Power Conversion: Plant-level vs. Turbine-level, Temperature, Static vs. Self-learning

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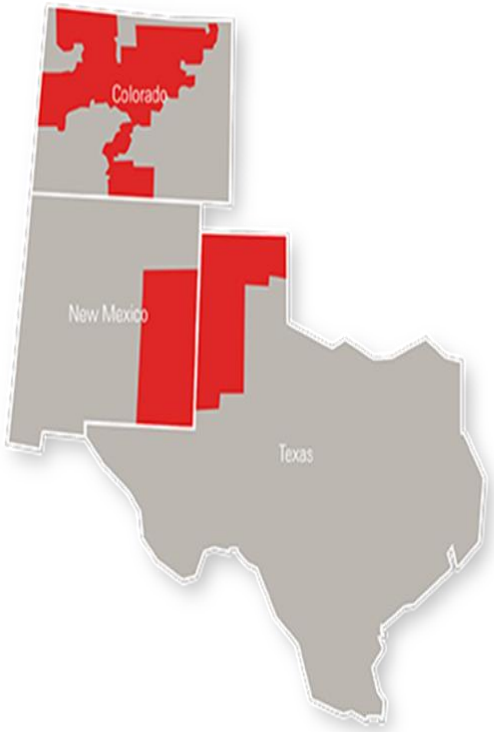
About Xcel Energy

Serving eight states
- 3.6 million electricity customers
- Two million natural gas customers

Nationally Recognized Leader:
- Wind energy
- Energy efficiency
- Voluntary emissions reductions
- Pursuit of new technologies

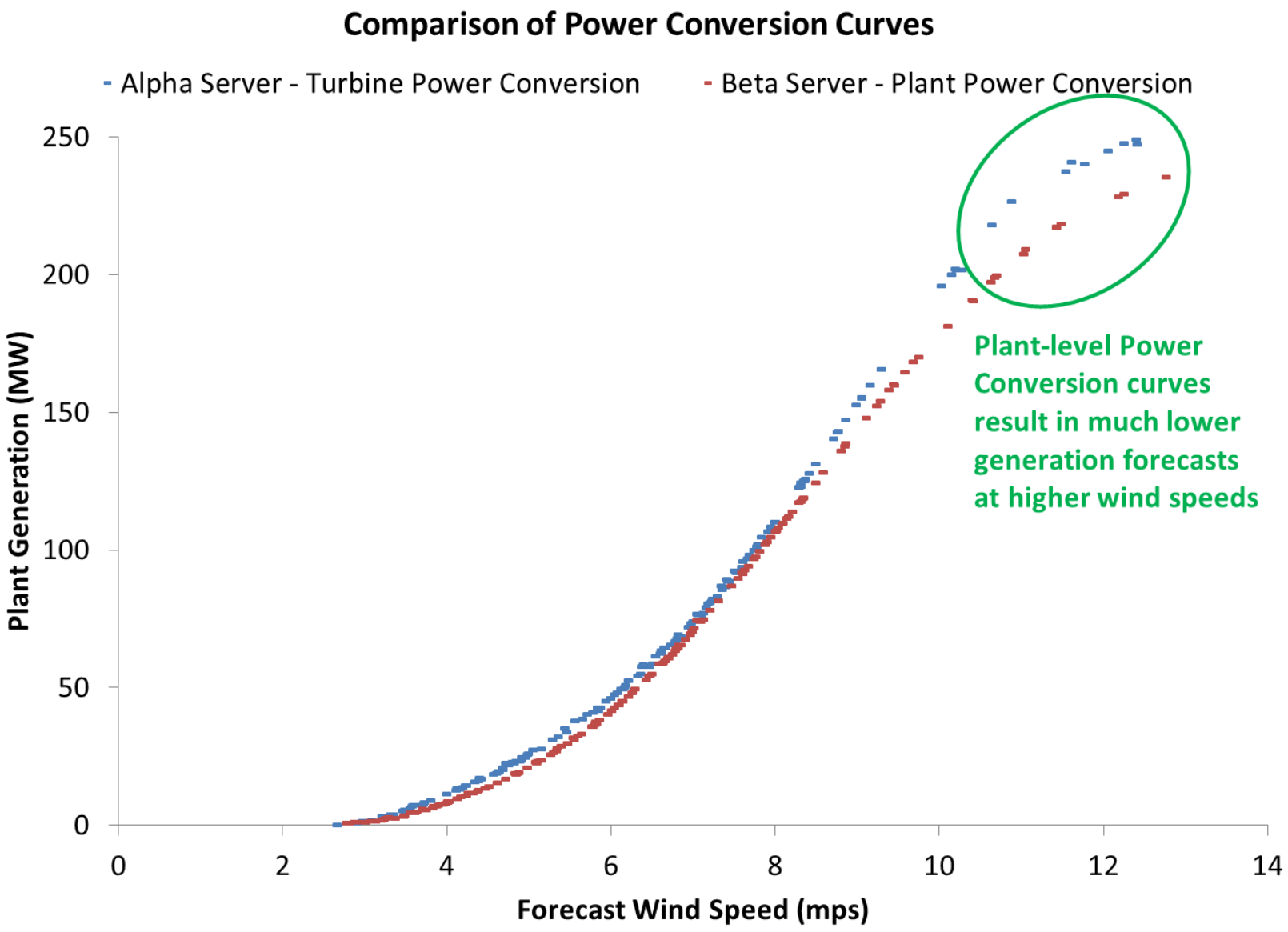


What is Power Conversion?

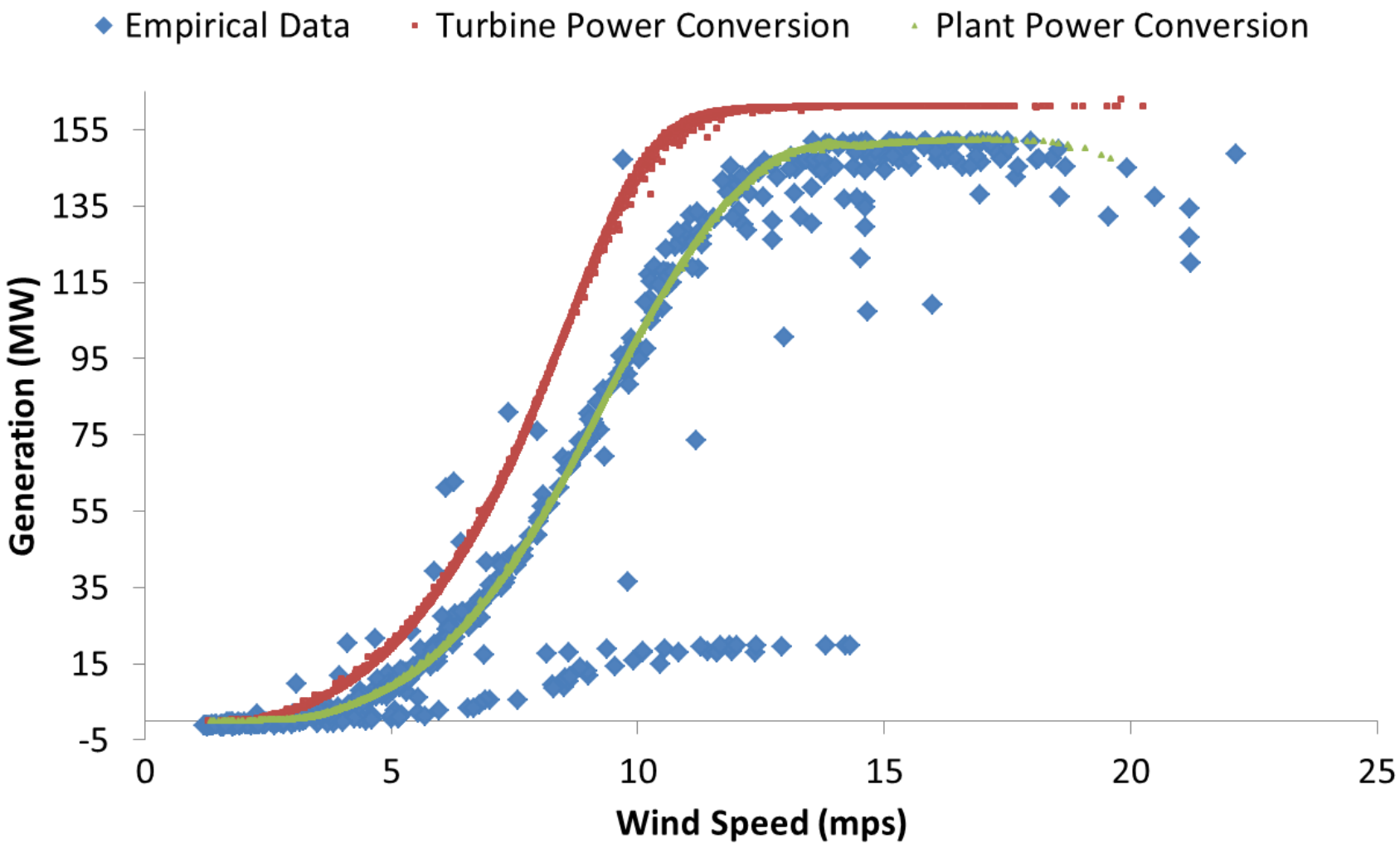
- Xcel Energy's wind generation forecast includes two components:
  1. Underlying weather forecast
  2. Power Conversion from underlying weather to power generation

Plant-level vs. Turbine-level

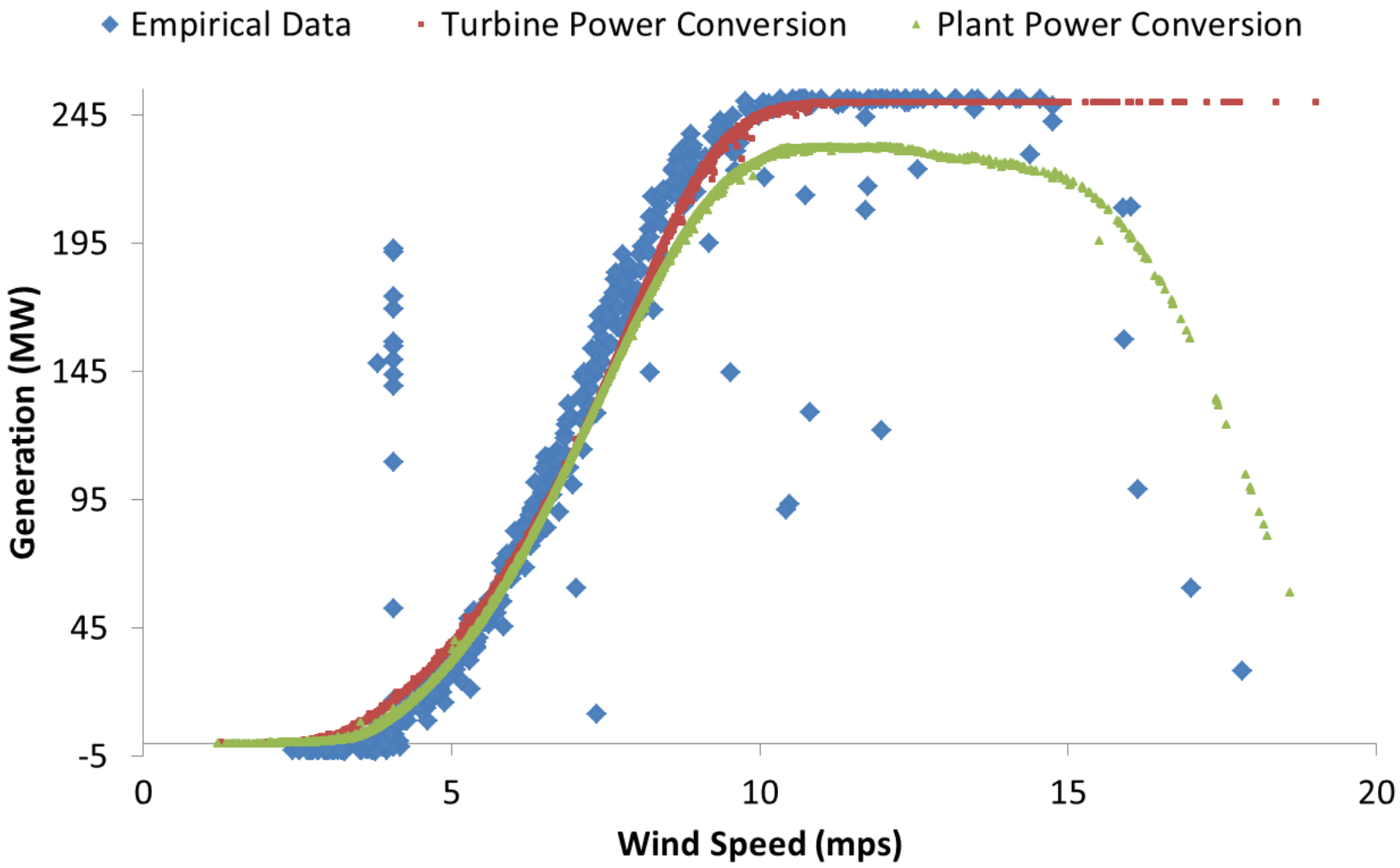
- Xcel Energy currently utilizes a turbine-level power conversion
  - Empirical “super turbine” power conversion, multiplied by number of plant turbines after availability adjustment
- We believe a plant-level power conversion would be superior
  - Plant-level data would naturally incorporate intra-plant geographic diversity
  - Also incorporates routine turbine unavailability


Comparison of Power Conversion Curves
Alpha Server - Turbine Power Conversion
Beta Server - Plant Power Conversion
Plant Generation (MW)
250
200
150
100
50
0
0
2
4
6
8
10
12
14
Forecast Wind Speed (mps)
Plant-level Power Conversion curves result in much lower generation forecasts at higher wind speeds

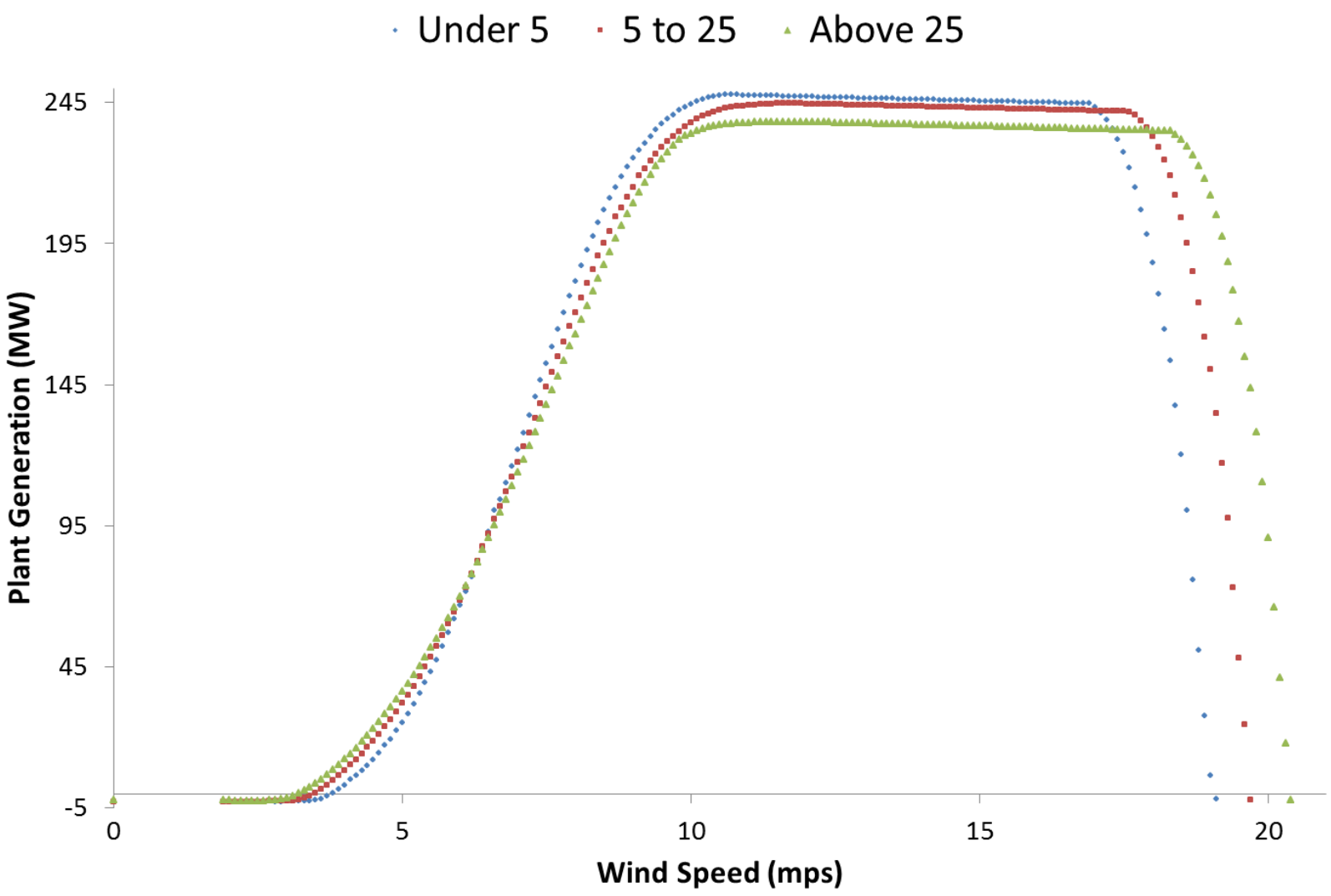
Older Wind Plant: Dec 23, 2017 - Jan 12, 2018

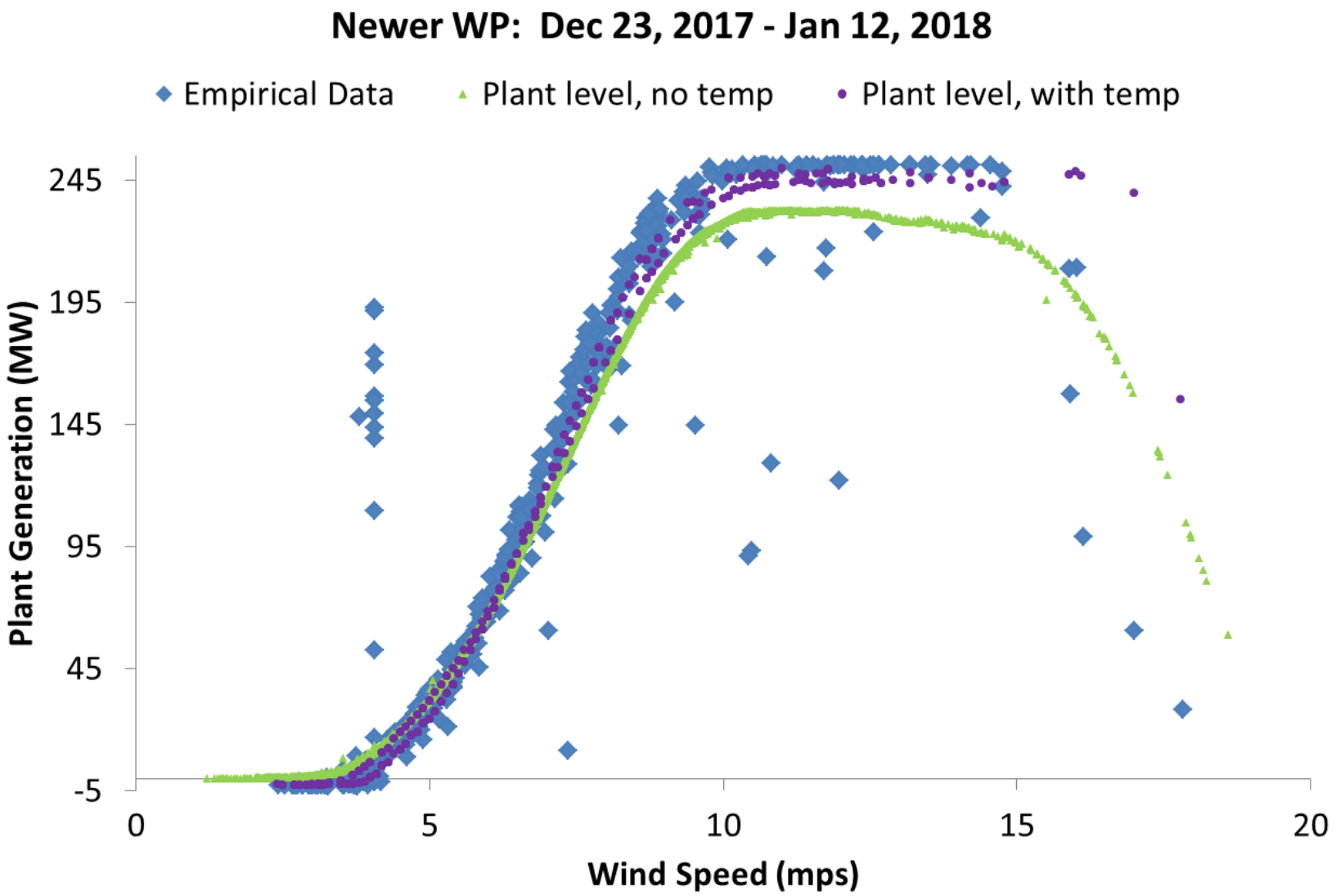


Newer Wind Plant: Dec 23, 2017 - Jan 12, 2018

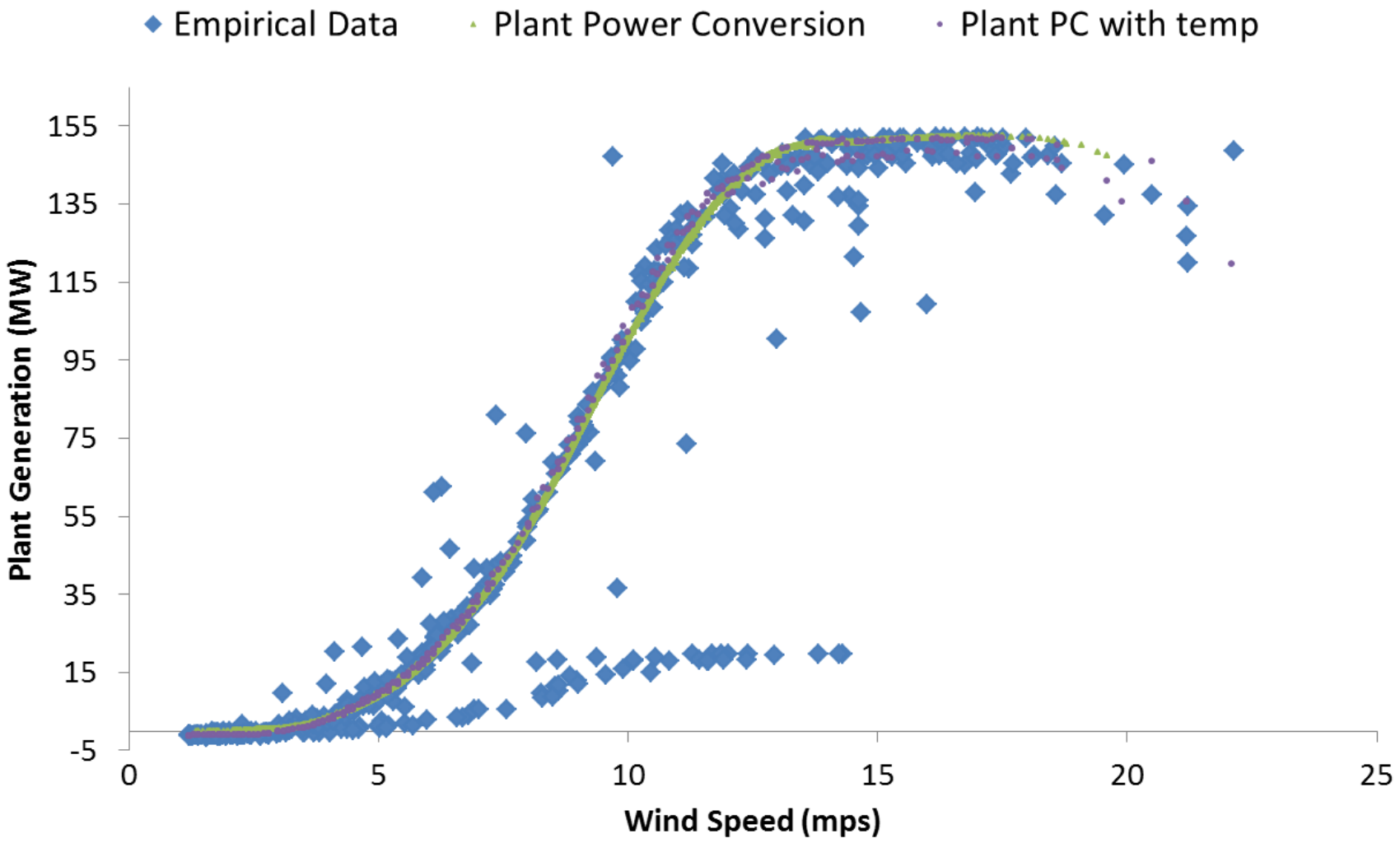


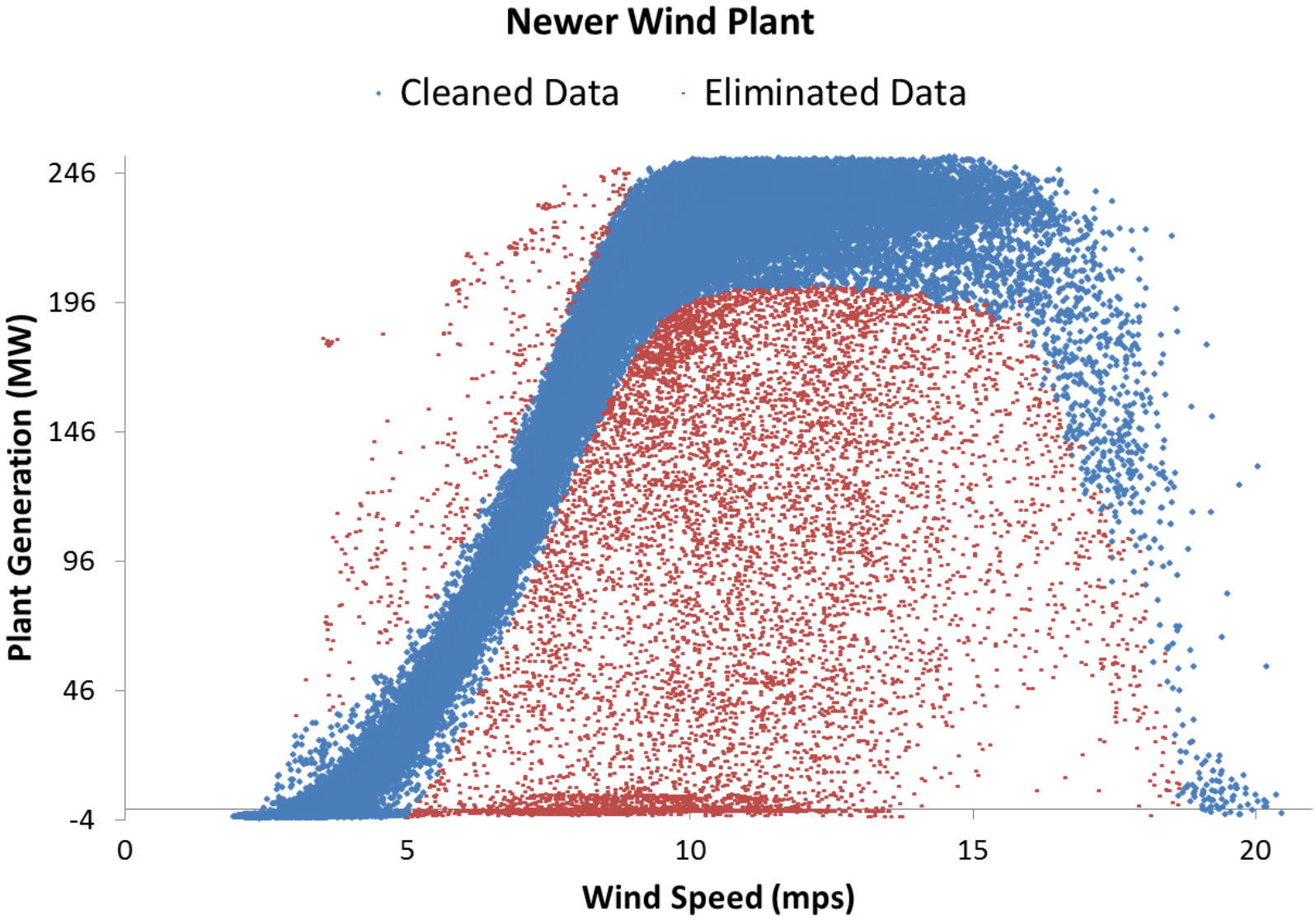
Example Newer WP Power Curves by Temp (Celsius)

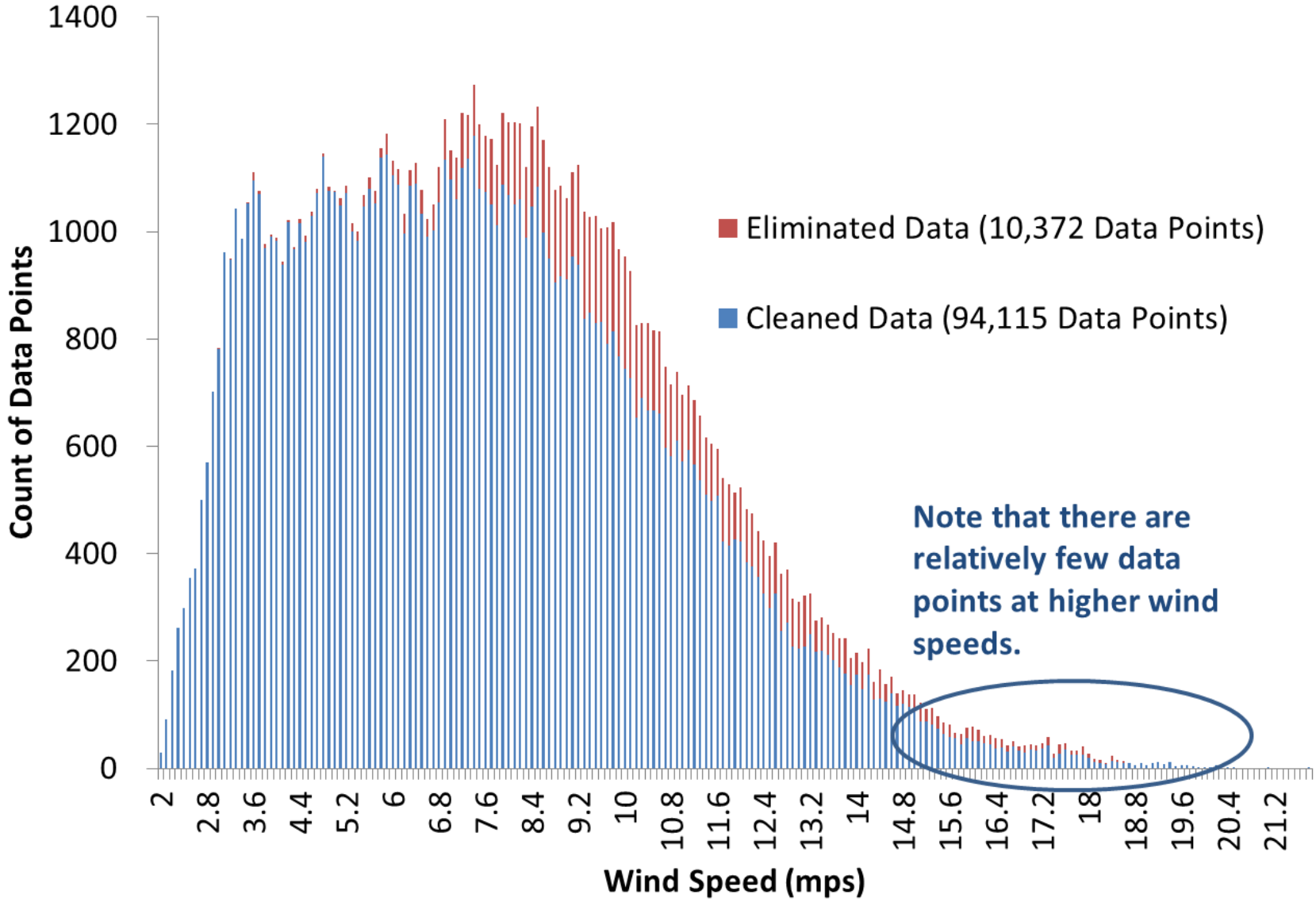


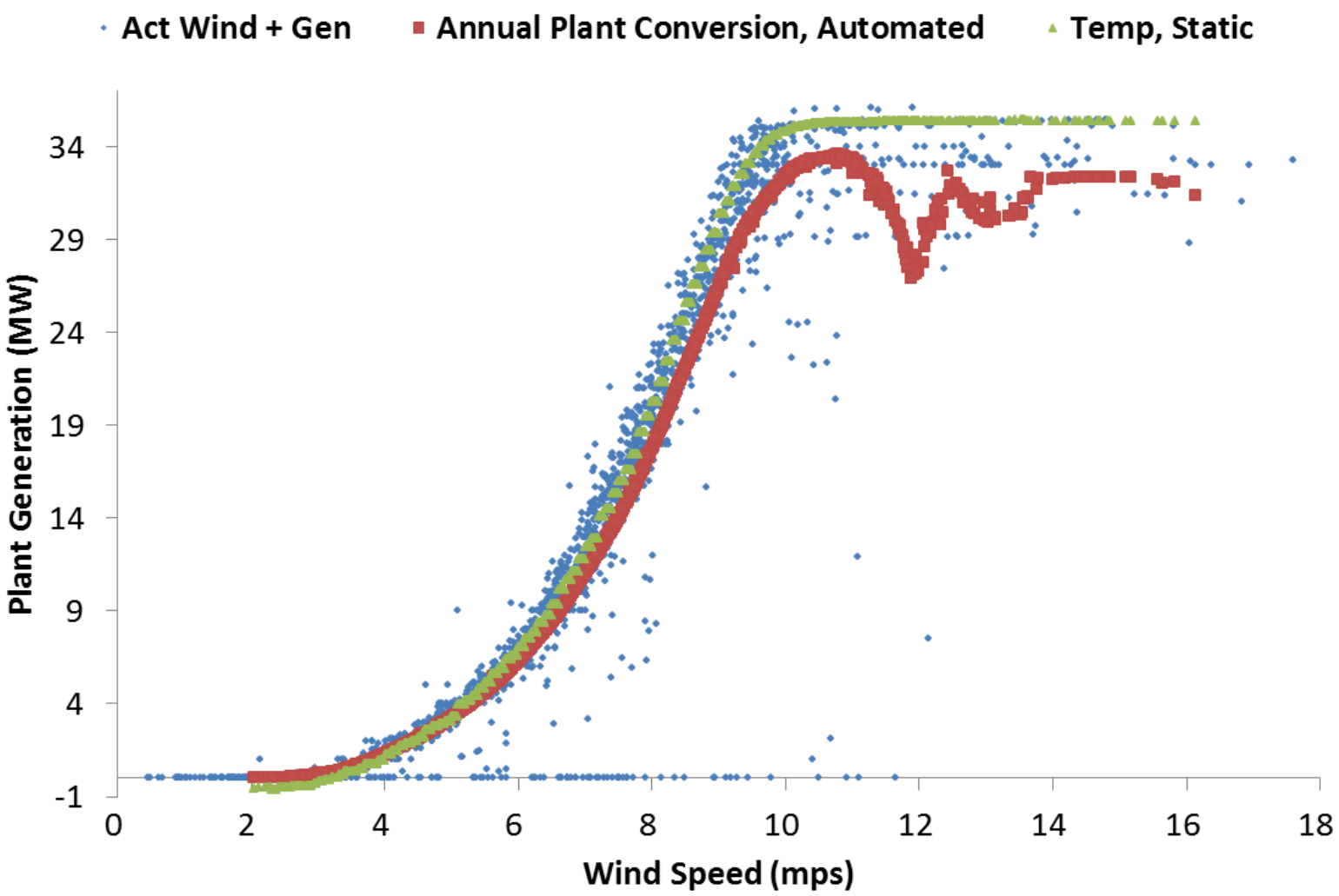

Newer WP: Dec 23, 2017 - Jan 12, 2018
Empirical Data
Plant level, no temp
Plant level, with temp
Plant Generation (MW)
245
195
145
95
45
-5
0
5
10
15
20
Wind Speed (mps)

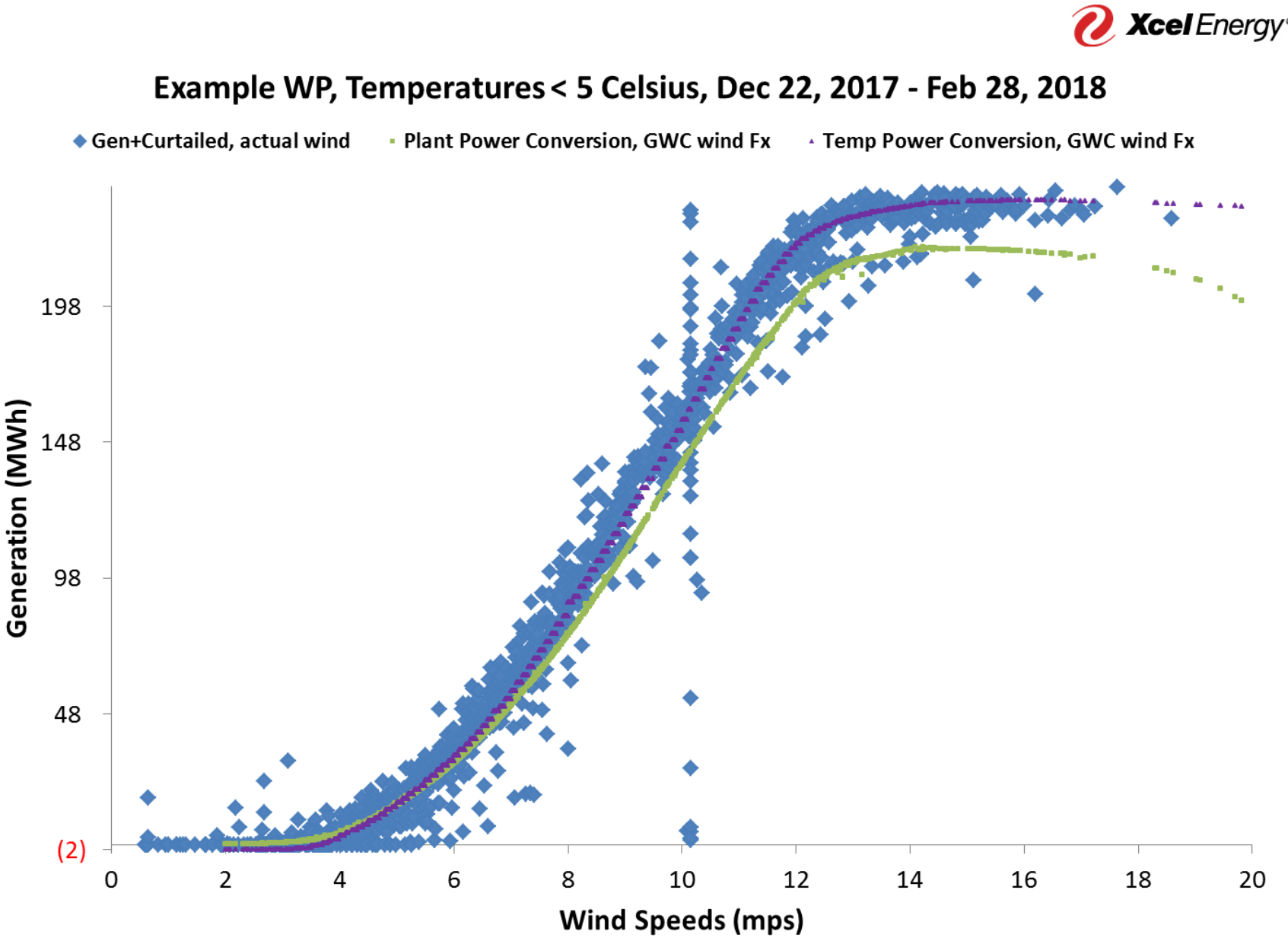
Older Wind Plant: Dec 23, 2017 - Jan 12, 2018



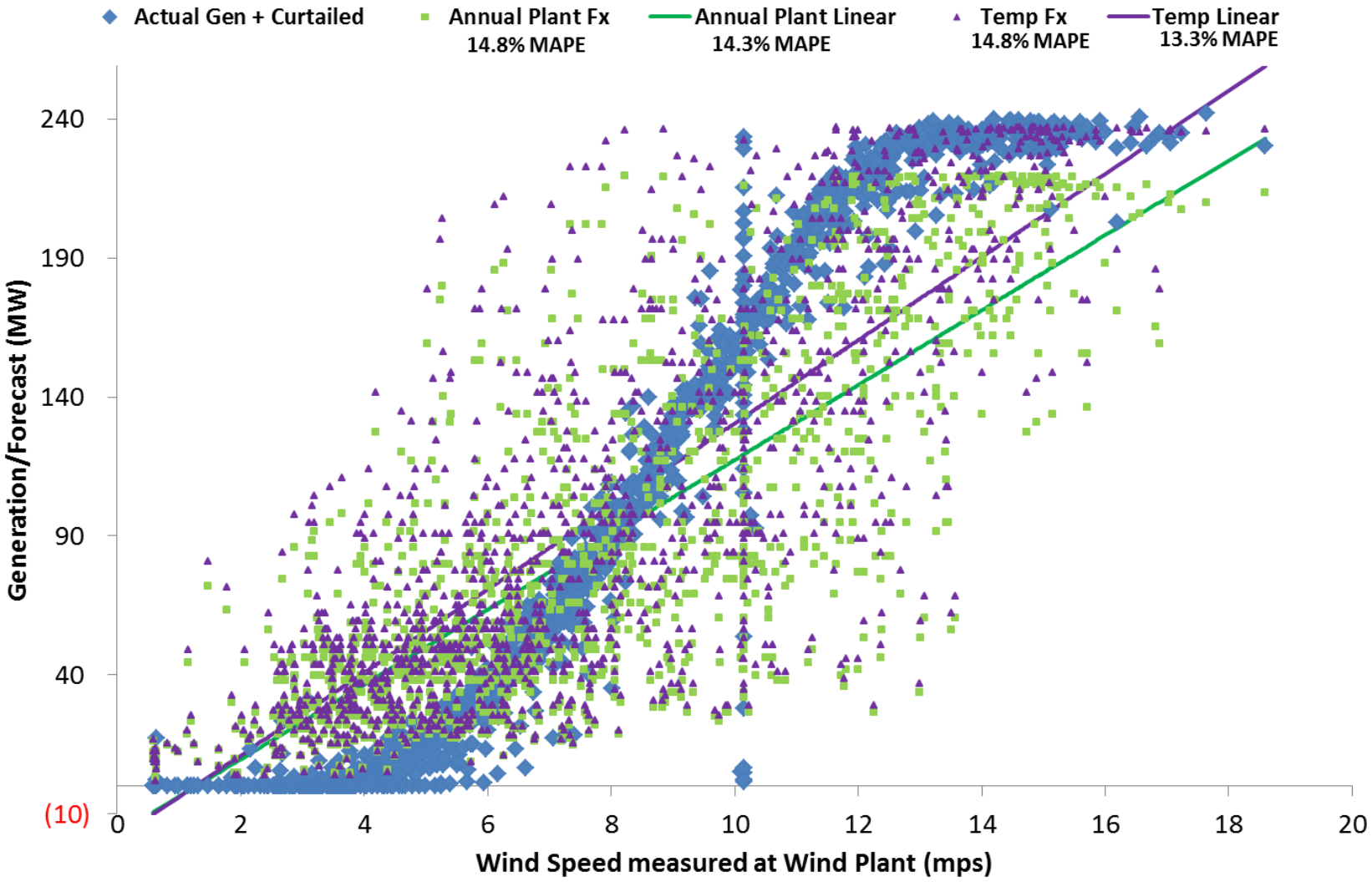

Newer Wind Plant
Cleaned Data
Eliminated Data
Plant Generation (MW)
246
196
146
96
46
-4
0
5
10
15
20
Wind Speed (mps)

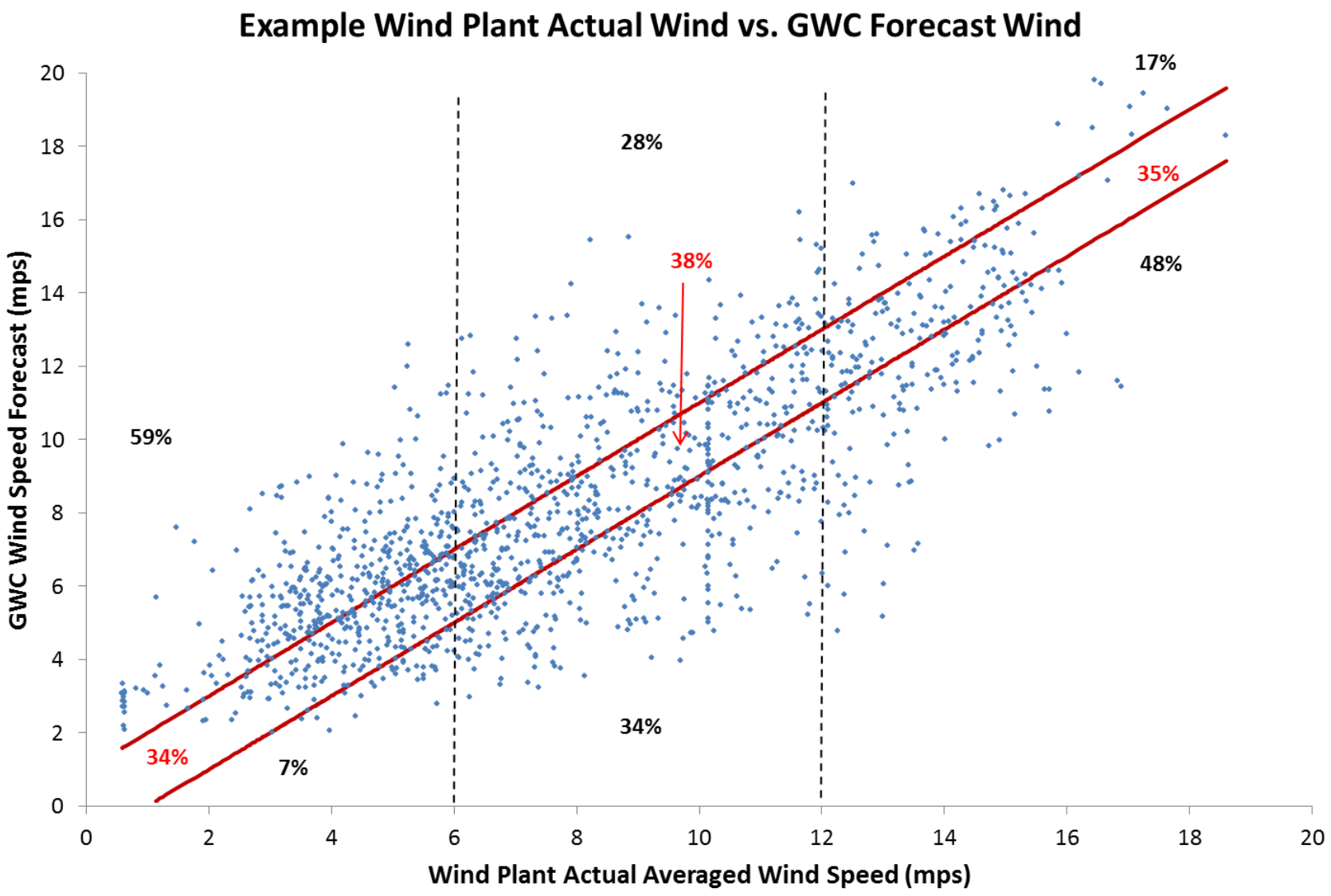

1400
1200
1000
800
600
400
200
0
Count of Data Points
Eliminated Data (10,372 Data Points)
Cleaned Data (94,115 Data Points)
Note that there are relatively few data points at higher wind speeds.
2
2.8
3.6
4.4
5.2
6
6.8
7.6
8.4
9.2
10
10.8
11.6
12.4
13.2
14
14.8
15.6
16.4
17.2
18
18.8
19.6
20.4
21.2
Wind Speed (mps)


NSP Wind Plant: 12/22/17-3/21/18, Temp < 0
Act Wind + Gen
Annual Plant Conversion, Automated
Temp, Static
Plant Generation (MW)
34
29
24
19
14
9
4
-1
0
2
4
6
8
10
12
14
16
18
Wind Speed (mps)

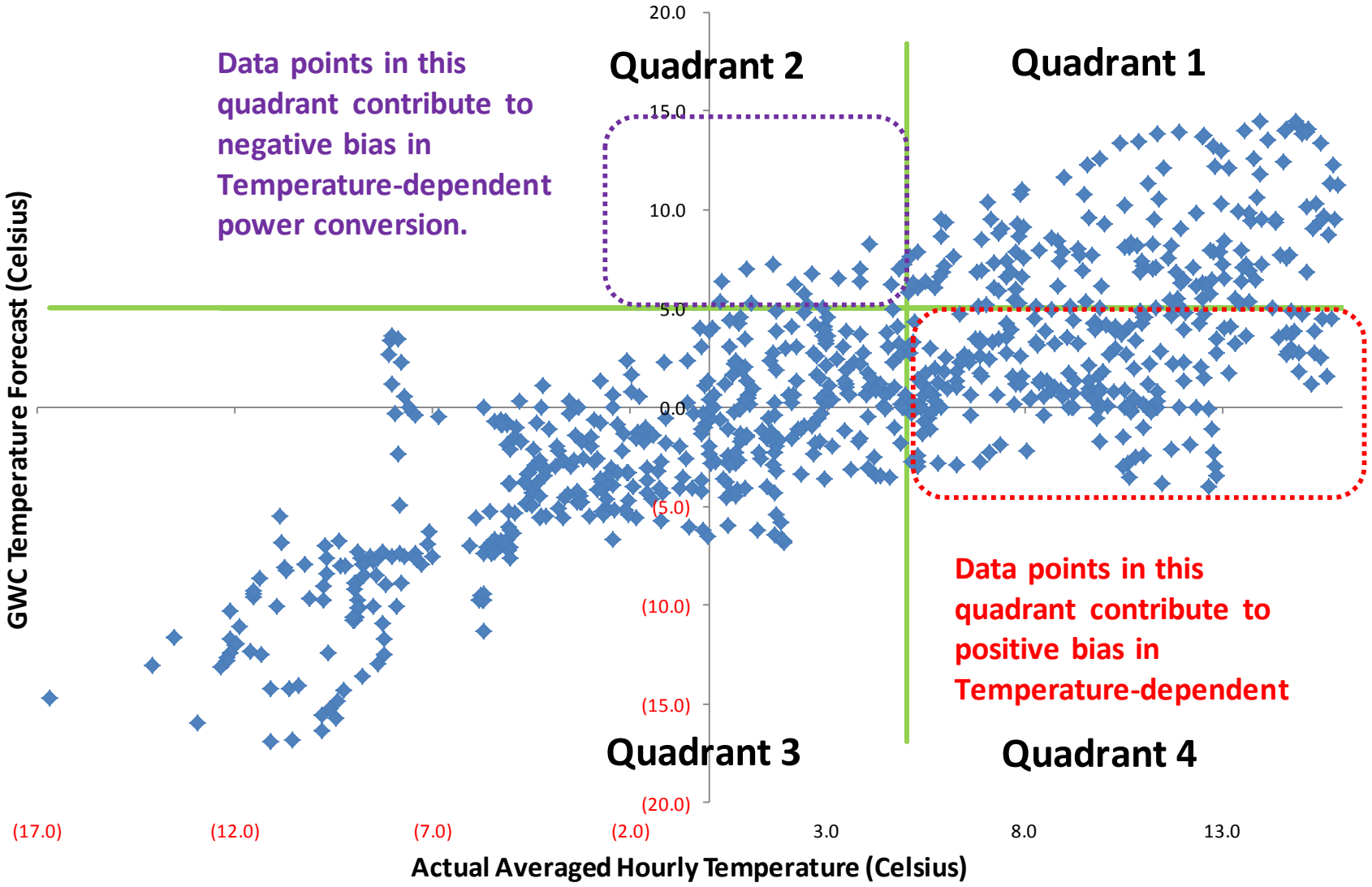

Example WP, Temperatures < 5 Celsius, Dec 22, 2017 - Feb 28, 2018
Gen+Curtailed, actual wind
Plant Power Conversion, GWC wind Fx
Temp Power Conversion, GWC wind Fx
Generation (MWh)
198
148
98
48
(2)
0
2
4
6
8
10
12
14
16
18
20
Wind Speeds (mps)

Example Wind Plant, Dec 22, 2017 - Feb 28, 2018




Example Wind Plant Actual Wind vs. GWC Forecast Wind
GWC Wind Speed Forecast (mps)
Wind Plant Actual Averaged Wind Speed (mps)
0
2
4
6
8
10
12
14
16
18
20
17%
28%
35%
38%
48%
59%
34%
7%
34%

Example WP Actual Temp vs. Forecast Temp, Feb 13 - Mar 21, 2018



Conclusion Summary

- Plant-level Power Conversion is superior to Turbine-level
- For newer wind plants and on a going-forward basis, temperature is a significant variable in Power Conversion
- Xcel is replacing self-learning Power Conversion with static, plant-specific Power Conversion
- Continued room for improvement in the underlying weather forecasts
- Averaged error statistics (MAE, RMSE) are useful, but insufficient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