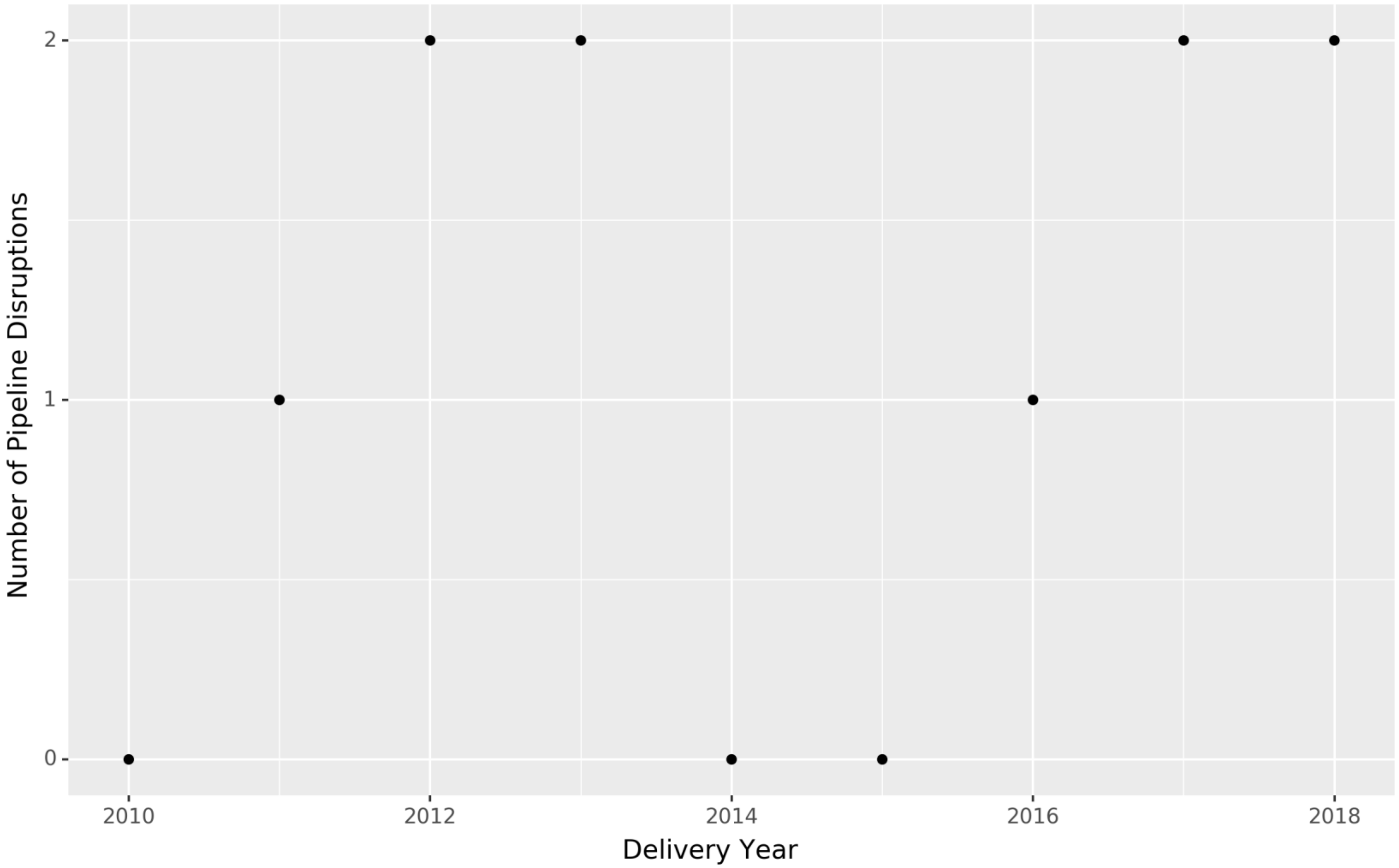
Pipeline Disruptions – Definition

- Pipeline failure event impacting the onshore gas transmission system where the reported failure mode is classified as either a Rupture or a Mechanical Puncture
  - Events where the reported failure mode is classified as a Leak or Other are not included as Pipeline Disruptions because they are deemed to be less impactful

Pipeline Disruptions – Data

- Event data collected by the Pipeline and Hazardous Material Safety Administration (PHMSA) of the United States Department of Transportation in the period 2010 – 2019 Q2
- Events with a start date in Winter time (Dec – Feb) are included
- Events reported by Pipelines or Local Distribution Companies (LDCs) to which PJM generators are connected are included
- Events that have occurred within a PJM State are included

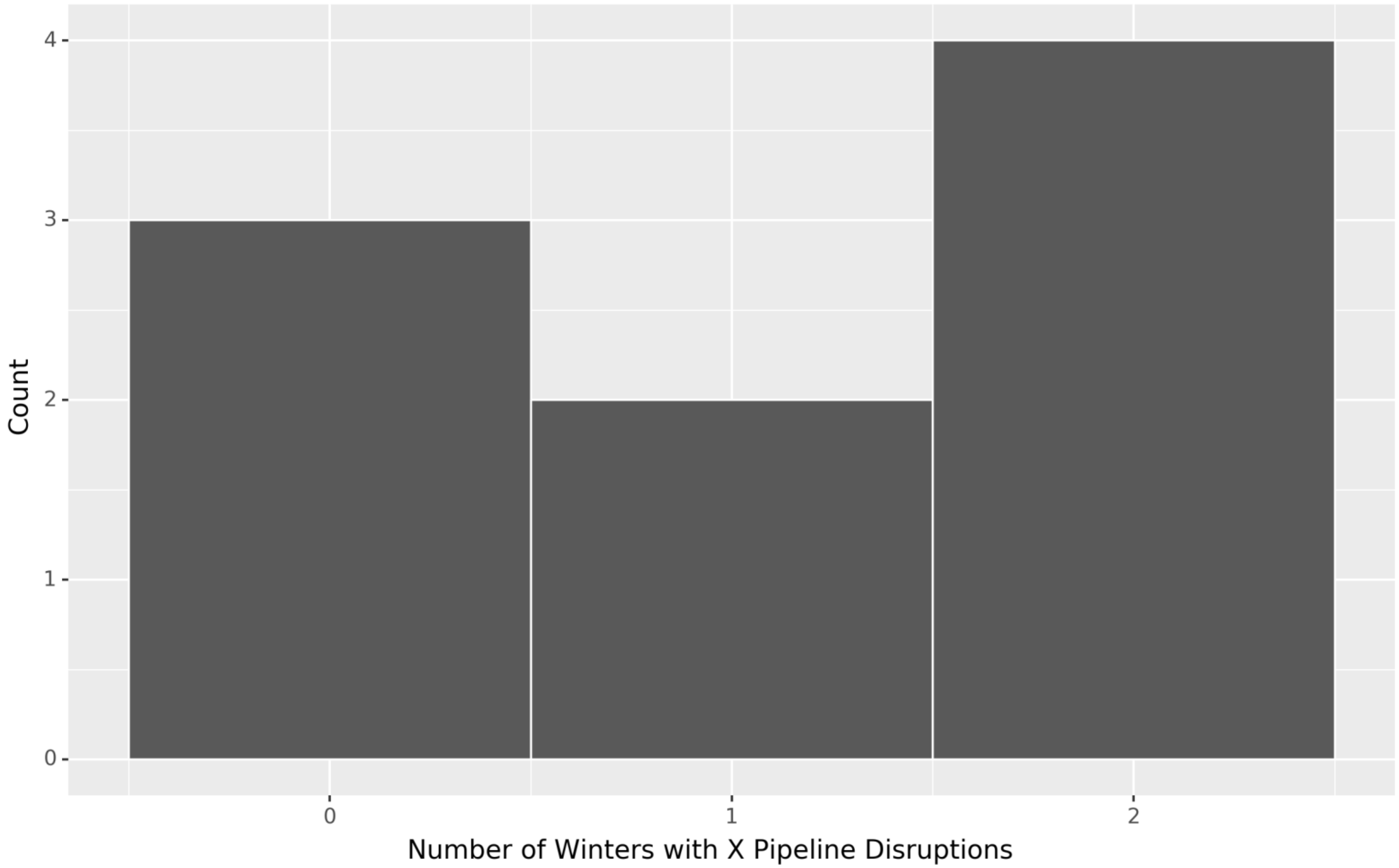
Delivery Year (Winter) vs Number of Pipeline Disruptions



A total of 10 disruptions in 9 winter periods are identified

Average: 1.1 Pipeline Disruptions per Delivery Year (Winter)

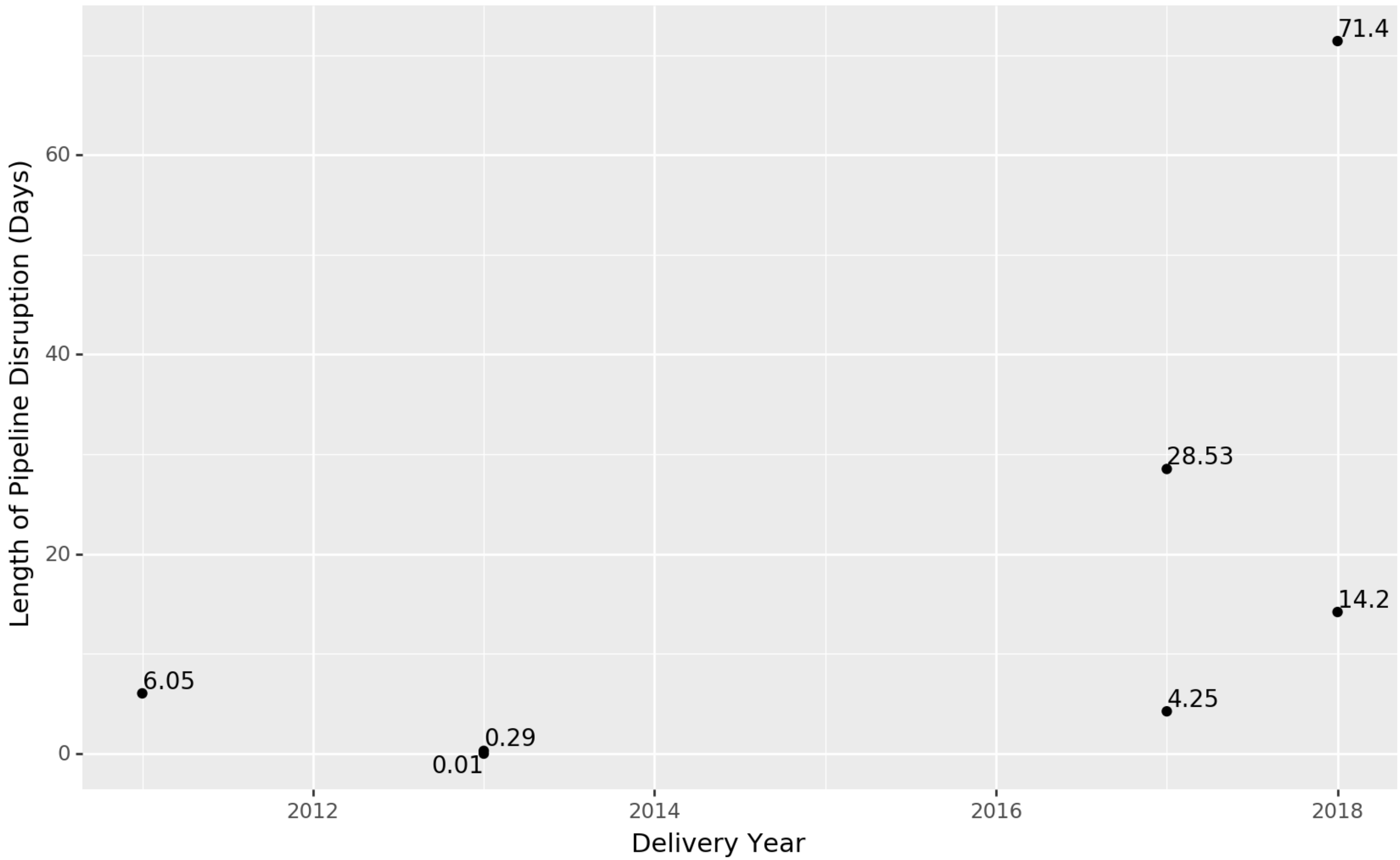
Number of DYs (Winters) with X Pipeline Disruptions



A total of 10 disruptions in 9 winter periods are identified

Average: 1.1 Pipeline Disruptions per Delivery Year (Winter)

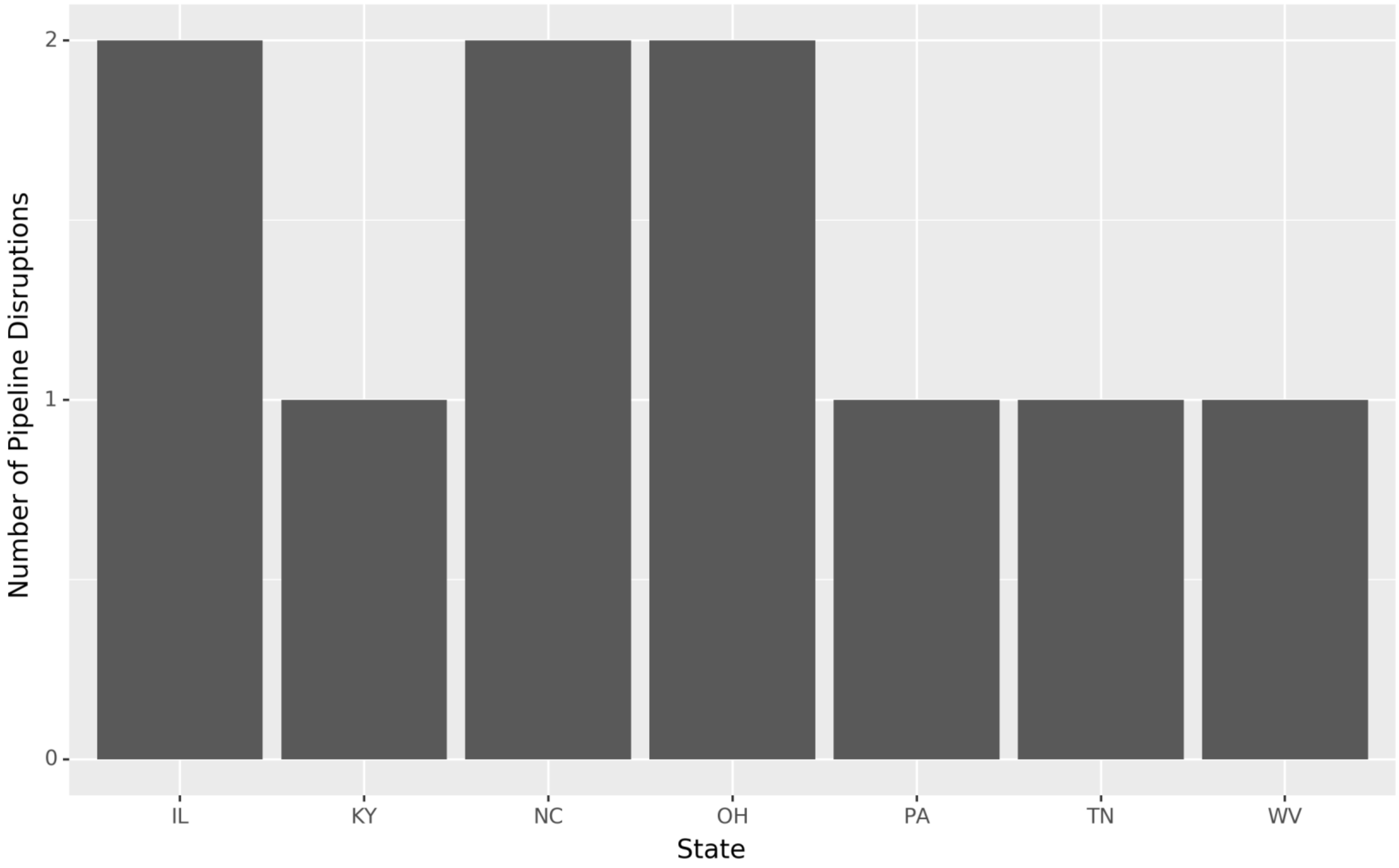
Delivery Year (Winter) vs Duration of Pipeline Disruptions



Duration shown for 7 events only.

Outliers and events with missing data are not shown

State vs Number of Pipeline Disruptions



Historical Data on Relevant Risks

FSSTF

08/12/2019

Risk Assessment Review

June
- Relevant Risk filtering and identification

July
- Historical Cold Snap data
- Historical Pipeline Disruption frequency data

August
- Historical Pipeline Disruption impact data
- Historical Wind and Solar Intermittency
- Historical Relevant Risk data

Relevant Risks

Relevant Risks	
Long Duration Cold Snap	Covered in July
Short Duration Cold Snap	Covered in July
Natural Gas Pipeline Disruptions	Covered in July and to be continued today
Solar Intermittency	To be covered today
Wind Intermittency	To be covered today
Coal Refueling (Bridge Failure)	To be covered today
Coal Refueling (Lock and Dam Failure)	To be covered today
Coal Refueling (Rail Failure)	To be covered today
Coal Refueling (River Freezing)	To be covered today
Coal Unavailability (Coal Quality)	To be covered today
Natural Gas Unavailability Non-Firm Units	To be covered today
Oil Refueling (Oil Terminal)	To be covered today
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Nuclear Regulatory Shutdown (Fuel Related)	To be covered today
Nuclear Regulatory Shutdown (Non-Fuel Related)	To be covered today
Nuclear Unavailability (High Winds)	To be covered today
Hydro Unavailability (Freezing Rivers)	To be covered today
River Freezing (Cooling Water Impacts)	To be covered today
Ice Storm (Transportation Impacts)	To be covered today

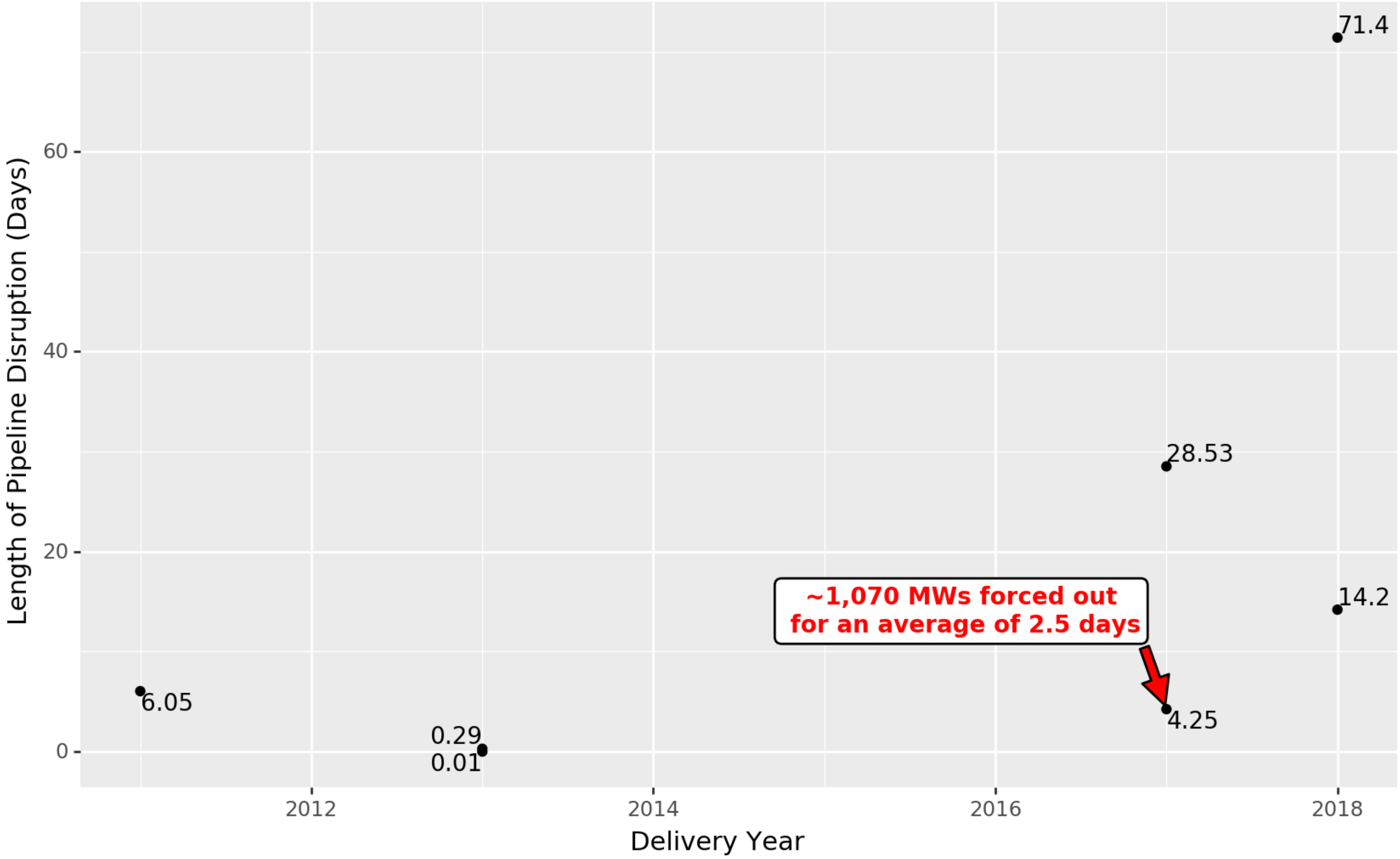
Relevant Risk:
Pipeline Disruptions

Frequency of Pipeline Disruptions

Based on Pipeline and Hazardous Material Safety Administration (PHMSA) data:

$$\frac{10 \text{ Pipeline Disruptions}}{9 \text{ Winter Periods}} \rightarrow 1.1 \frac{\text{Pipeline Disruptions}}{\text{DY Winter}}$$

Historical Impact of Pipeline Disruptions



Duration shown for 7 events only. Outliers and events with missing data are not shown

Only the December 2017 disruption impacted PJM generation (approximately 1,070 MW of forced outages)

The rest of the pipeline disruptions that have occurred during Winter in the PJM footprint since 2010 have not impacted PJM generation

Impact of Pipeline Disruptions

- It is difficult to establish the impact of a pipeline disruption on PJM generation based on GADS data because there are no specific cause codes referencing pipeline disruptions
- The limited impact that PJM generation has experienced due to recent pipeline disruptions is not necessarily an indicator of future impact levels
- Had some of the past disruptions occurred at different geographic locations or other times of the year under more stressful conditions, the impact on PJM generation could have been more significant

Relevant Risk:
Wind and Solar Intermittency

Cold Snaps Analyzed:

Cold Snap	Start	Stop	Duration
1	Jan. 21, 2014	Jan. 30 2014	10 Days
2	Jan. 6, 2015	Jan. 10, 2015	5 Days
3	Feb. 13, 2015	Feb. 20, 2015	8 Days
4	Dec. 26, 2017	Jan. 7, 2018	13 Days

Winter Peak Hours:

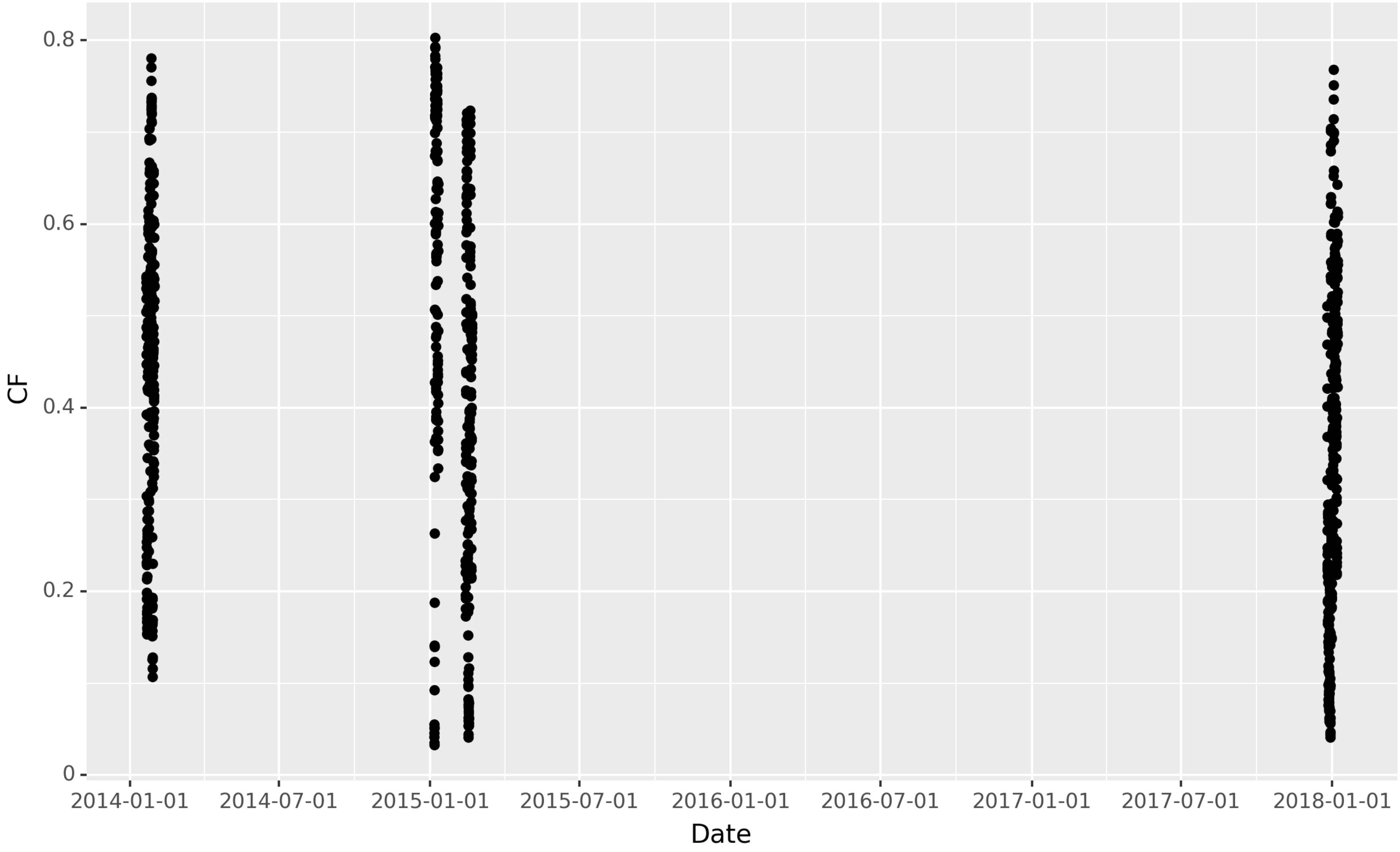
AM Peak	PM Peak
HE08 & HE09	HE19 & HE20

Capacity Factor:

$$\text{CF} = \frac{\text{Actual Hourly Output}}{\text{Total Installed Nameplate}}$$

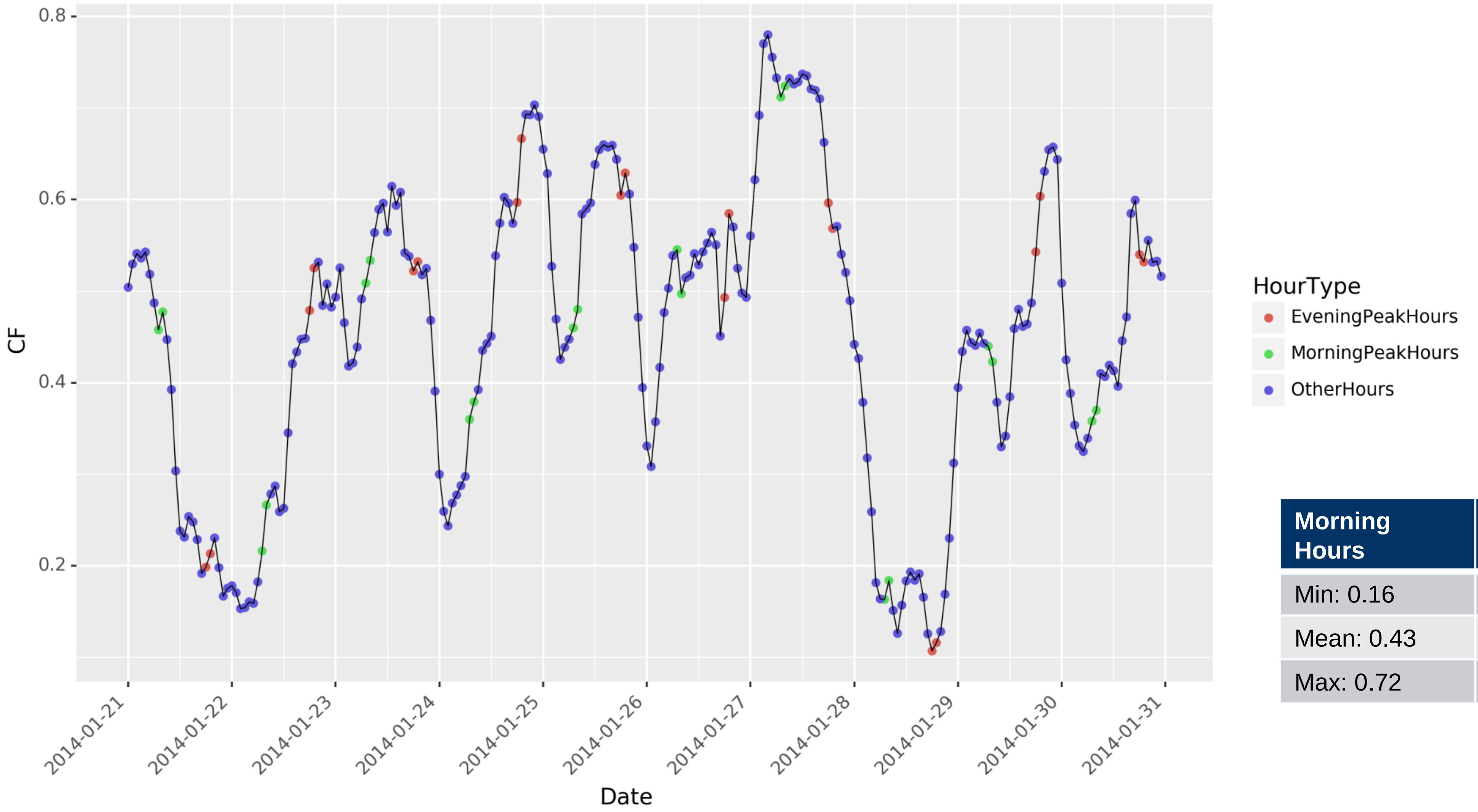
For solar and wind resources, capacity factor serves as an indicator of how effectively the resources are performing

Wind Hourly Capacity Factors



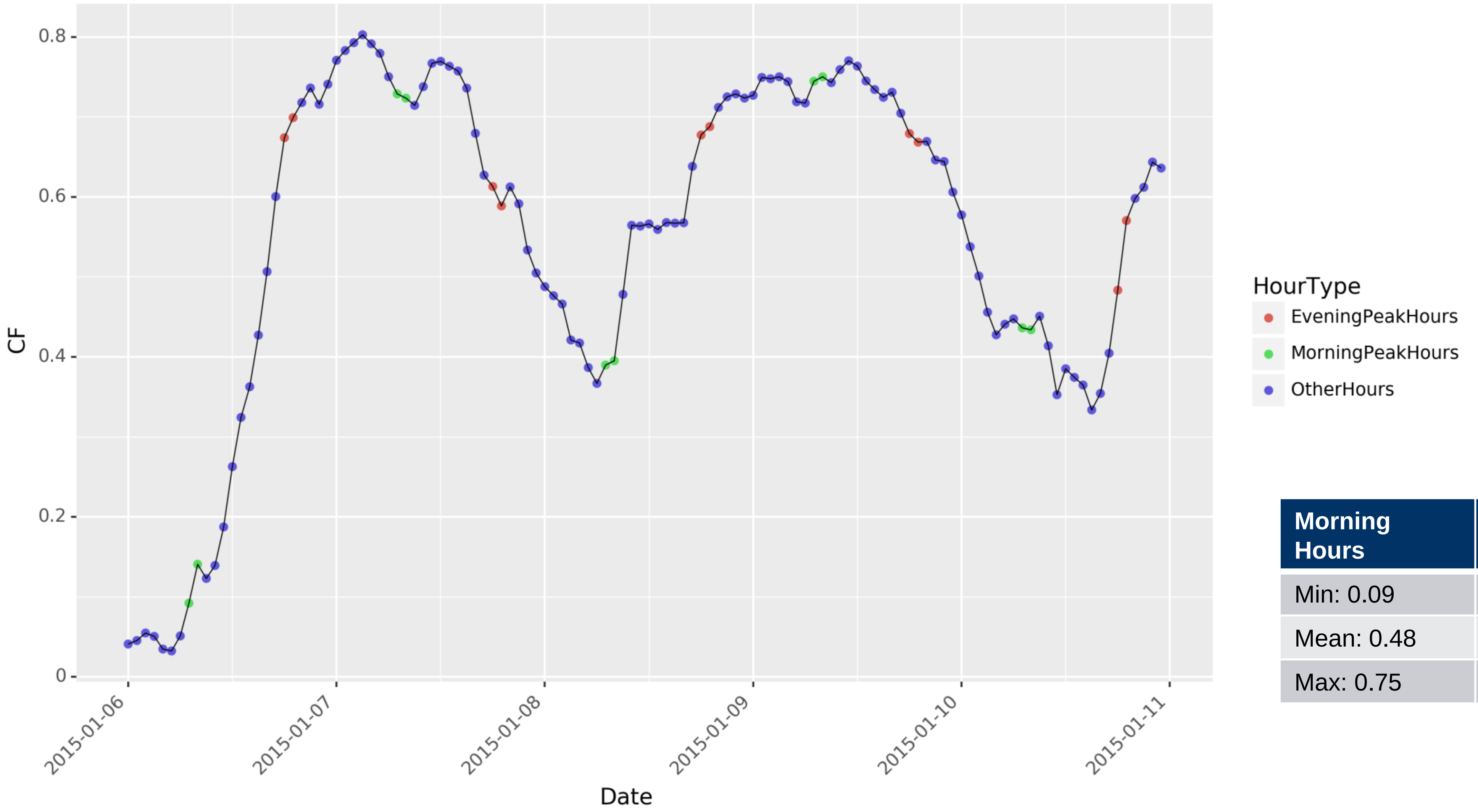
- Wide CF distribution
- All CFs > 0.00
- Many hours are much higher than the anticipated 0.13 CF

Wind Hourly Capacity Factor (01/21/14 – 01/30/14)



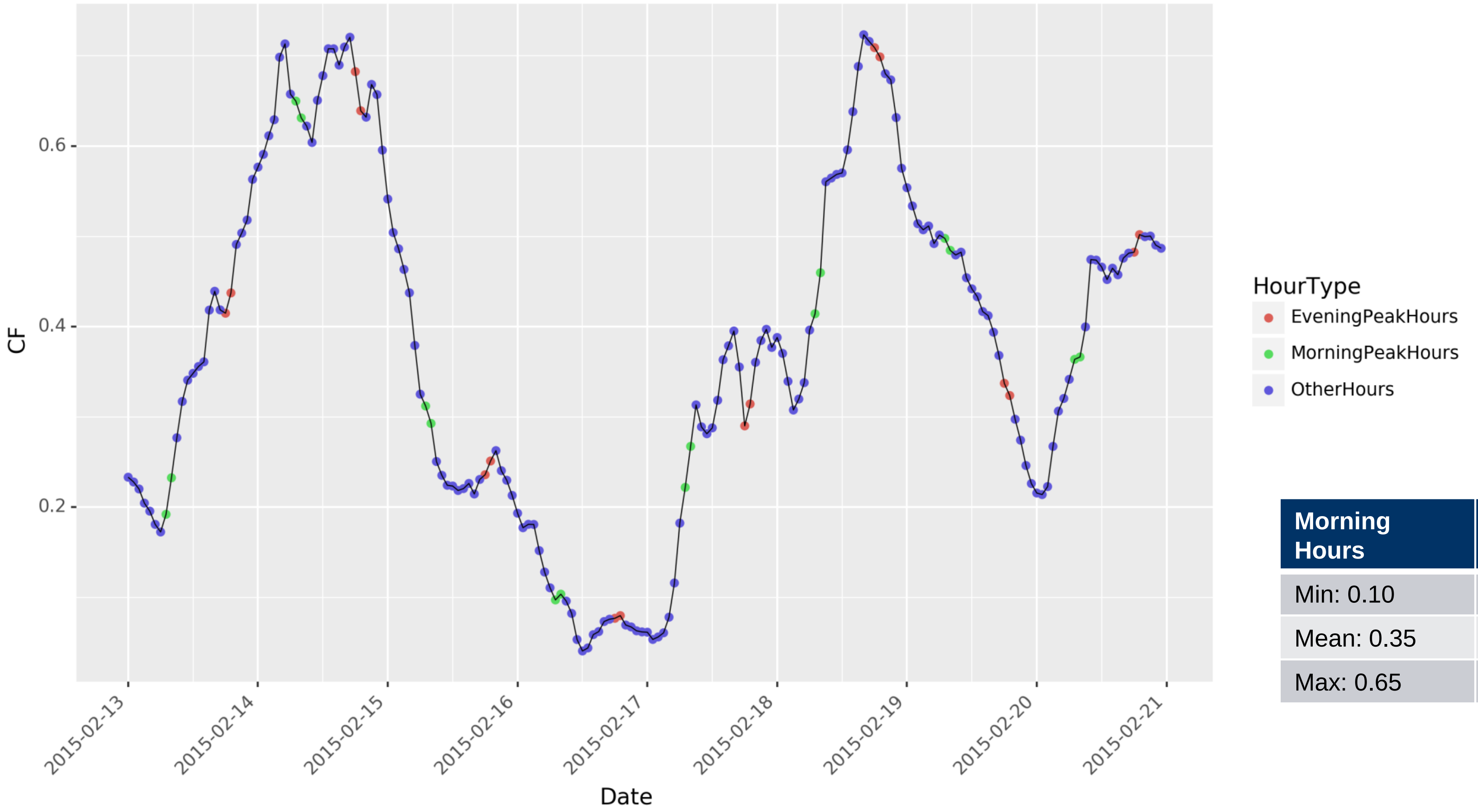
Morning Hours	Evening Hours
Min: 0.16	Min: 0.11
Mean: 0.43	Mean: 0.48
Max: 0.72	Max: 0.67

Wind Hourly Capacity Factor (01/06/15 – 01/10/15)



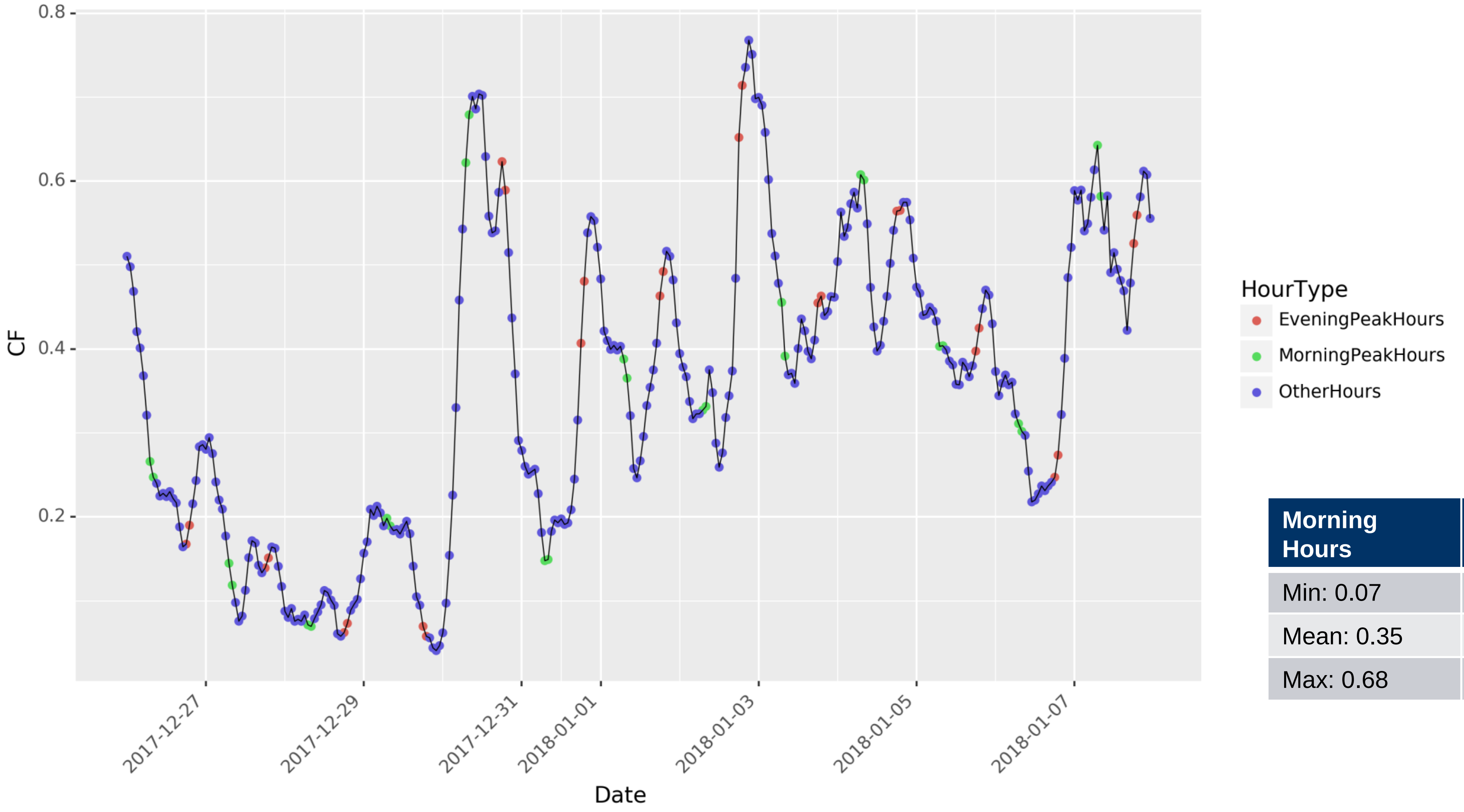
Morning Hours	Evening Hours
Min: 0.09	Min: 0.48
Mean: 0.48	Mean: 0.63
Max: 0.75	Max: 0.70

Wind Hourly Capacity Factor (02/13/15 – 02/20/15)



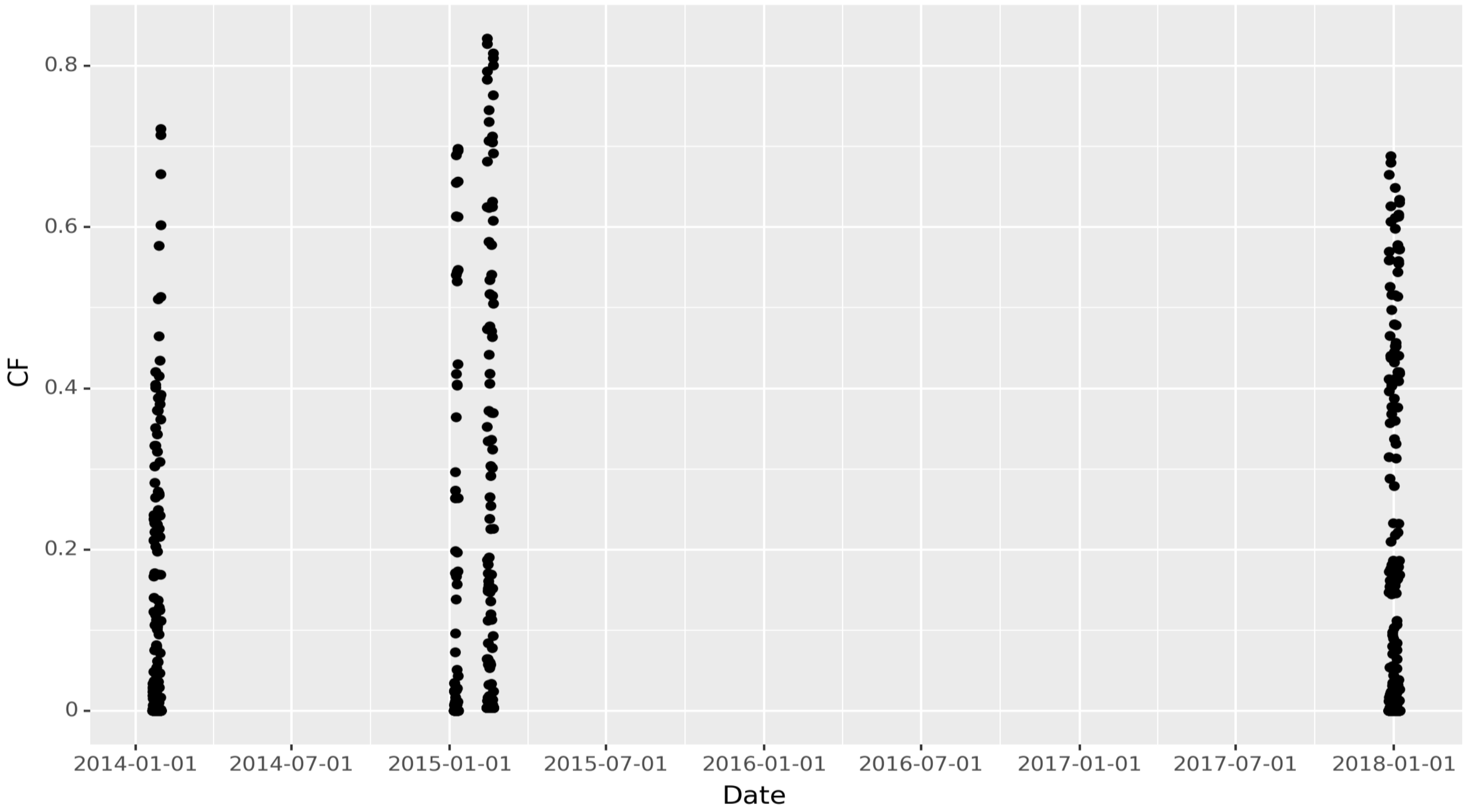
Morning Hours	Evening Hours
Min: 0.10	Min: 0.08
Mean: 0.35	Mean: 0.40
Max: 0.65	Max: 0.71

Wind Hourly Capacity Factor (12/26/17 – 01/07/18)



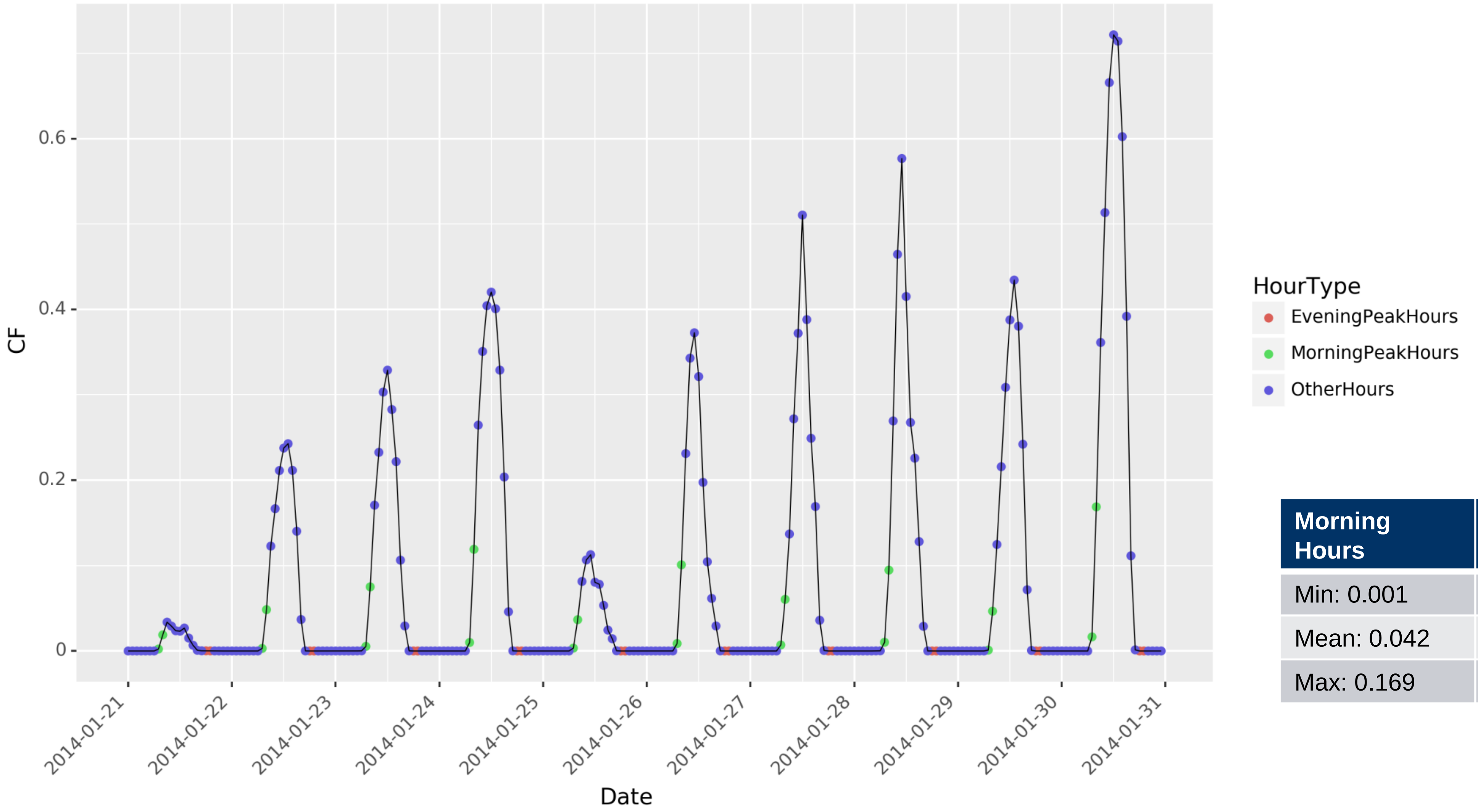
Morning Hours	Evening Hours
Min: 0.07	Min: 0.06
Mean: 0.35	Mean: 0.38
Max: 0.68	Max: 0.71

Solar Hourly Capacity Factors



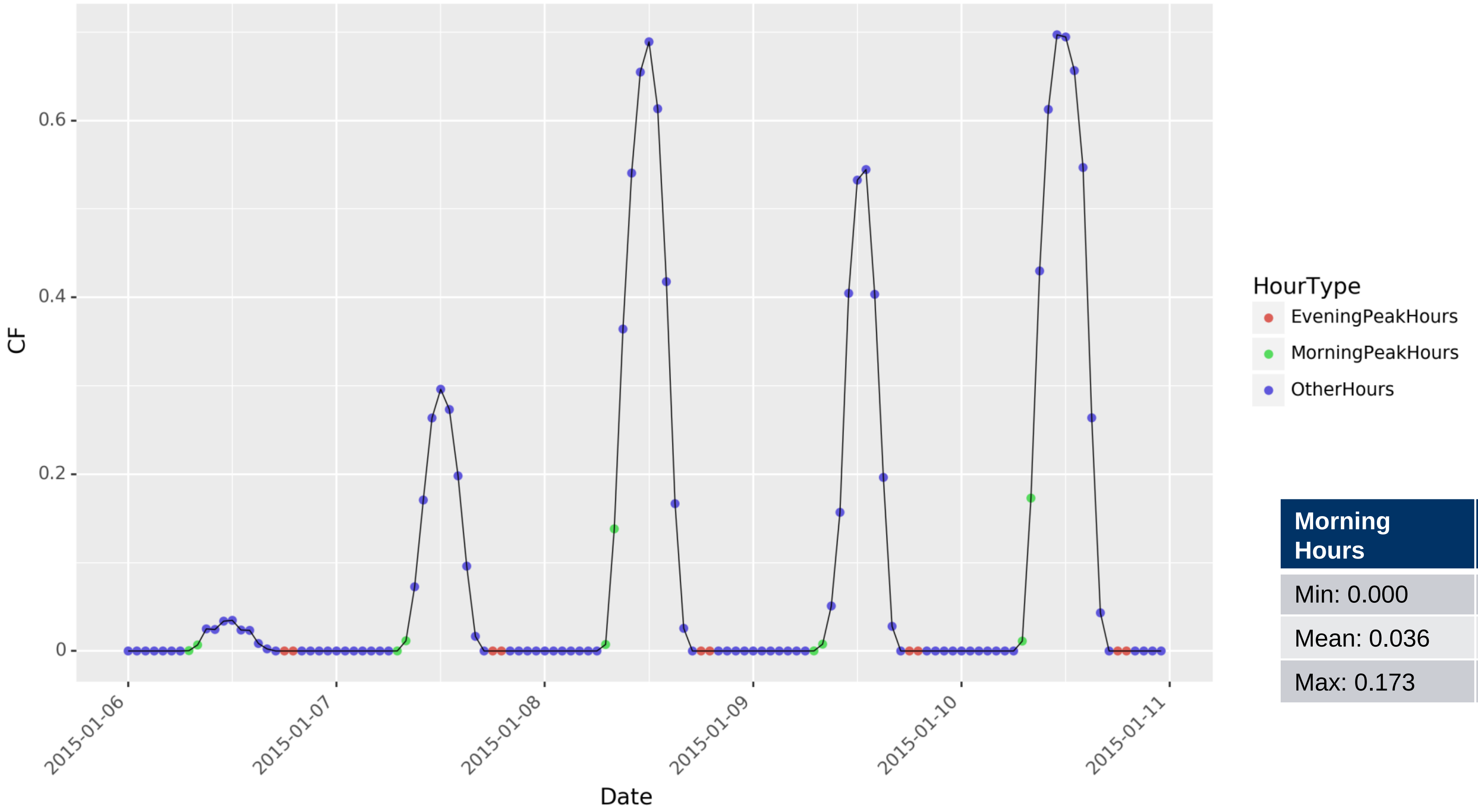
- Wide CF distribution
- Many CFs = 0.00
- Overall average is lower than the anticipated 0.38 CF

Solar Hourly Capacity (01/21/14 – 01/30/14)



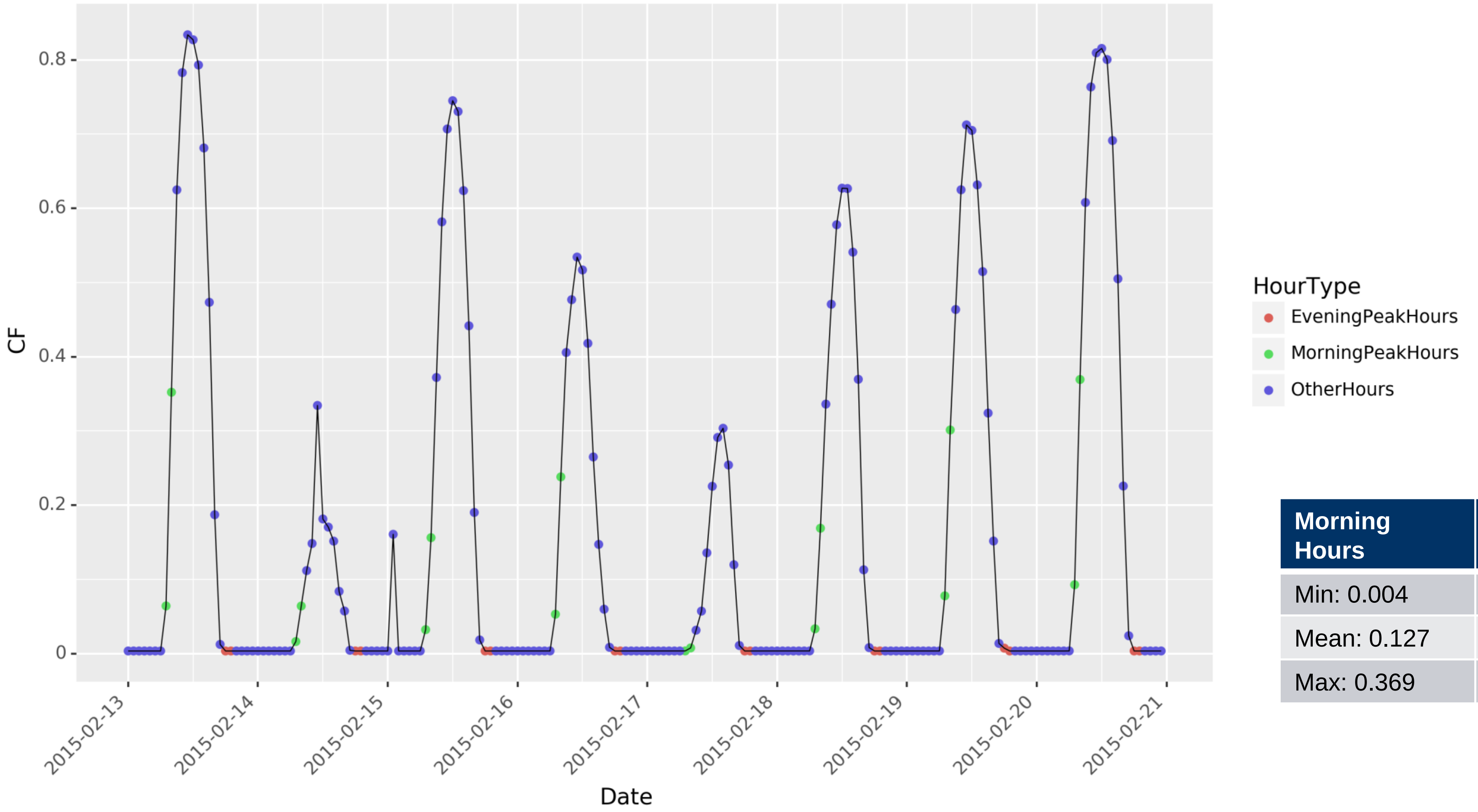
Morning Hours	Evening Hours
Min: 0.001	Min: 0.000
Mean: 0.042	Mean: 0.000
Max: 0.169	Max: 0.000

Solar Hourly Capacity Factor (01/06/15 – 01/10/15)



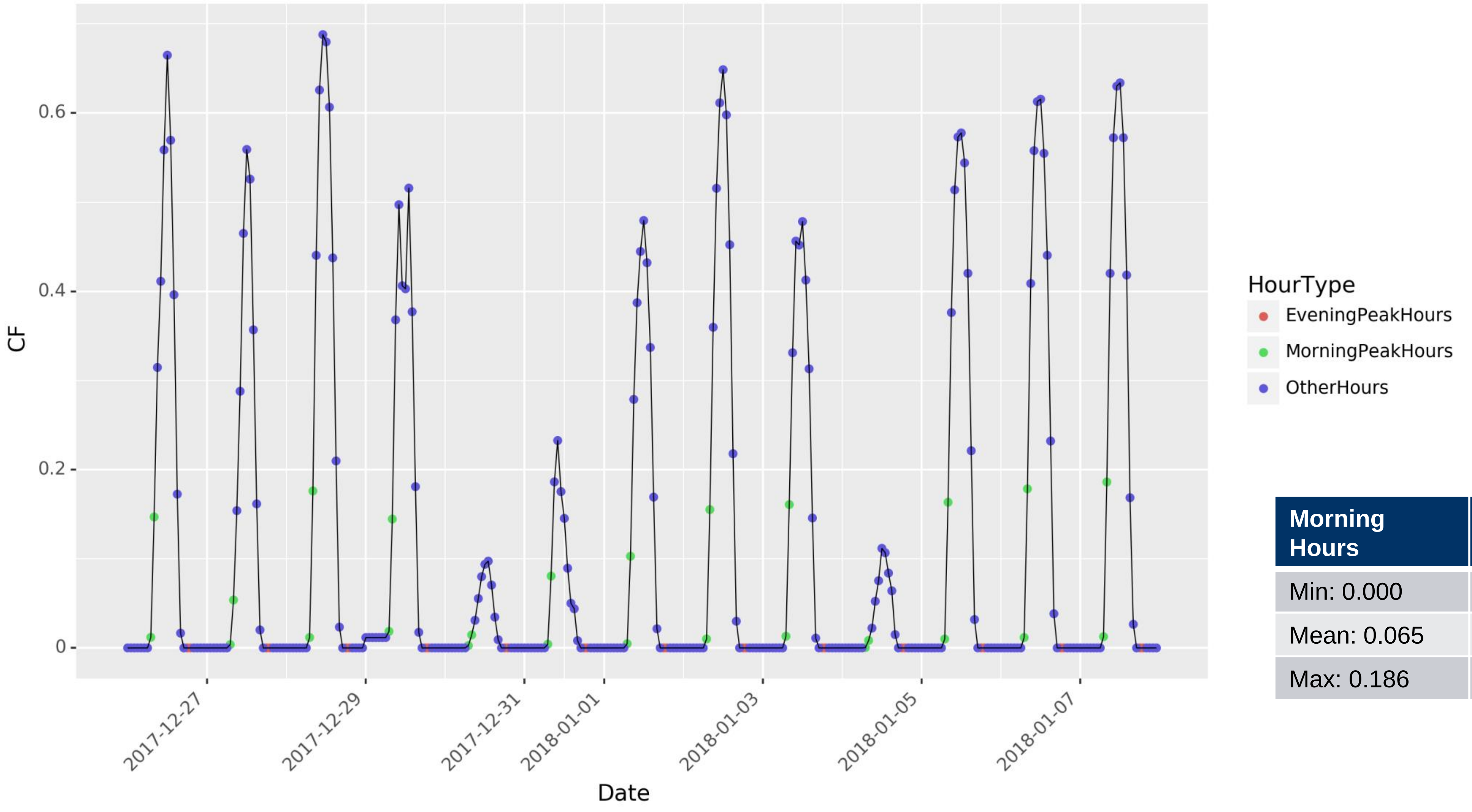
Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.036	Mean: 0.000
Max: 0.173	Max: 0.000

Solar Hourly Capacity Factor (02/13/15 – 02/20/15)



Morning Hours	Evening Hours
Min: 0.004	Min: 0.004
Mean: 0.127	Mean: 0.004
Max: 0.369	Max: 0.007

Solar Hourly Capacity Factor (12/26/17 – 01/07/18)



Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.065	Mean: 0.000
Max: 0.186	Max: 0.000

Wind and Solar Intermittency Summary

Wind:

- Wide distribution of capacity factors during all four cold snaps
- Capacity factors generally outperform the anticipated capacity factor of 0.13 during both peak and non-peak hours

Solar:

- Wide distribution of capacity factors during all four cold snaps
- Capacity factors never reach the anticipated capacity factor of 0.38 during peak hours
- Shorter winter days translate to a small number of daily hours at or above the anticipated capacity factor of 0.38

Relevant Risk:
Fuel Specific Risks

Generating Availability Data System (GADS)

- NERC established data collection system with required data submission for conventional generators 20 MW and greater
- Each event is unique and has an event type that describes the outage/derate and a cause code that describes the mechanism triggering the event

NERC GADS Website:
https://www.nerc.com/pa/RAPA/gads/Pages/GeneratingAvailabilityDataSystem-(GADS).aspx

2019 GADS Cause Codes:
https://www.nerc.com/pa/RAPA/gads/DataReportingInstructions/2019_GADS_Cause_Codes.xlsx

Relevant Risks

Relevant Risks
Long Duration Cold Snap
Short Duration Cold Snap
Natural Gas Pipeline Disruptions
Solar Intermittency
Wind Intermittency
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Coal Refueling (Lock and Dam Failure)
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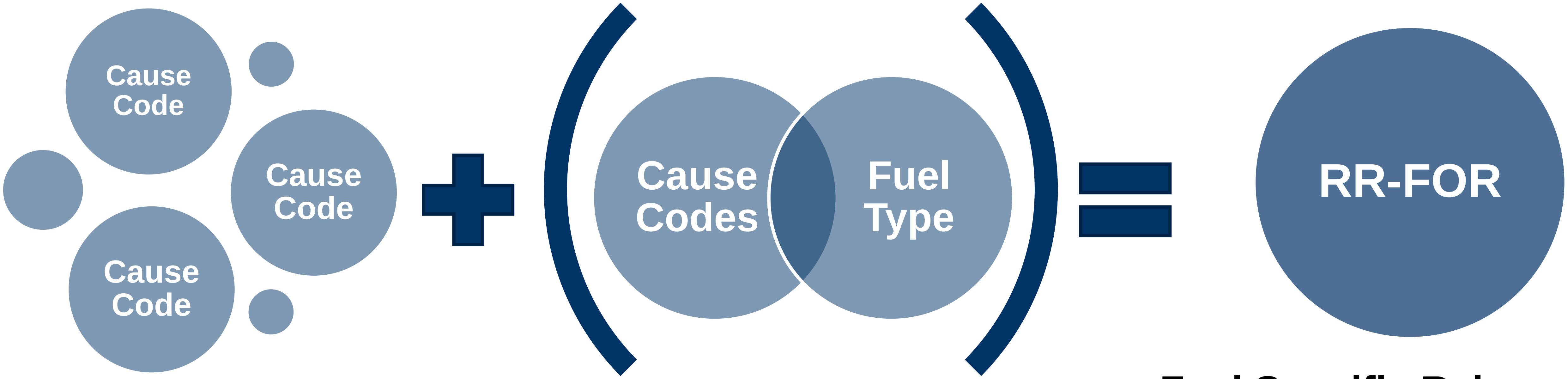
Ice Storm (Transportation Impacts)

Fuel Specific Relevant Risk Forced Outage Rate (RR-FOR)

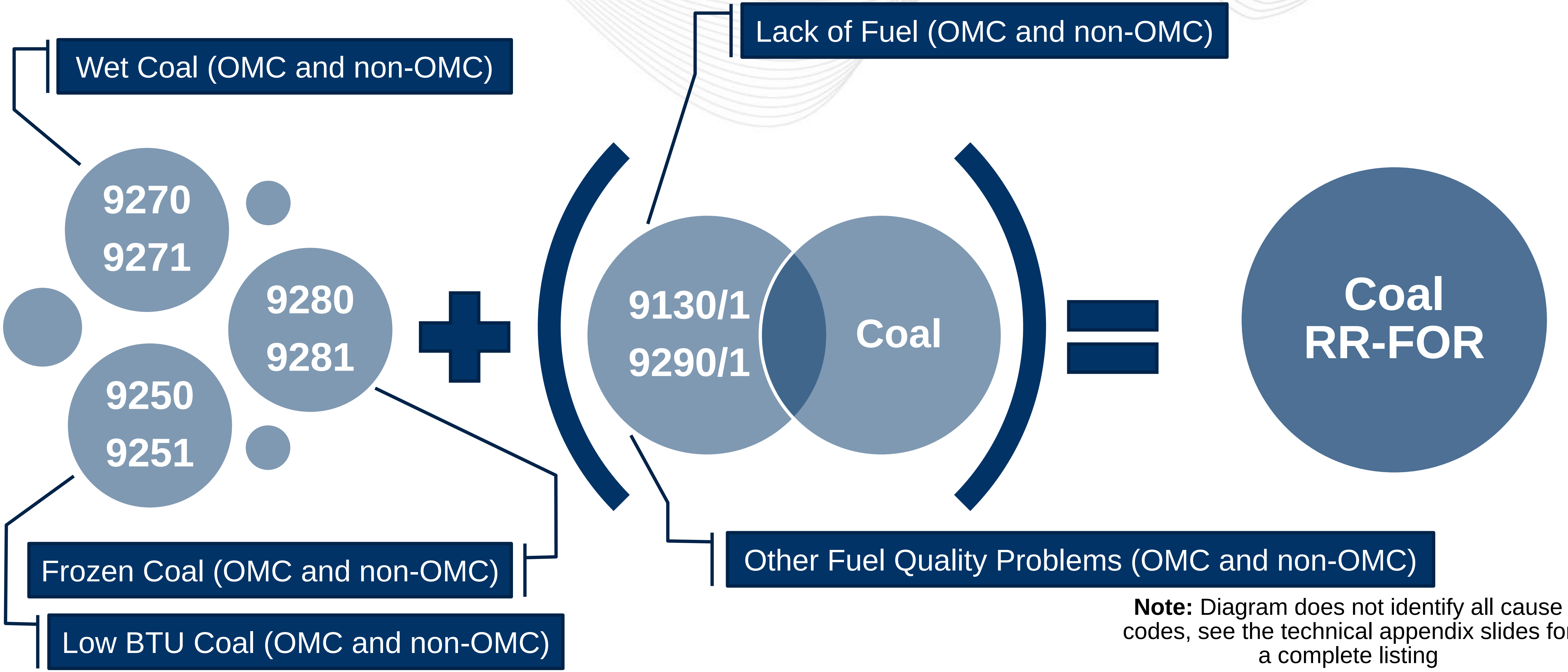


Fuel Specific Cause Codes

Common Cause Codes

Fuel Specific Relevant Risk Forced Outage Rate

Example



Note: Diagram does not identify all cause codes, see the technical appendix slides for a complete listing

Cold Snaps Analyzed:

Cold Snap	Start	Stop	Duration
1	Jan. 21, 2014	Jan. 30 2014	10 Days
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3	Feb. 13, 2015	Feb. 20, 2015	8 Days
4	Dec. 26, 2017	Jan. 7, 2018	13 Days

Winter Peak Hours:

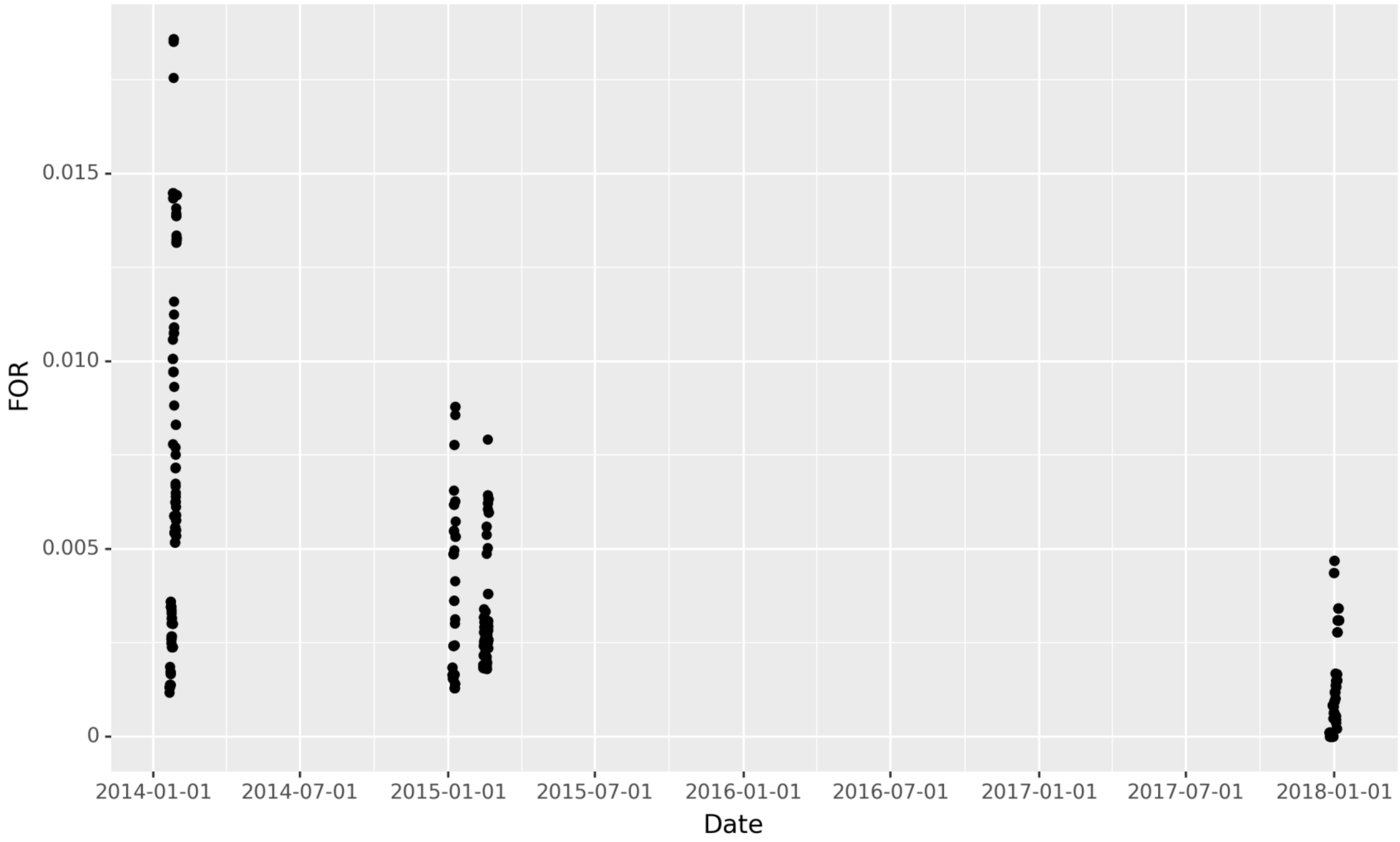
AM Peak	PM Peak
HE08 & HE09	HE19 & HE20

Forced Outage Rate:

$$\text{FOR} = \frac{\text{MW Forced Out}}{\text{Total Installed Nameplate}}$$

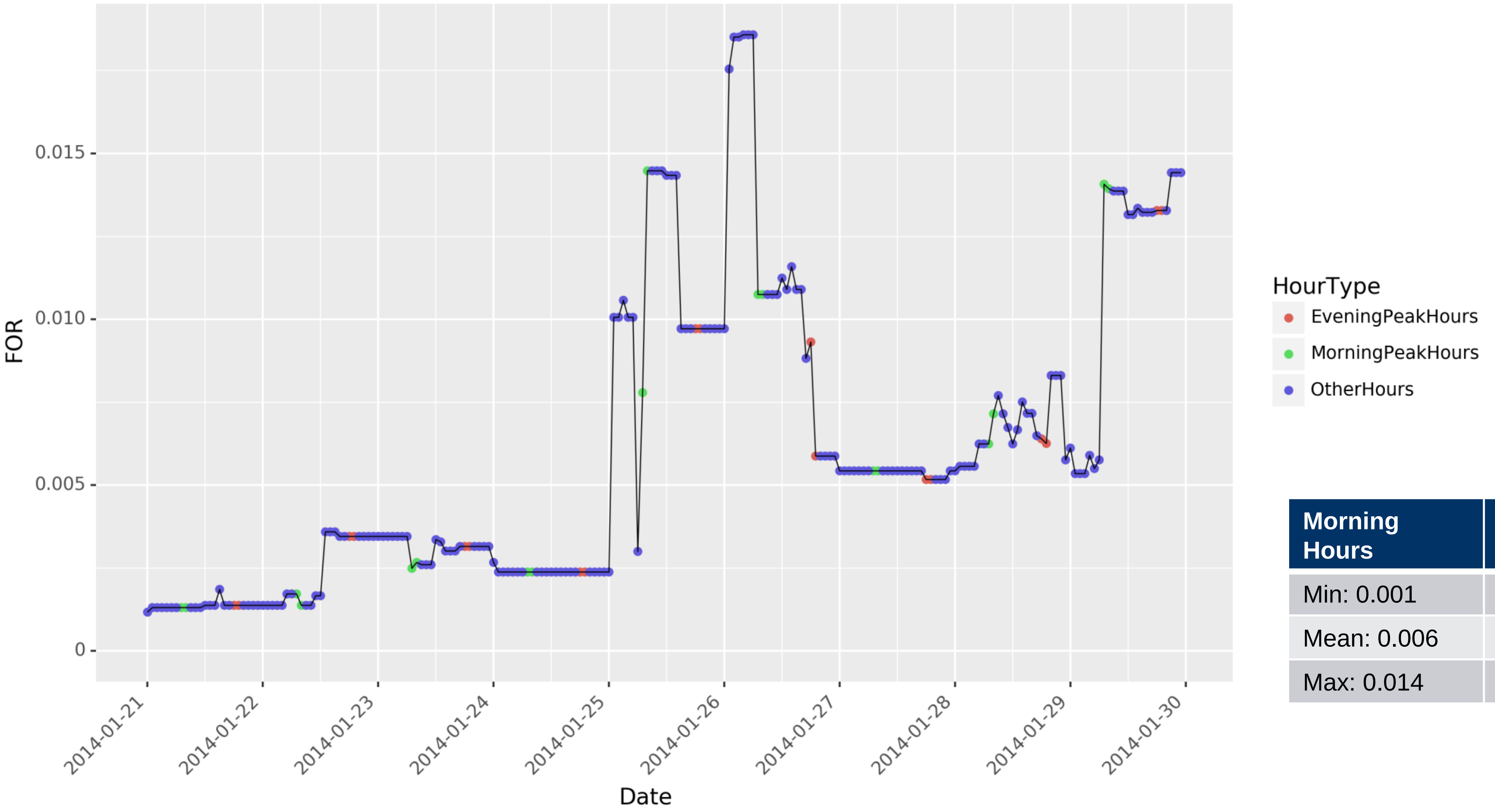
For coal, natural gas, nuclear, hydro, and oil resources, the forced outage rate serves as an indicator of the degree of unavailability for a set of resources

Coal RR-FOR



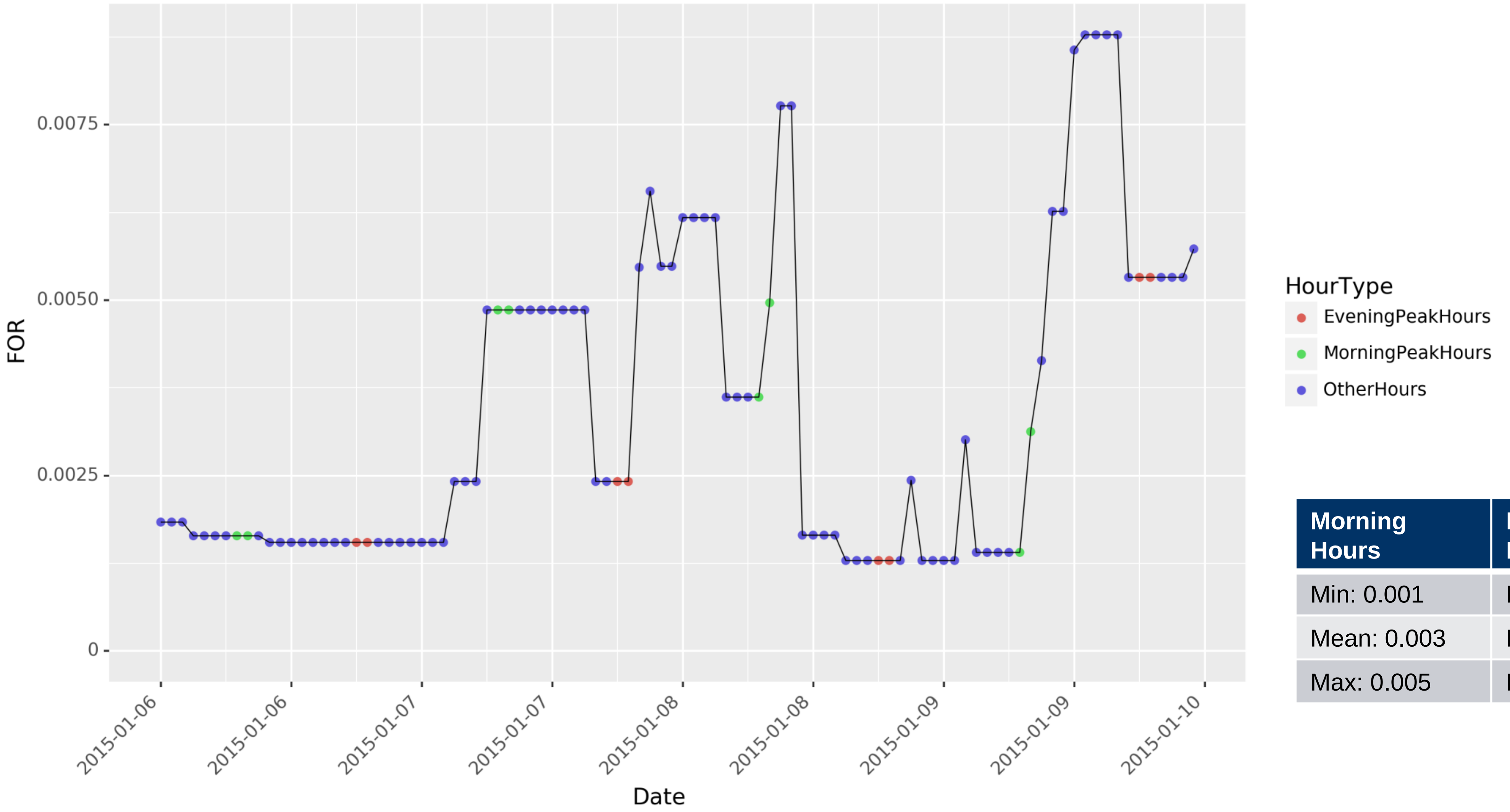
FOR
0.015
0.010
0.005
0
2014-01-01
2014-07-01
2015-01-01
2015-07-01
2016-01-01
2016-07-01
2017-01-01
2017-07-01
2018-01-01
Date

Coal RR-FOR (01/21/14 – 01/30/14)



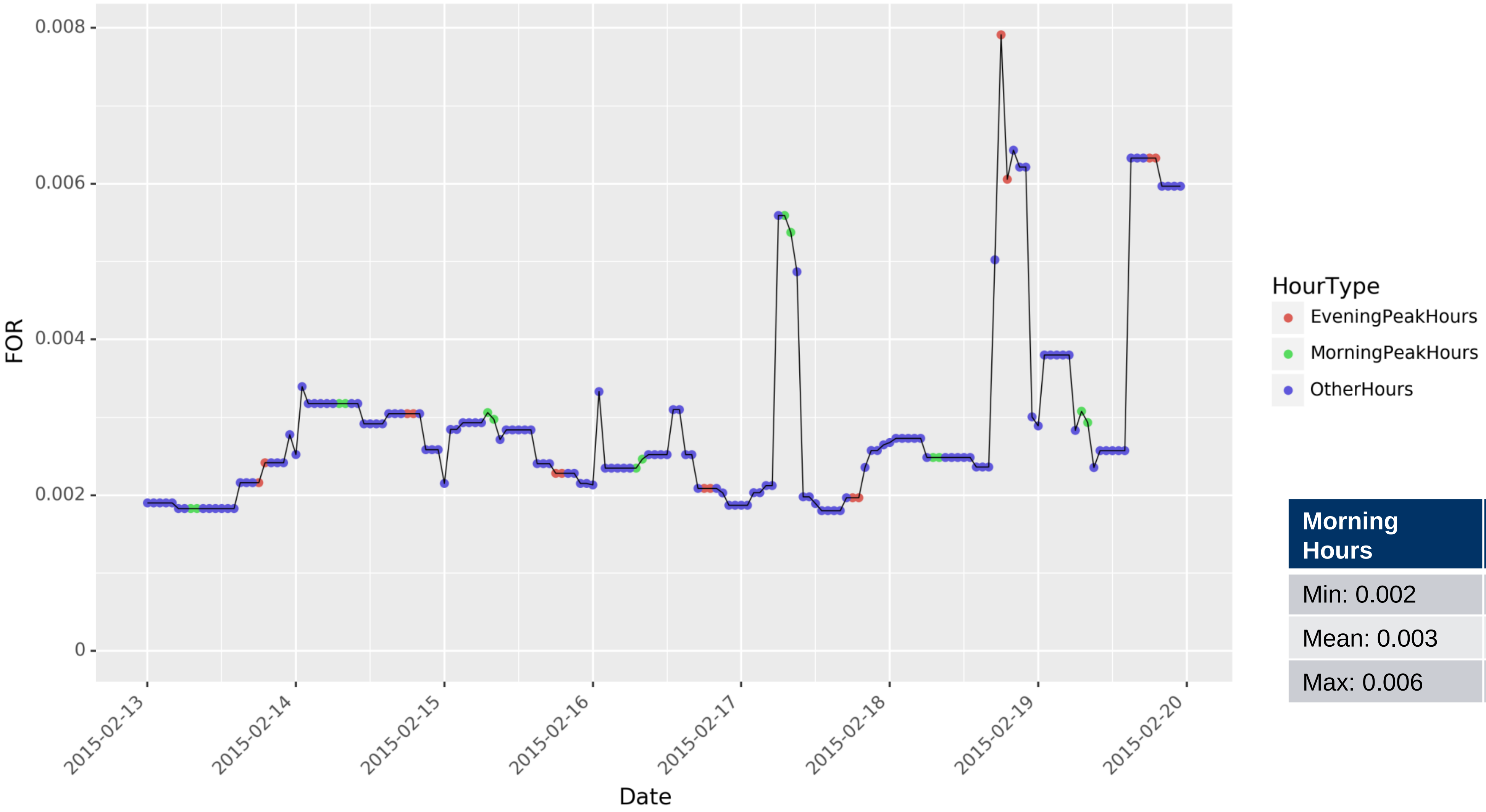
Morning Hours	Evening Hours
Min: 0.001	Min: 0.001
Mean: 0.006	Mean: 0.006
Max: 0.014	Max: 0.013

Coal RR-FOR (01/06/15 – 01/10/15)



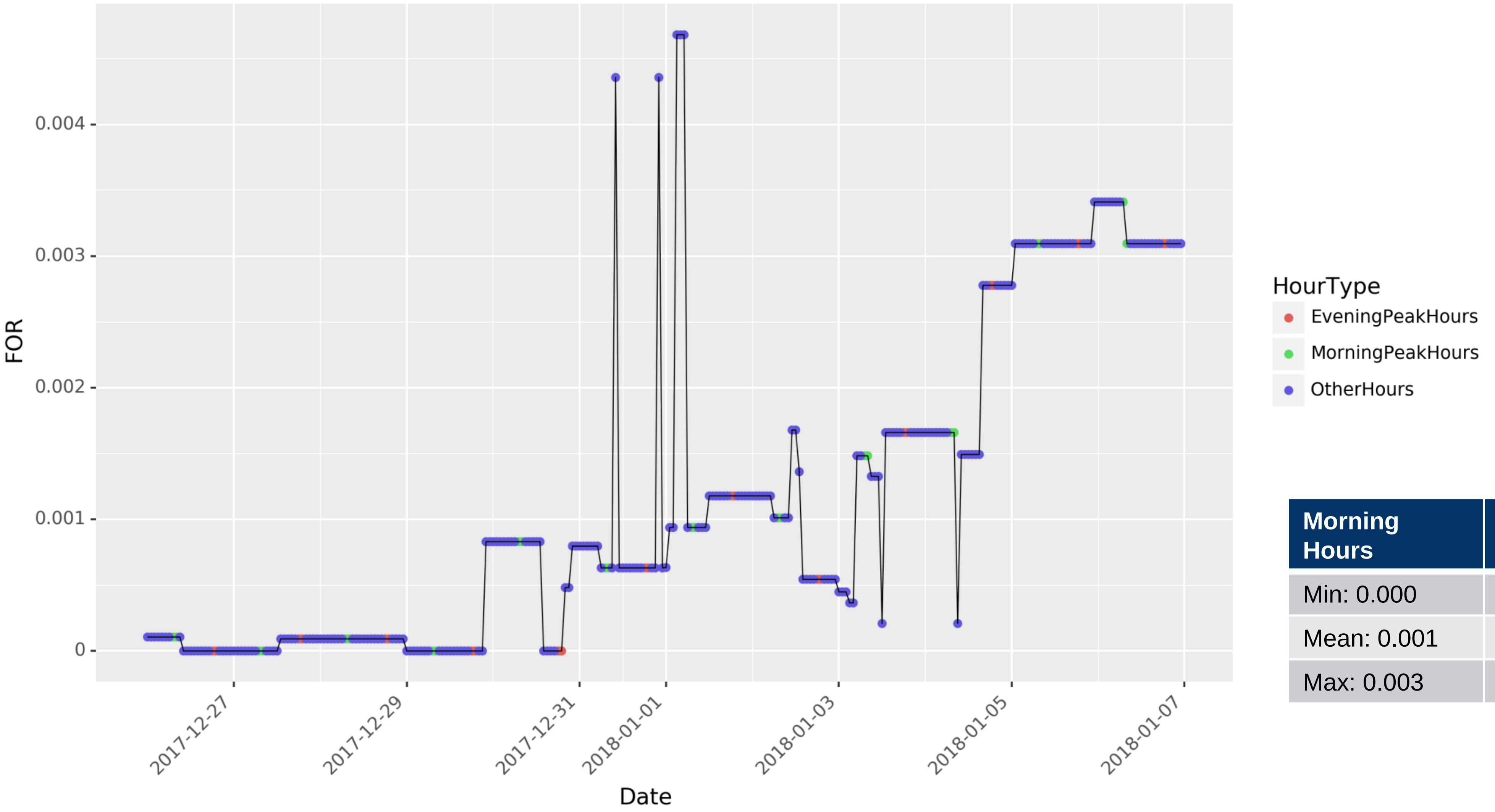
Morning Hours	Evening Hours
Min: 0.001	Min: 0.001
Mean: 0.003	Mean: 0.003
Max: 0.005	Max: 0.005

Coal RR-FOR (02/13/15 – 02/20/15)



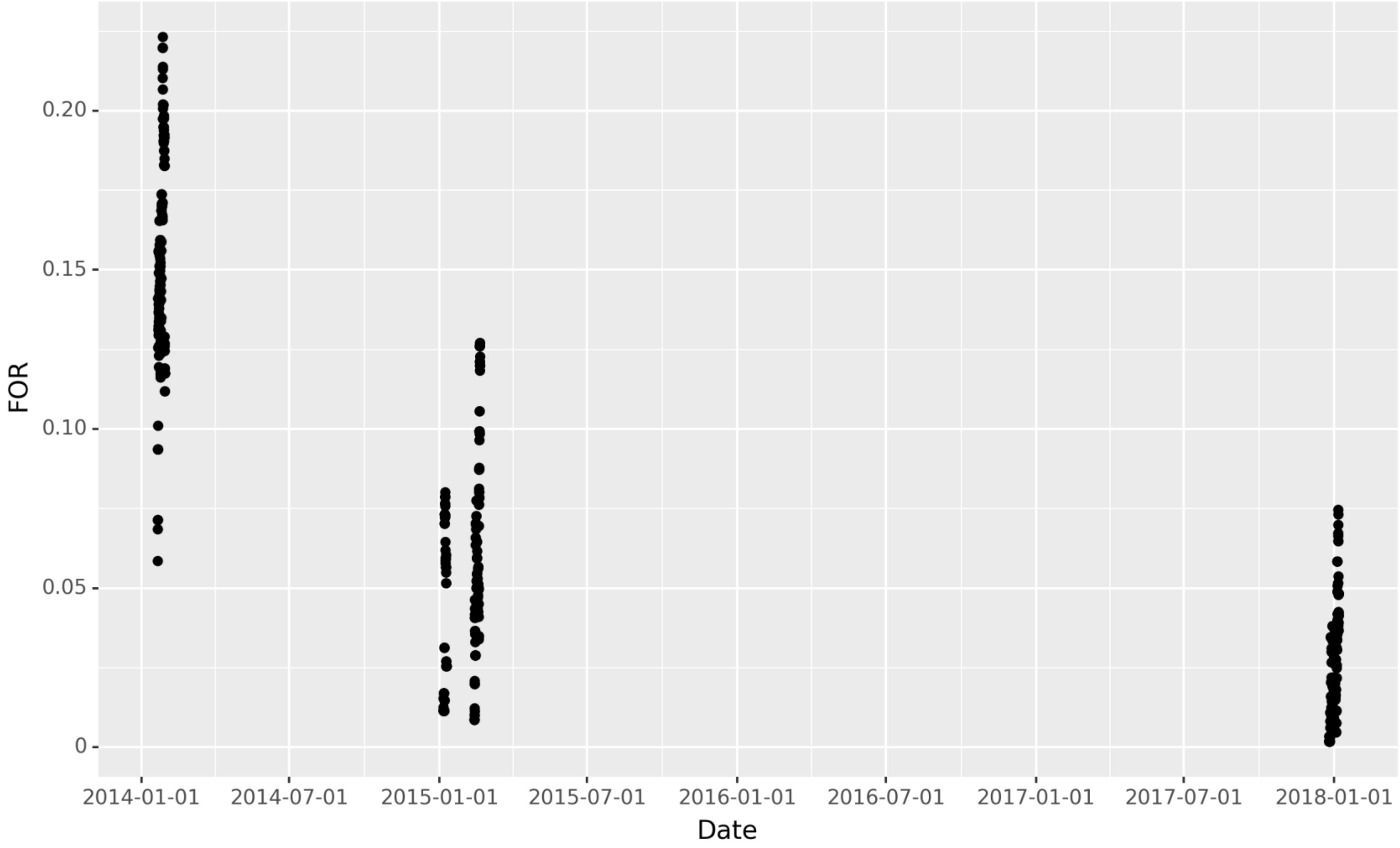
Morning Hours	Evening Hours
Min: 0.002	Min: 0.002
Mean: 0.003	Mean: 0.004
Max: 0.006	Max: 0.008

Coal RR-FOR (12/26/17 – 01/07/18)

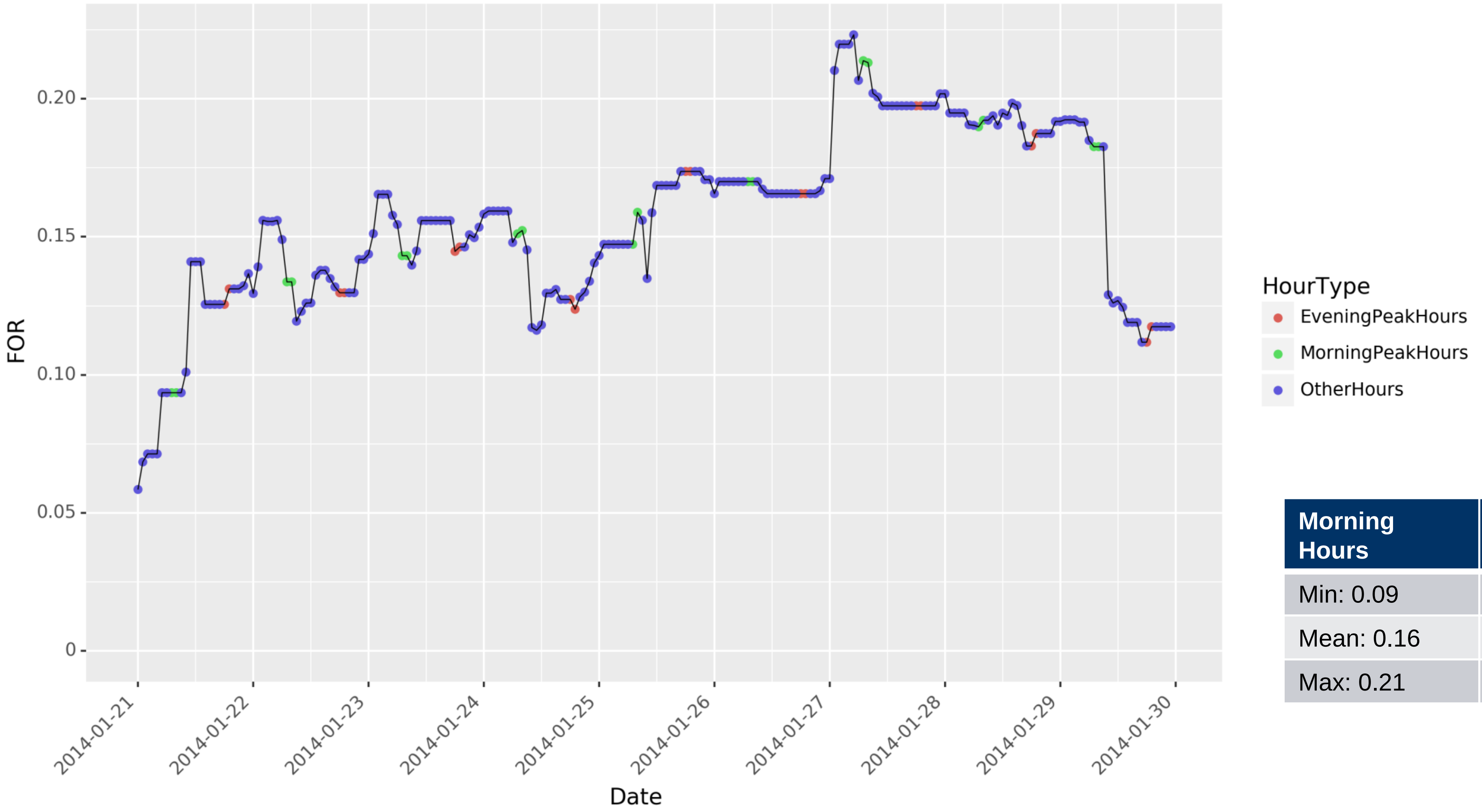


Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.001	Mean: 0.001
Max: 0.003	Max: 0.003

Natural Gas RR-FOR

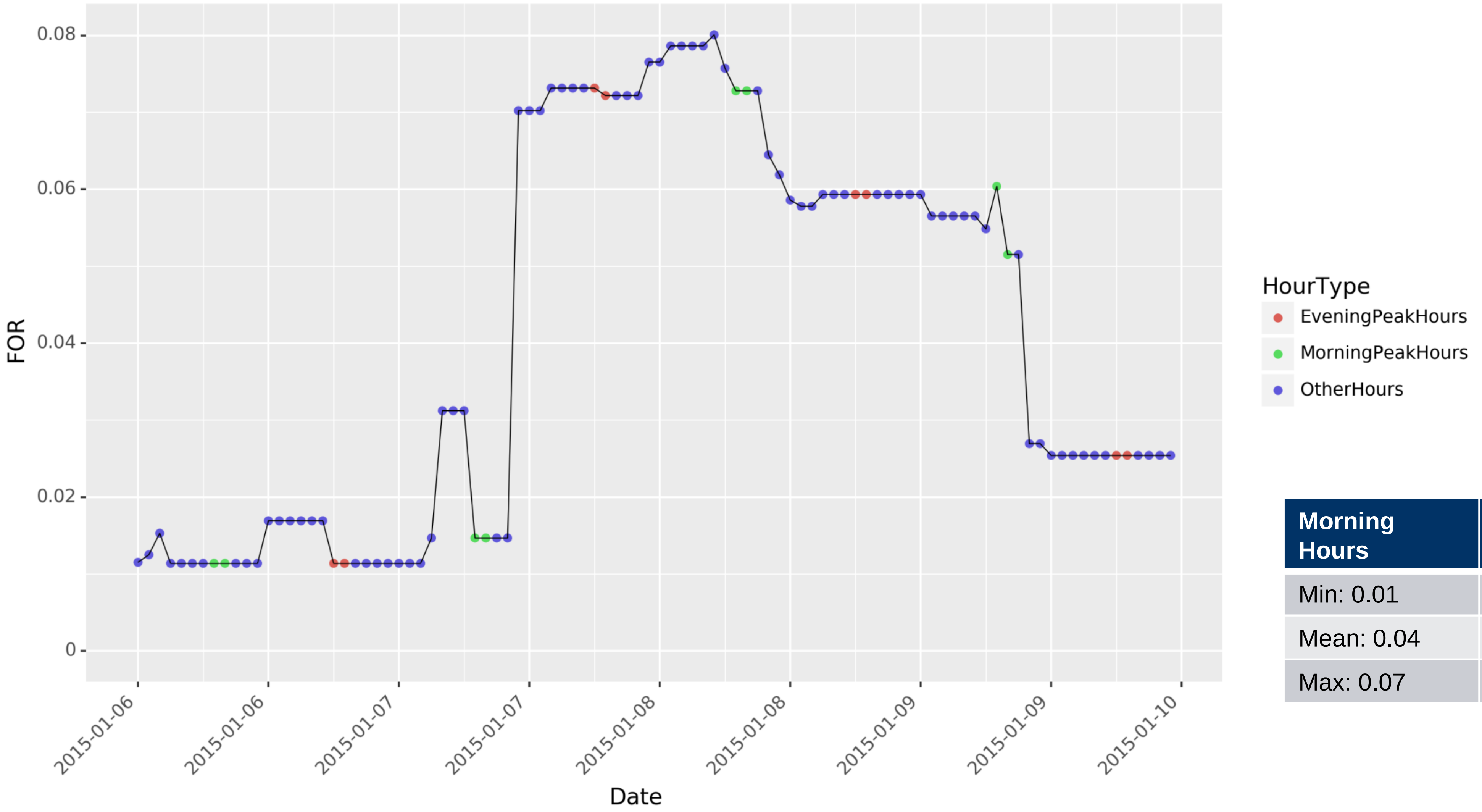


Natural Gas RR-FOR (01/21/14 – 01/30/14)



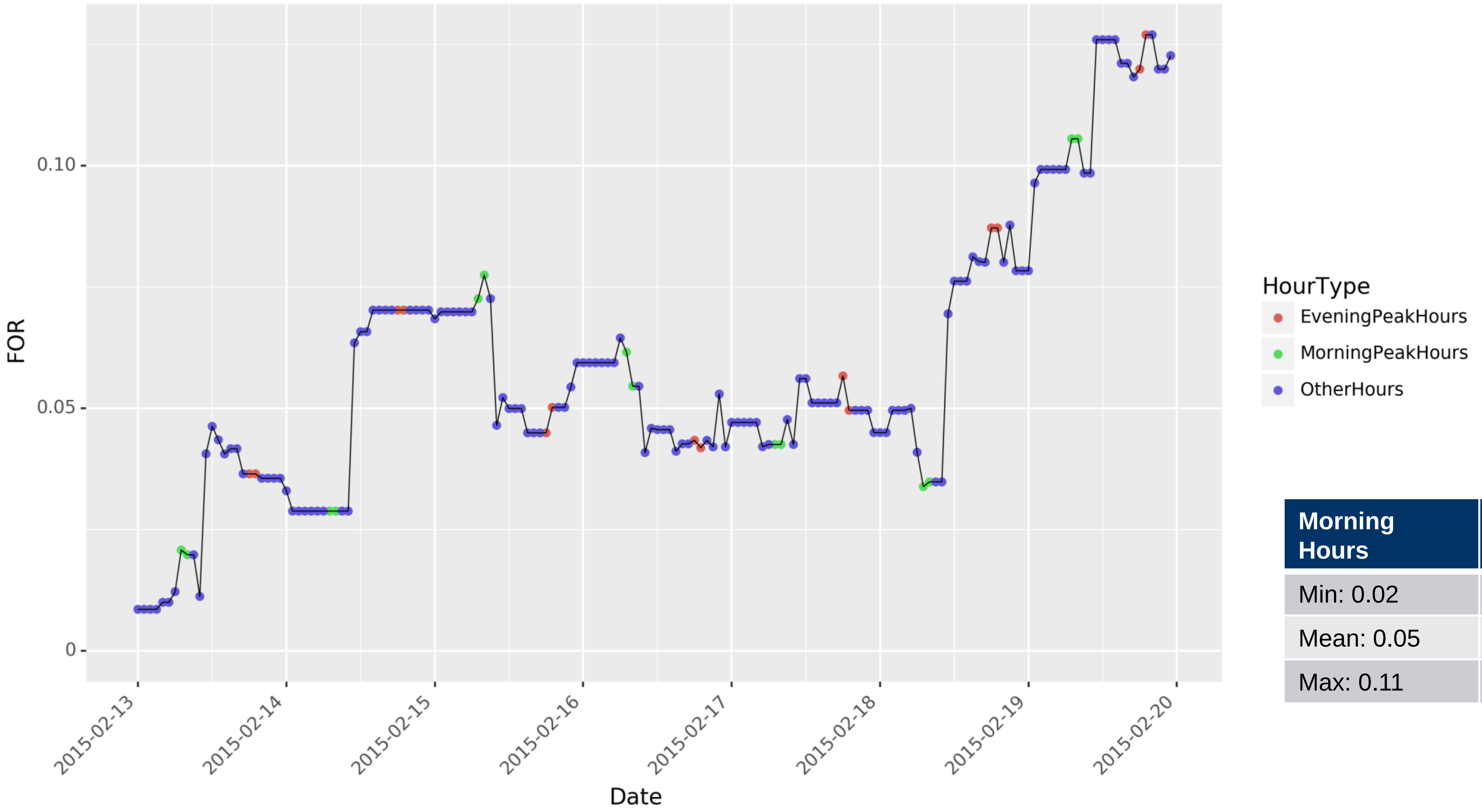
Morning Hours	Evening Hours
Min: 0.09	Min: 0.11
Mean: 0.16	Mean: 0.15
Max: 0.21	Max: 0.20

Natural Gas RR-FOR (01/06/15 – 01/10/15)



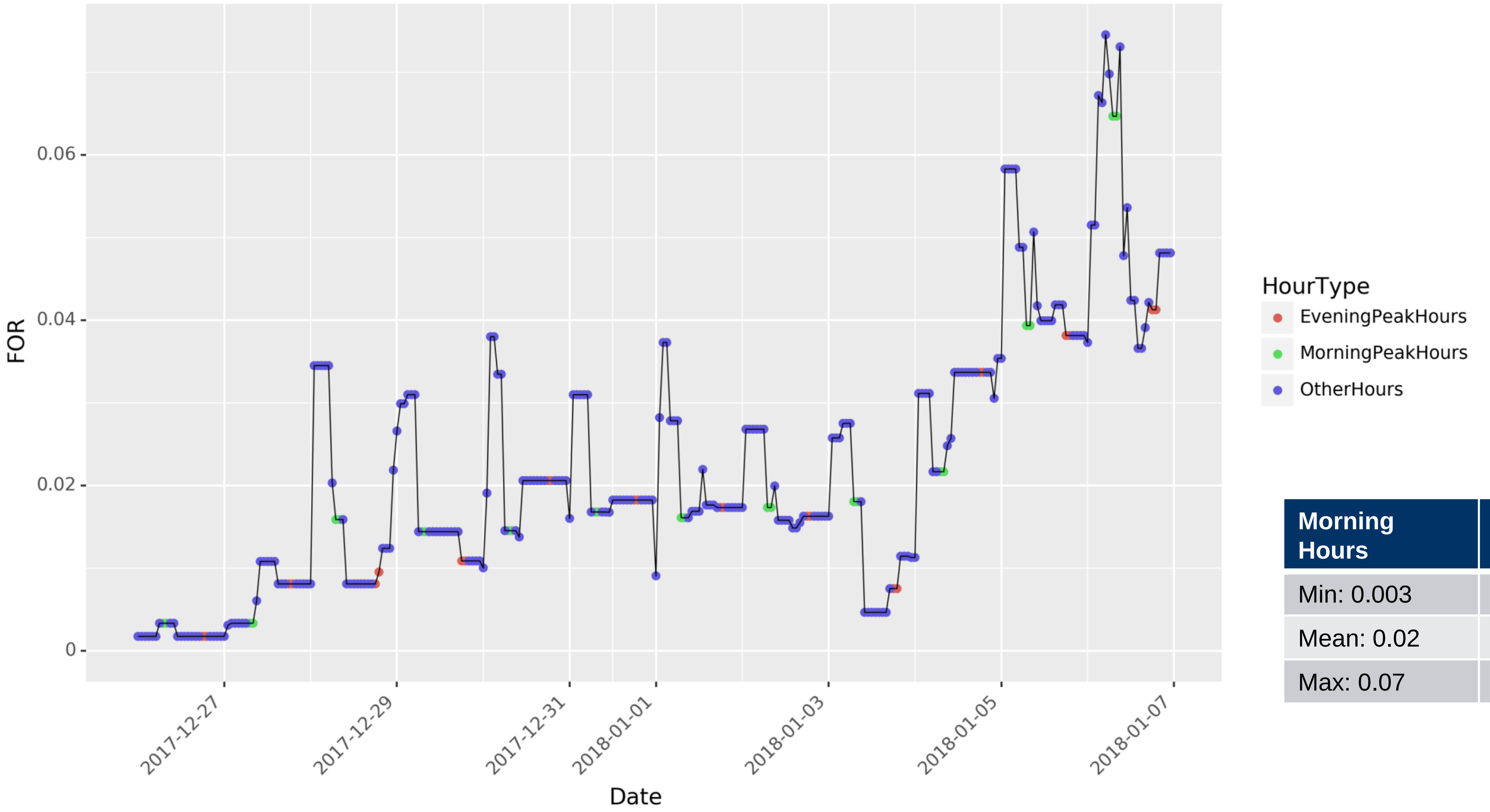
Morning Hours	Evening Hours
Min: 0.01	Min: 0.01
Mean: 0.04	Mean: 0.04
Max: 0.07	Max: 0.07

Natural Gas RR-FOR (02/13/15 – 02/20/15)



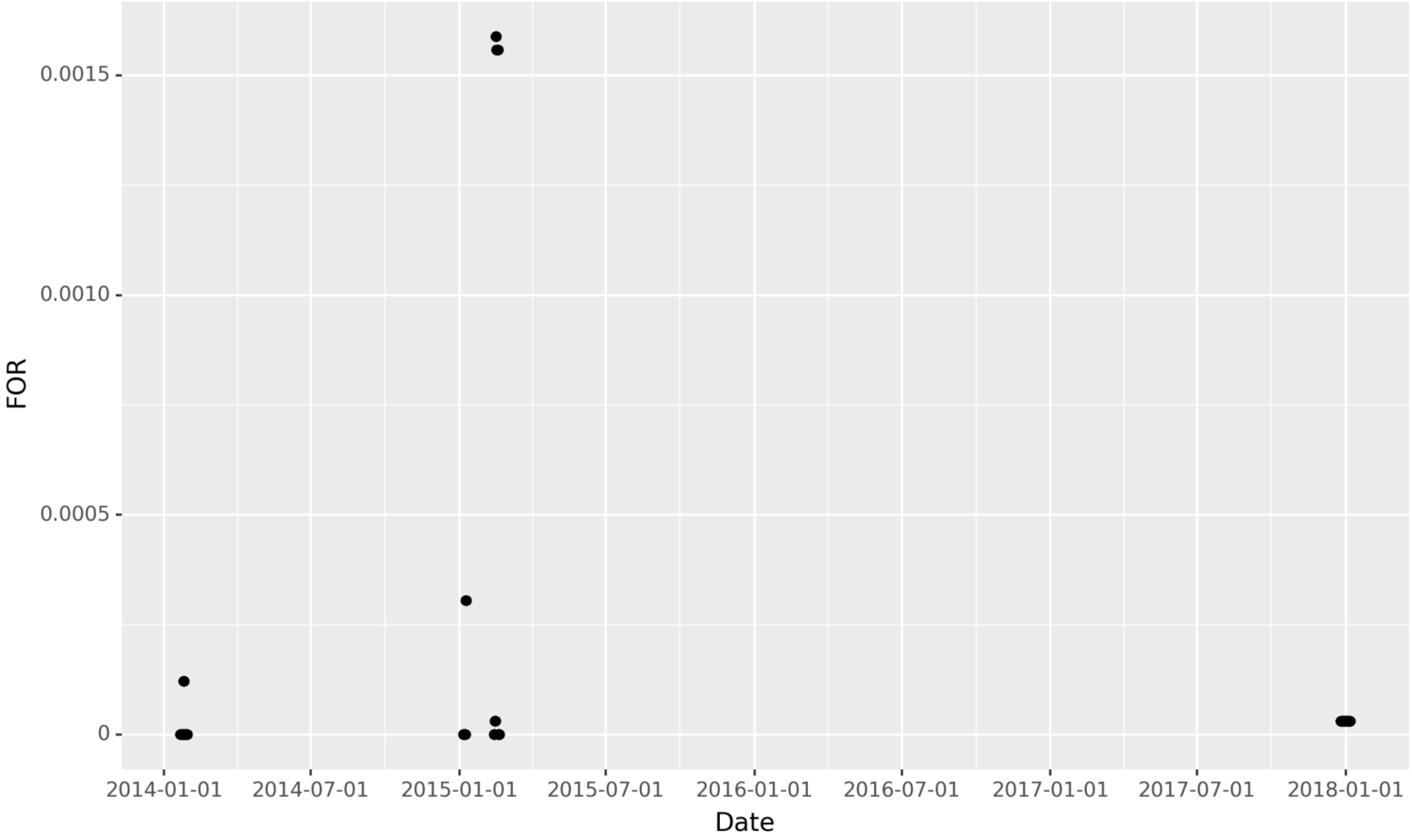
Morning Hours	Evening Hours
Min: 0.02	Min: 0.04
Mean: 0.05	Mean: 0.07
Max: 0.11	Max: 0.13

Natural Gas RR-FOR (12/26/17 – 01/07/18)

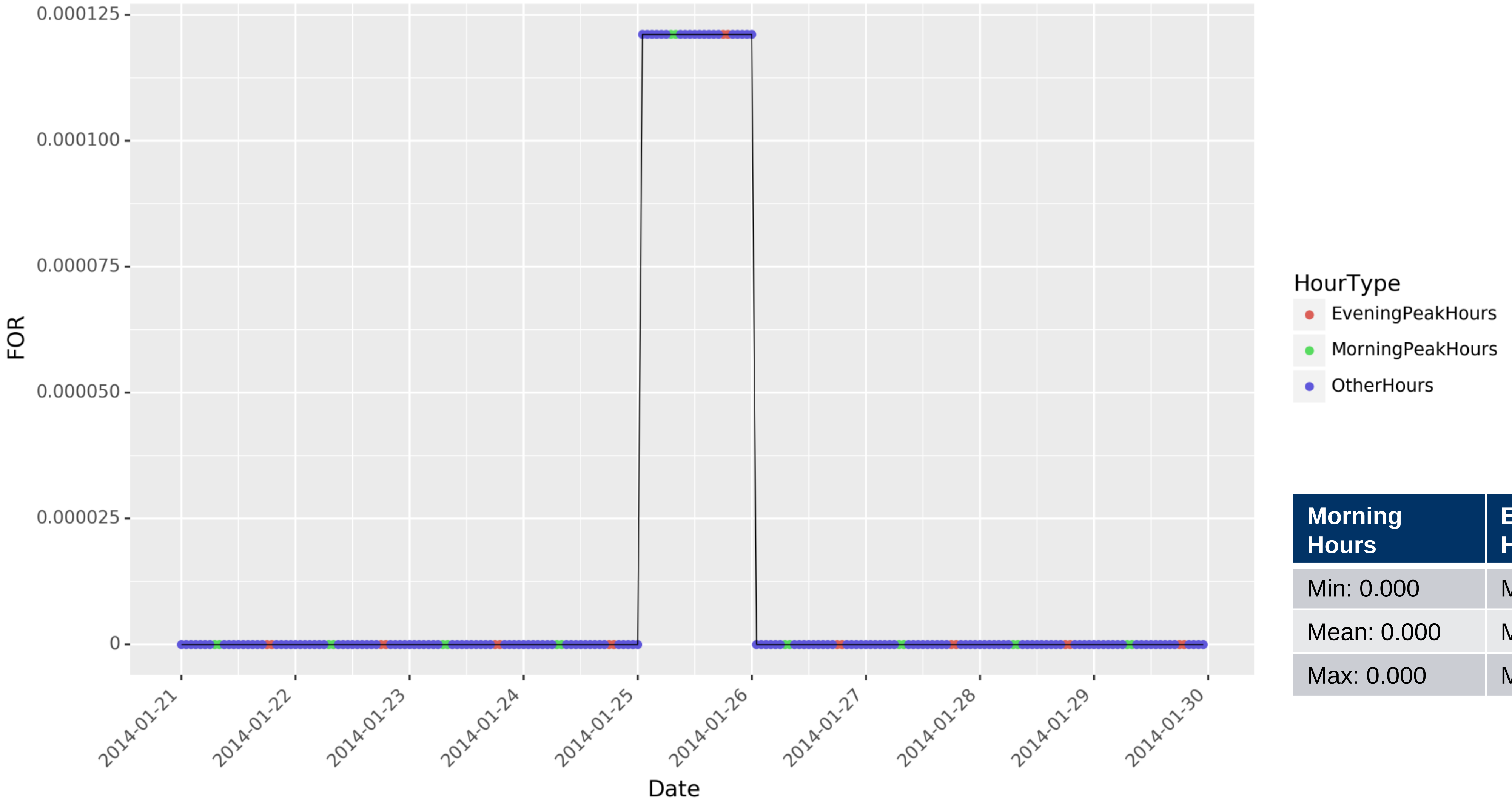


Morning Hours	Evening Hours
Min: 0.003	Min: 0.002
Mean: 0.02	Mean: 0.02
Max: 0.07	Max: 0.04

Nuclear RR-FOR

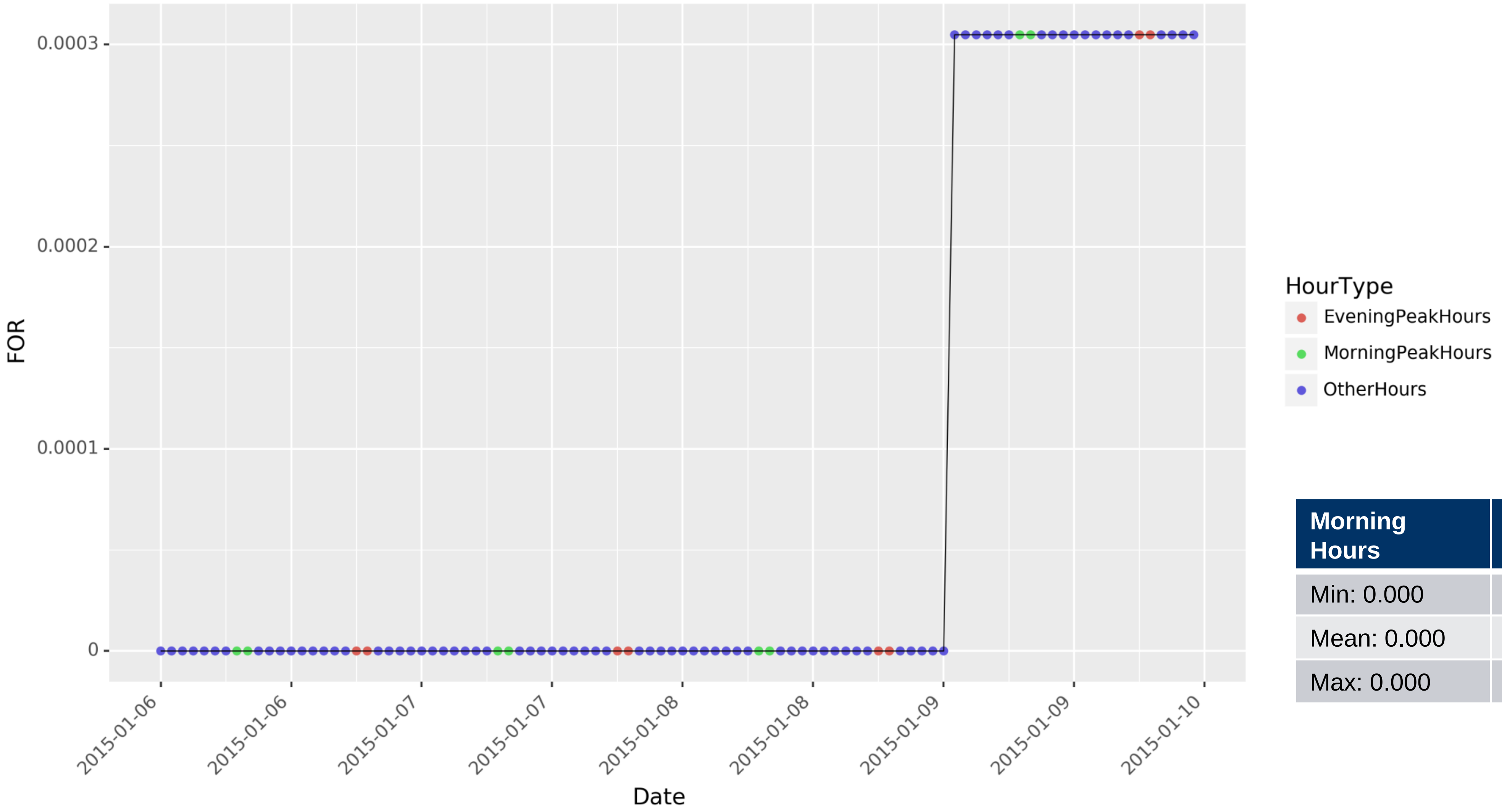


Nuclear RR-FOR (01/21/14 – 01/30/14)



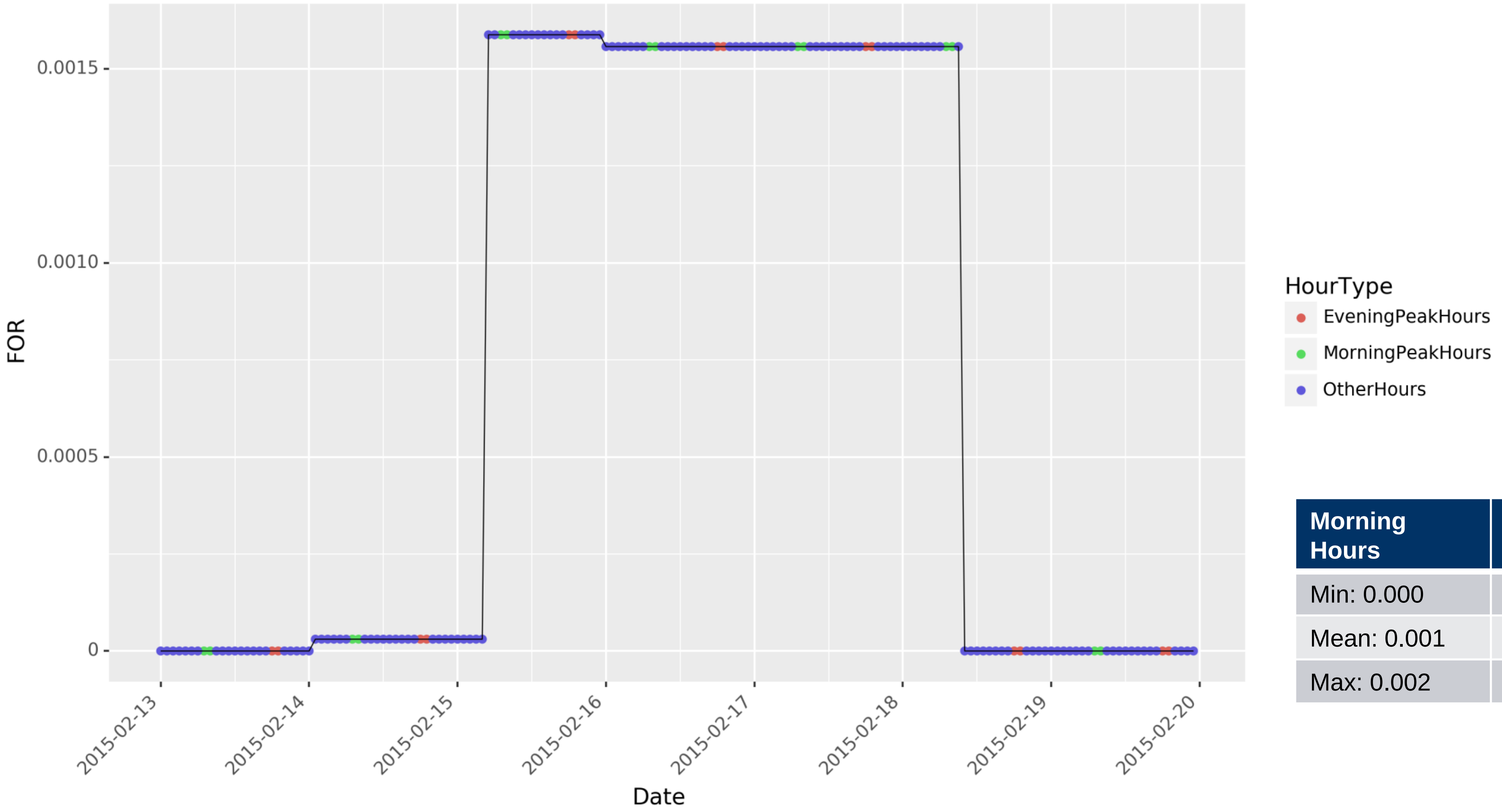
Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.000	Mean: 0.000
Max: 0.000	Max: 0.000

Nuclear RR-FOR (01/06/15 – 01/10/15)



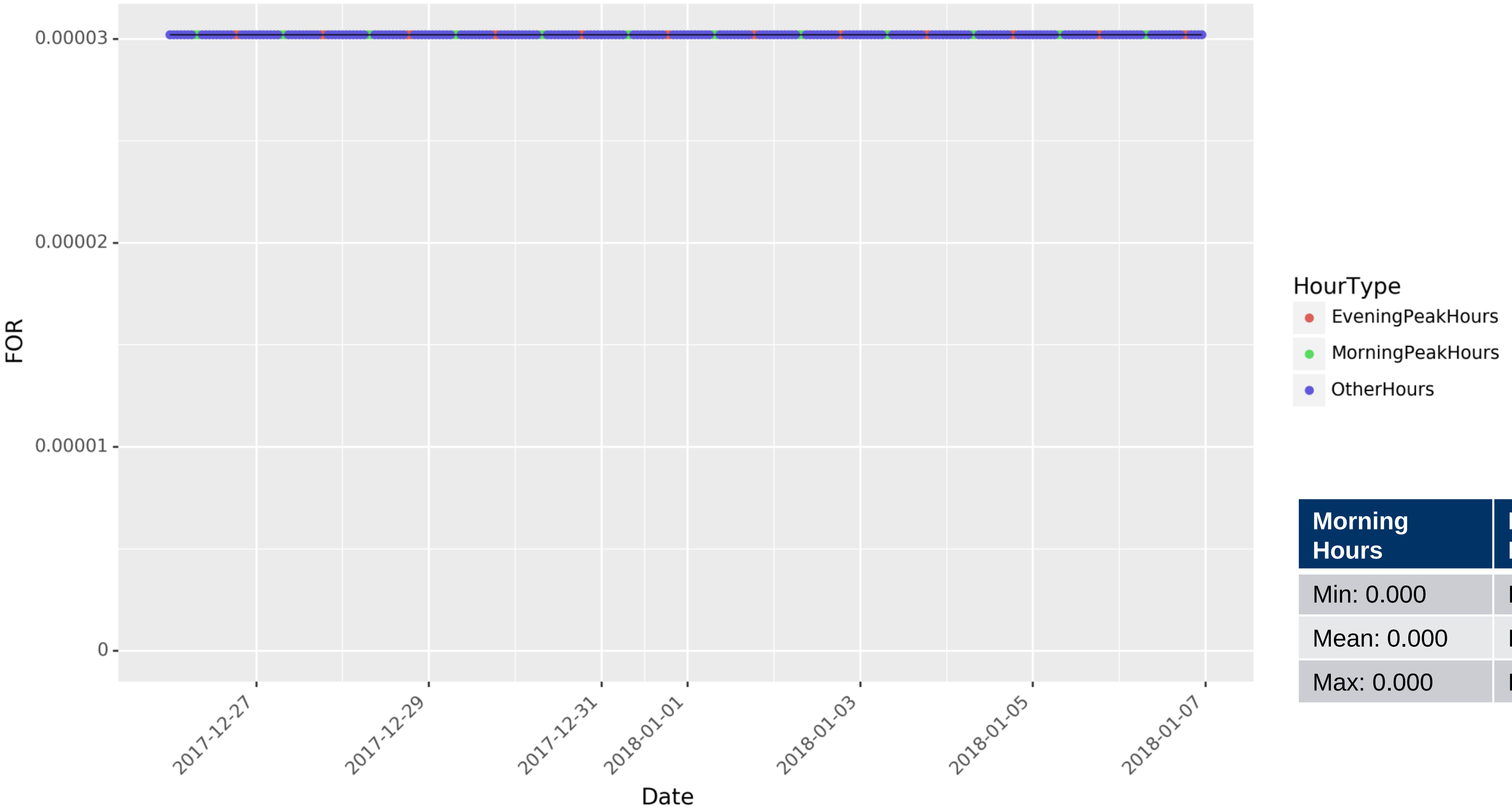
Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.000	Mean: 0.000
Max: 0.000	Max: 0.000

Nuclear RR-FOR (02/13/15 – 02/20/15)



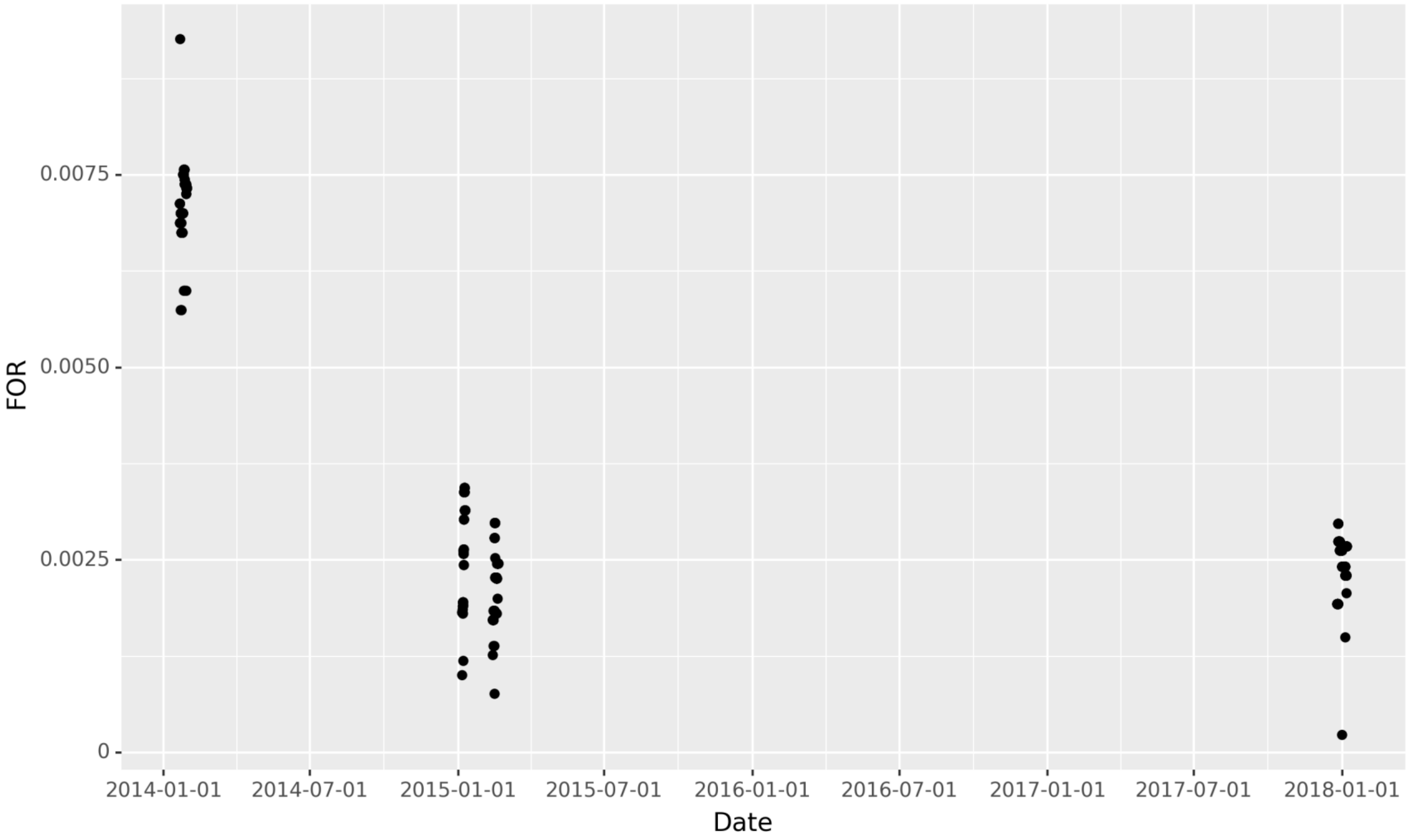
Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.001	Mean: 0.001
Max: 0.002	Max: 0.002

Nuclear RR-FOR (12/26/17 – 01/07/18)



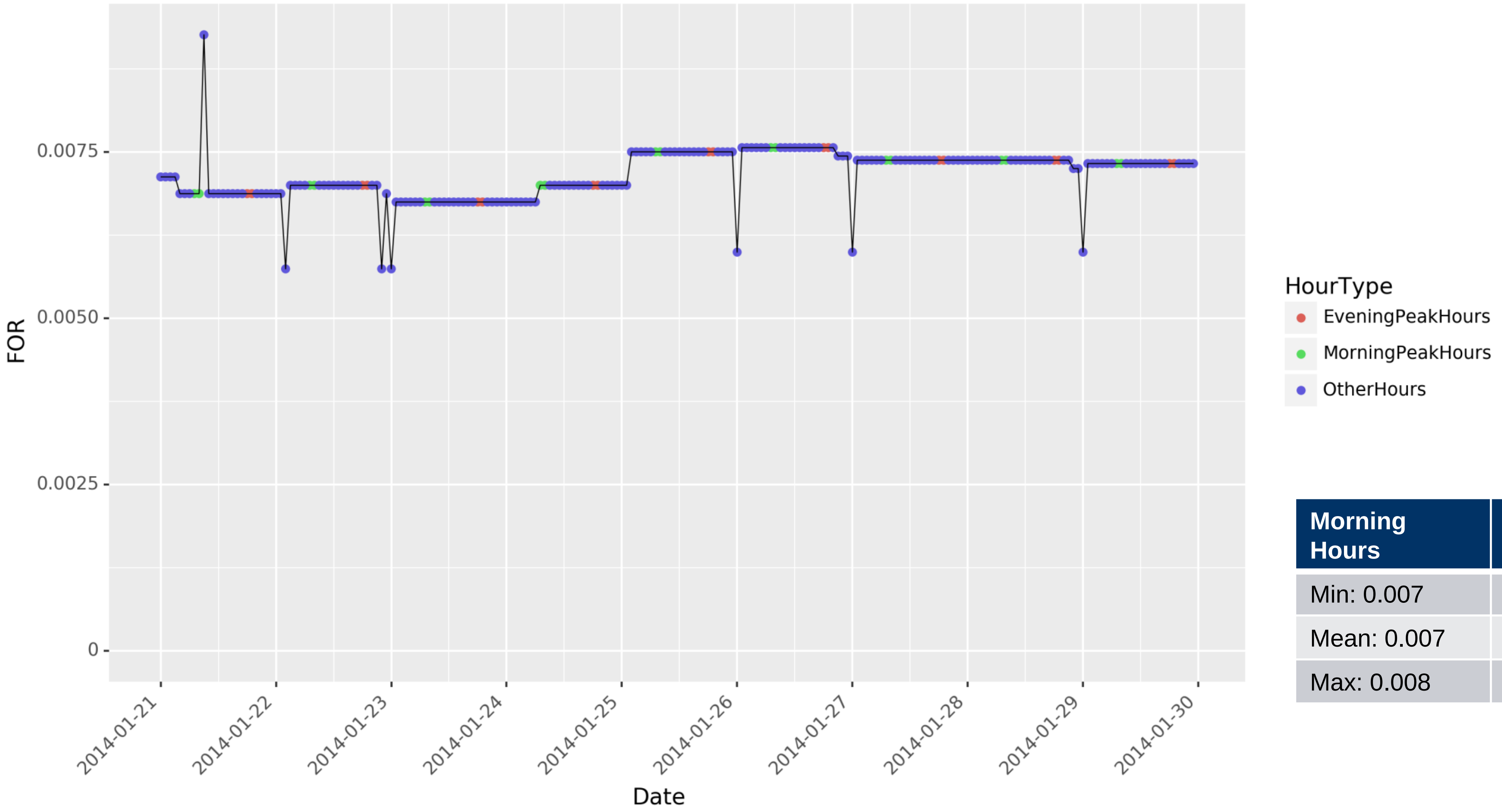
Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.000	Mean: 0.000
Max: 0.000	Max: 0.000

Hydro RR-FOR



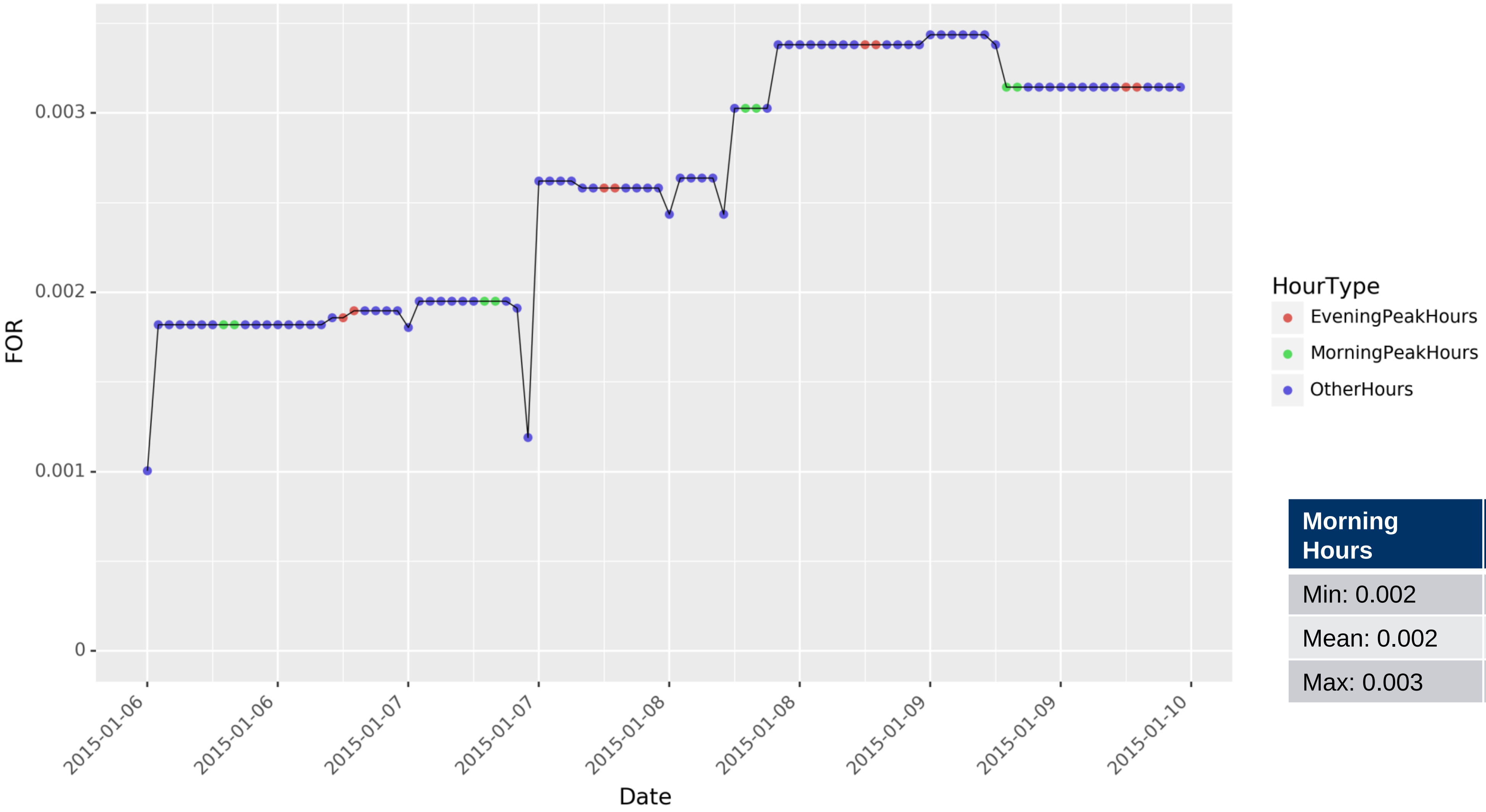
0.0075
0.0050
0.0025
0
FOR
2014-01-01
2014-07-01
2015-01-01
2015-07-01
2016-01-01
2016-07-01
2017-01-01
2017-07-01
2018-01-01
Date

Hydro RR-FOR (01/21/14 – 01/30/14)



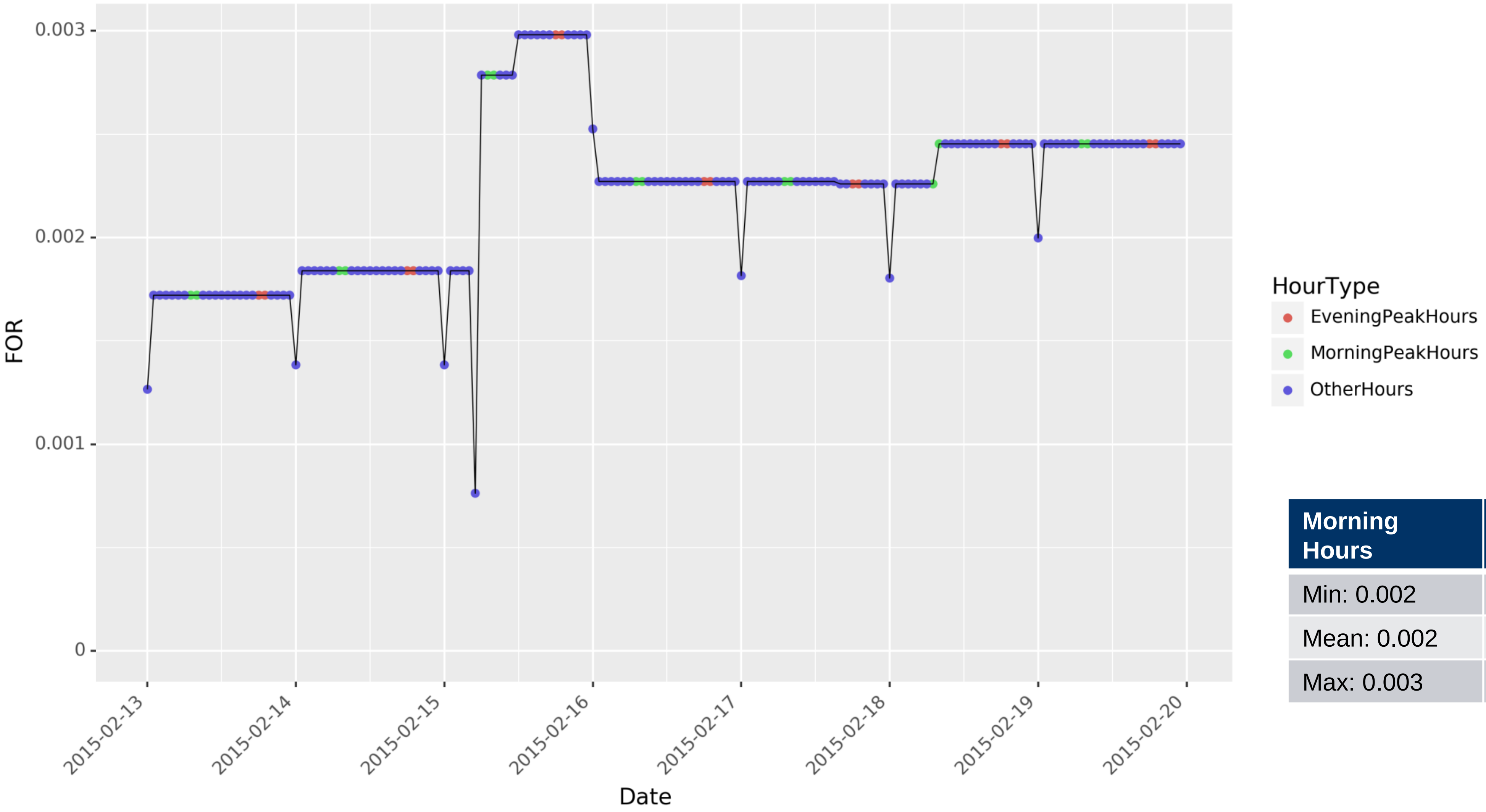
Morning Hours	Evening Hours
Min: 0.007	Min: 0.007
Mean: 0.007	Mean: 0.007
Max: 0.008	Max: 0.008

Hydro RR-FOR (01/06/15 – 01/10/15)



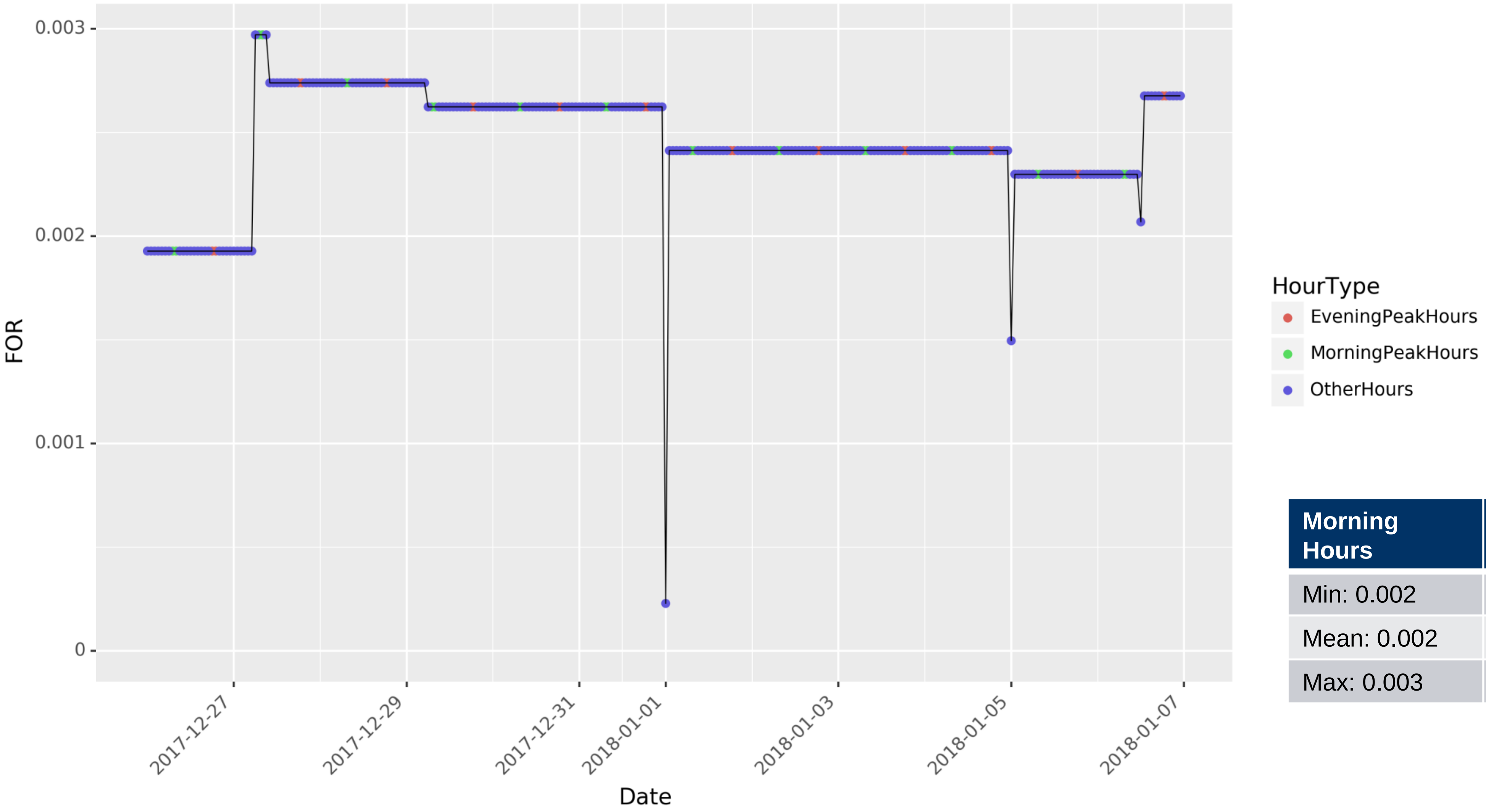
Morning Hours	Evening Hours
Min: 0.002	Min: 0.002
Mean: 0.002	Mean: 0.003
Max: 0.003	Max: 0.003

Hydro RR-FOR (02/13/15 – 02/20/15)



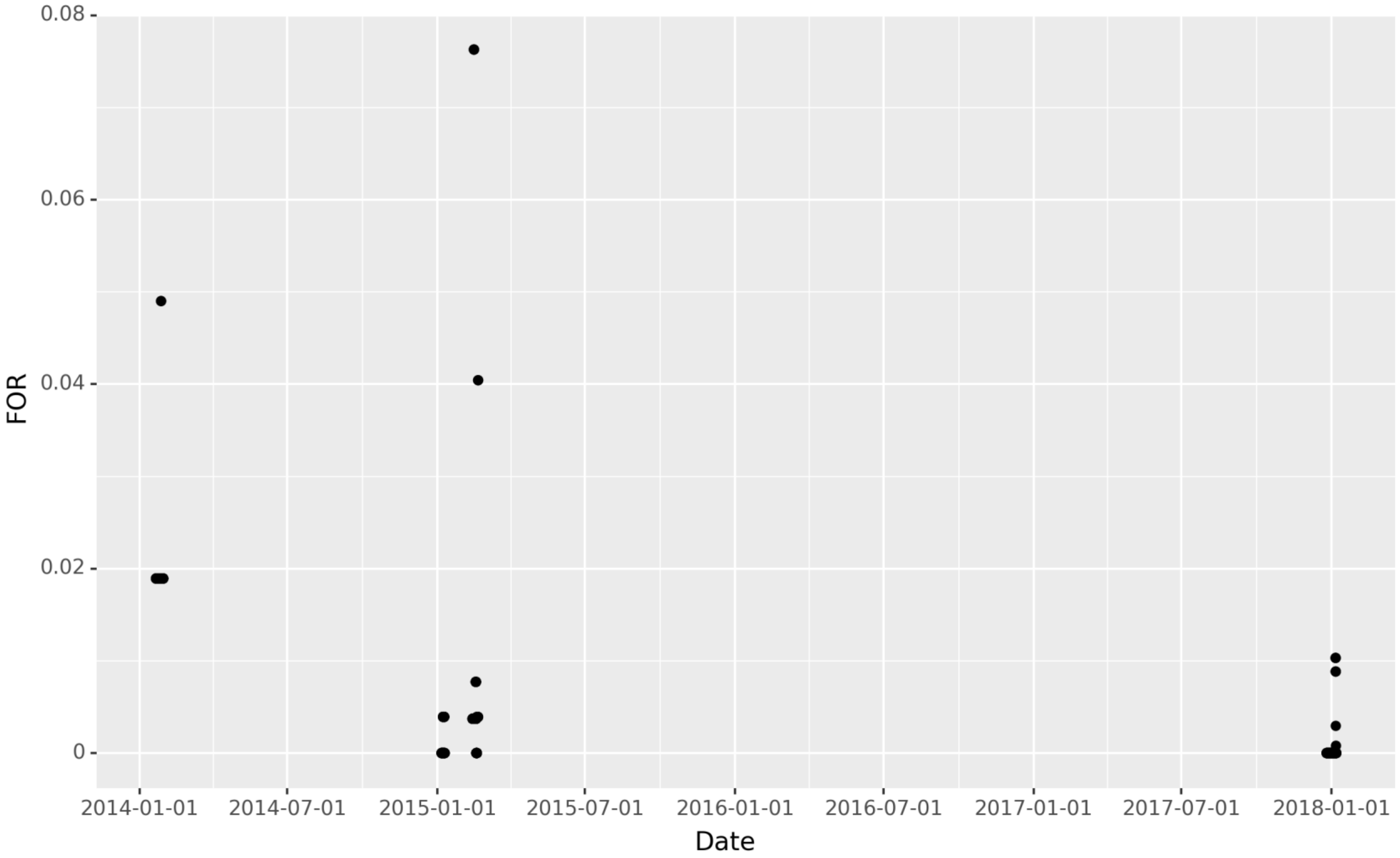
Morning Hours	Evening Hours
Min: 0.002	Min: 0.002
Mean: 0.002	Mean: 0.002
Max: 0.003	Max: 0.003

Hydro RR-FOR (12/26/17 – 01/07/18)



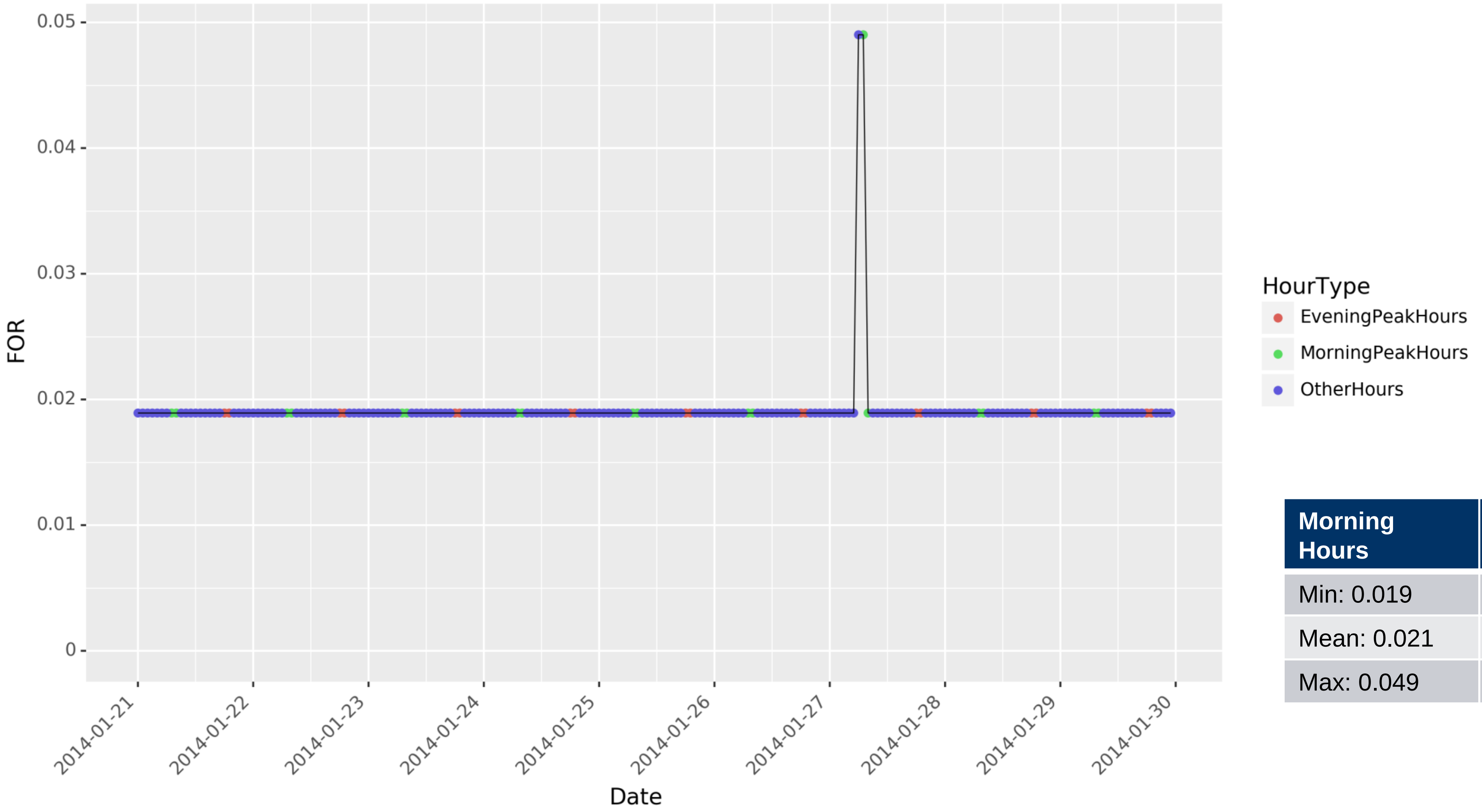
Morning Hours	Evening Hours
Min: 0.002	Min: 0.002
Mean: 0.002	Mean: 0.002
Max: 0.003	Max: 0.003

Oil RR-FOR



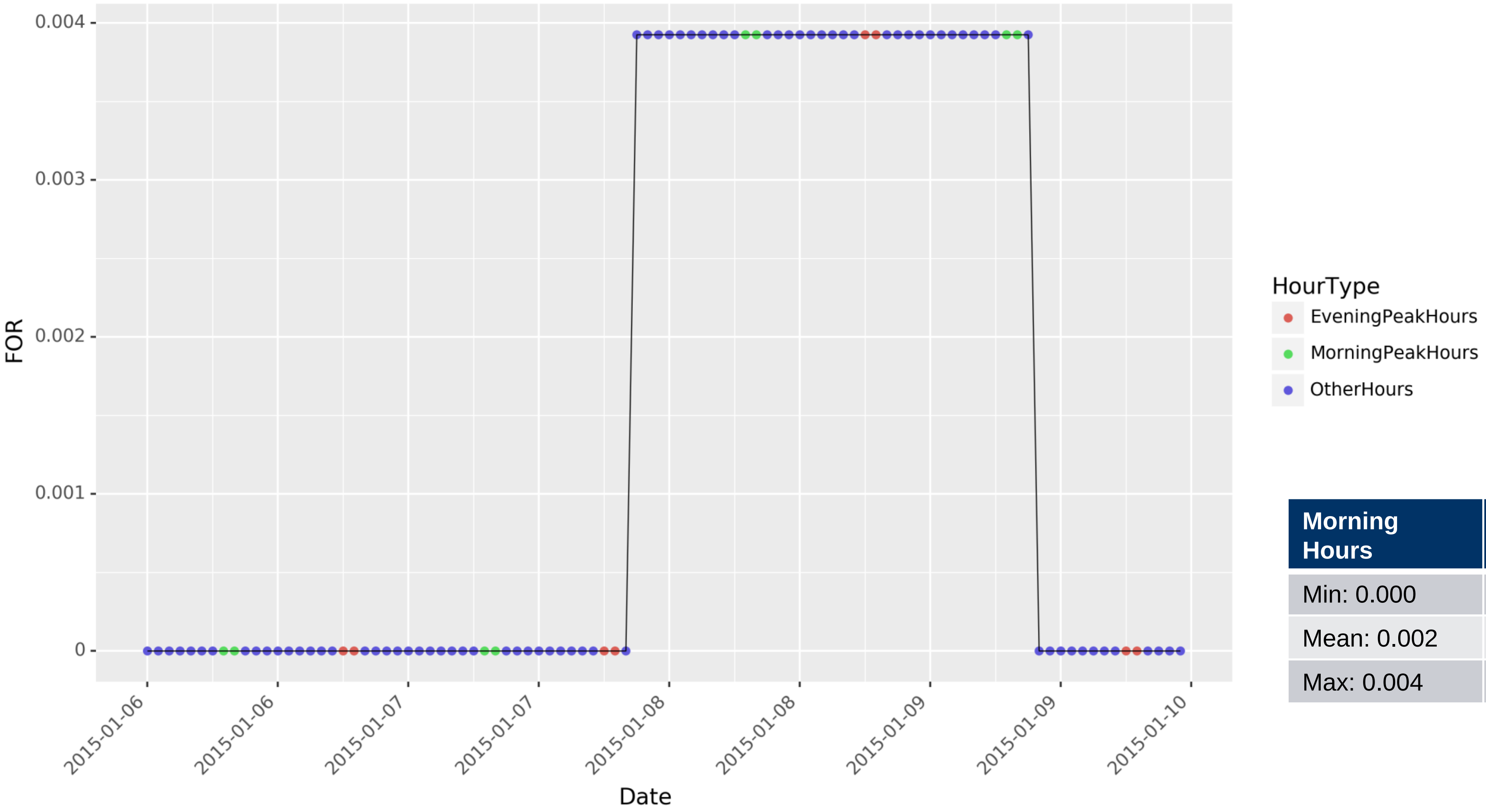
0.08
0.06
0.04
0.02
0
FOR
2014-01-01
2014-07-01
2015-01-01
2015-07-01
2016-01-01
2016-07-01
2017-01-01
2017-07-01
2018-01-01
Date

Oil RR-FOR (01/21/14 – 01/30/14)



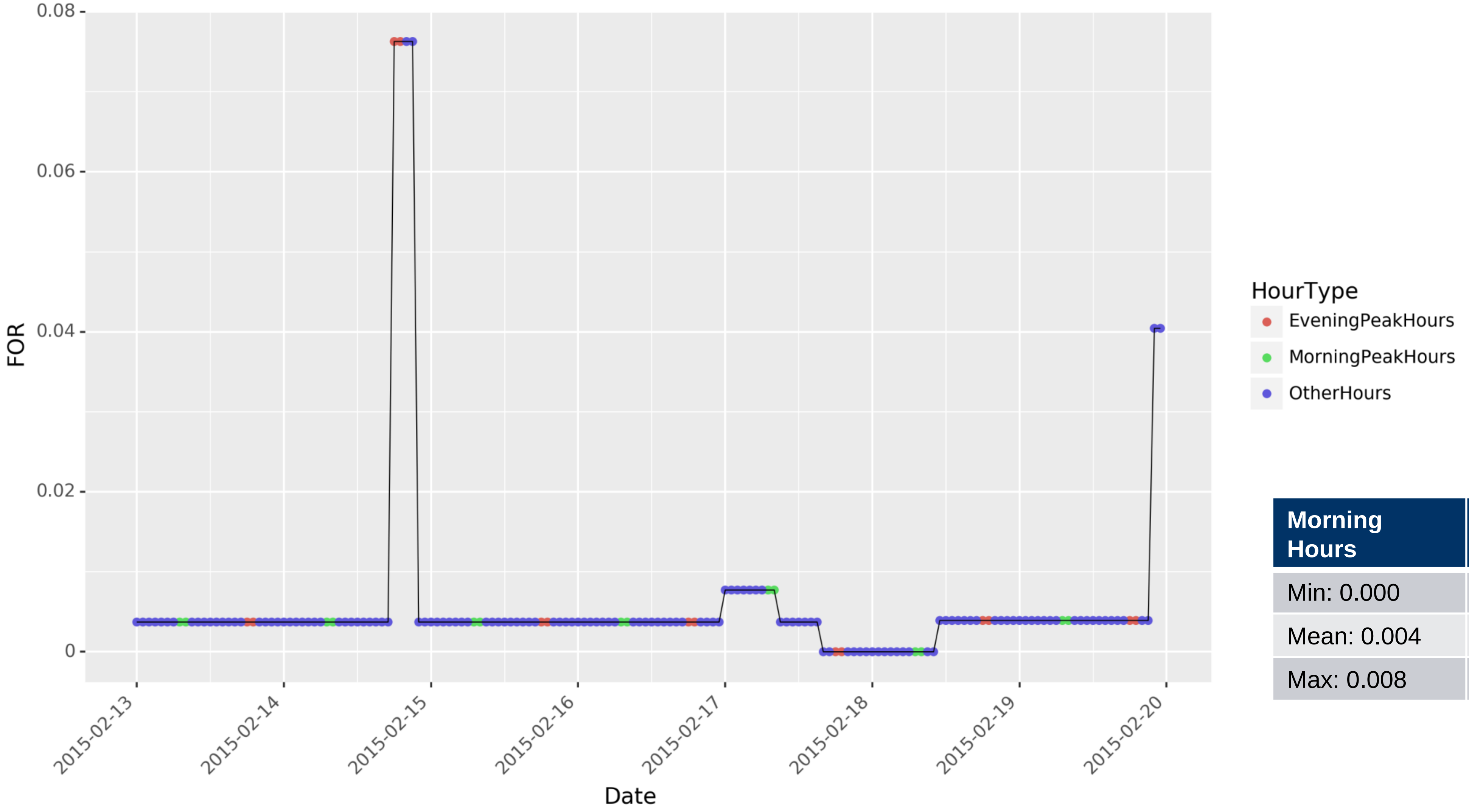
Morning Hours	Evening Hours
Min: 0.019	Min: 0.019
Mean: 0.021	Mean: 0.019
Max: 0.049	Max: 0.019

Oil RR-FOR (01/06/15 – 01/10/15)



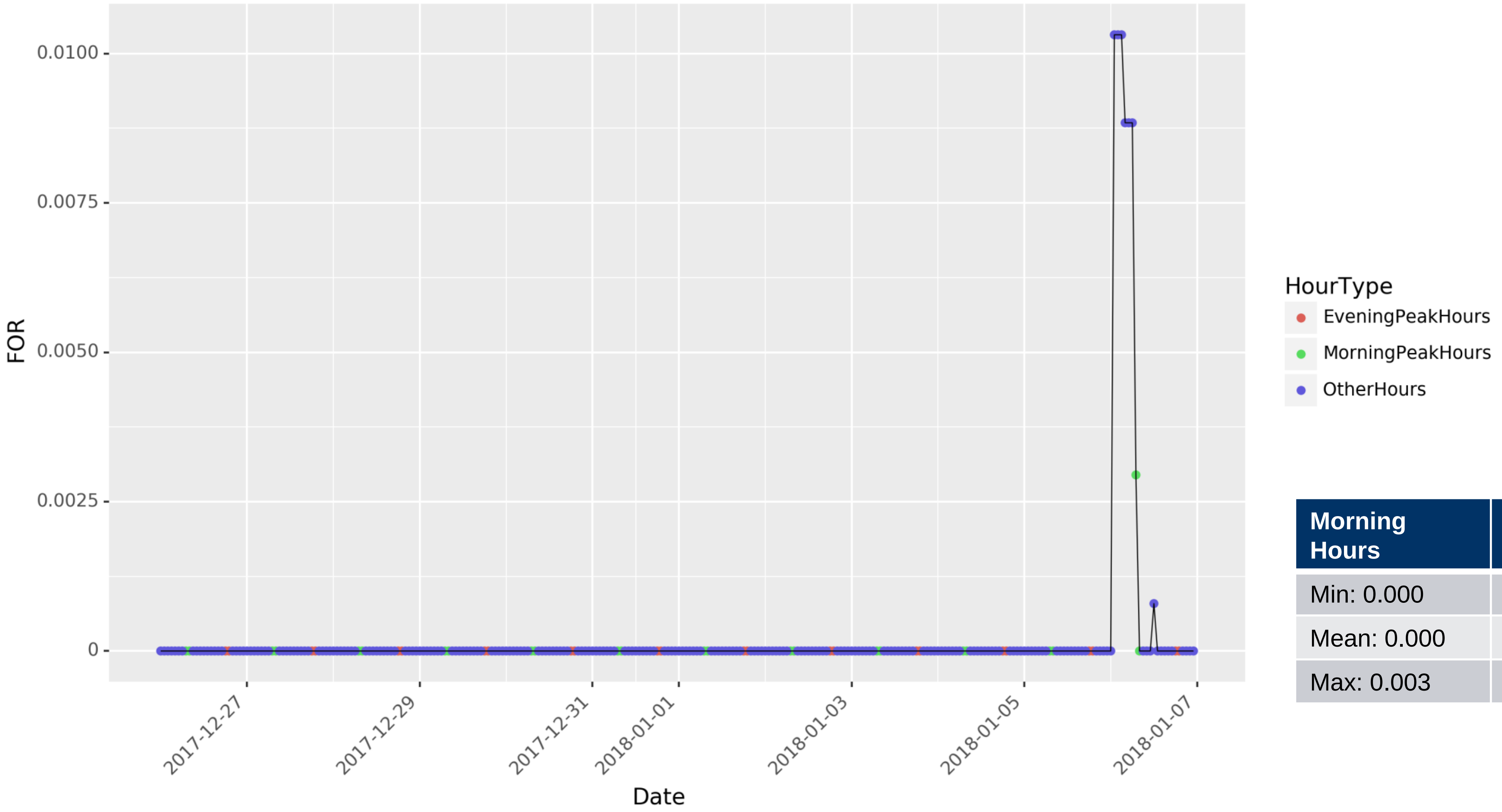
Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.002	Mean: 0.001
Max: 0.004	Max: 0.004

Oil RR-FOR (02/13/15 – 02/20/15)



Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.004	Mean: 0.014
Max: 0.008	Max: 0.076

Oil RR-FOR (12/26/17 – 01/07/18)



Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.000	Mean: 0.000
Max: 0.003	Max: 0.000

Scenario Development

Scenario Analysis

<table>
<tr><th>Scenario Analysis</th><th>Winter Load</th><th>Renewable Profiles</th><th>Relevant Risk Forced Outages</th><th>Other Forced Outages</th></tr>
<tr><td>Phase 1</td><td>Typical
• 50/50 peak (134,976 MW)
• 2011/12 load profile
Extreme Winter
• 95/5 peak (147,721 MW)
• 2017/18 load profile
14 day study period</td><td>2017/18 winter profiles, scaled to nameplate capacity in portfolio</td><td>Explicitly modeled sensitivities for fuel delivery risks: oil refueling, non-firm gas availability, pipeline disruptions</td><td rowspan="3">Forced outage rates using GADS cause codes not used in relevant risks or sensitivities</td></tr>
<tr><td rowspan="2">Phase 2</td><td rowspan="2">Load shapes consistent with selected cold snaps</td><td rowspan="2">Profile from cold snap, scaled to nameplate capacity in portfolio</td><td>Relevant Risk Forced Outages Rates from cold snap scaled to portfolio</td></tr>
<tr><td>Sensitivities for discrete occurrences of risks outside of historical forced outage dataset</td></tr>
</table>

Phase 1 portfolios for all scenarios: Announced (25.8% IRM), Escalated 1 (15.8% IRM), Escalated 2 (15.8% IRM)

Approach for Phase 2 Scenarios Using Relevant Risk Data

1. Selected cold snaps from analysis of winter weather:
   - Jan 21, 2014 through Jan 30, 2014 (10 days)
   - Jan 6, 2015 through Jan 10, 2015 (5 days)
   - Feb 13, 2015 through Feb 20, 2015 (8 days)
   - Dec 26, 2017 though Jan 7, 2018 (13 days)

2. For each cold snap, will use associated:
   a) Resource-Type Specific Forced Outage profiles to address the relevant risks
   b) Renewable output profiles
   c) Forced outage rates using GADS cause codes not used in relevant risks or sensitivities

3. Sensitivities to model discrete occurrences of risks outside of historical forced outage dataset (pipeline disruptions, rail disruption, nuclear regulatory shutdown, etc.)

Technical Appendix:
Fuel Specific Cause Code Combinations

Coal Specific Cause Codes

Cause Code	Description
9200 & 9201	High Ash Content (OMC & non-OMC)
9210 & 9211	Low Grindability (OMC & non-OMC)
9220 & 9221	High Sulfur Content (OMC & non-OMC)
9230 & 9231	High Vanadium Content (OMC & non-OMC)
9240 & 9241	High Sodium Content (OMC & non-OMC)
9250 & 9251	Low BTU Coal (OMC & non-OMC)
9270 & 9271	Wet Coal (OMC & non-OMC)
9280 & 9281	Frozen Coal (OMC & non-OMC)

Coal Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
3280	High Circulating Water Temperature
9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation

Natural Gas Specific Cause Codes

Cause Code	Description
9205	Poor quality natural gas fuel, low heat content

Natural Gas Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
3280	High Circulating Water Temperature
9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation

Nuclear Specific Cause Codes

Cause Code	Description
9500	Regulatory (nuclear) proceedings and hearings – regulatory agency initiated
9502	Regulatory (nuclear) proceedings and hearings – intervenor initiated
9710	Investigation of possible nuclear safety problems
2010	Fuel failure, including high activity in Reactor Coolant System or off-gas system
2030	Fuel limits – peaking factors
2032	Fuel limits – minimum critical power ratio (BWR units only)
2033	Fuel limits – maximum average planar linear heat generation rate (BWR units only)
2037	Other fuel limits (excluding core coast down, conservation, or stretch)

Nuclear Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
3280	High Circulating Water Temperature
9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation

Hydro Specific Cause Codes

Cause Code	Description
7100	Upper reservoir dams and dikes
7101	Lower reservoir dams and dikes
7102	Auxiliary reservoir dams and dikes
7110	Intake channel or flume (excluding trash racks)
7111	Intake tunnel

Hydro Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
3280	High Circulating Water Temperature
9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation

Oil Specific Cause Codes

Cause Code	Description
9260 & 9261	Low BTU oil (OMC & non-OMC)

Oil Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
3280	High Circulating Water Temperature
9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation