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Sandia National Laboratories

Assessment of Wind Power Scenario Generation Methods for Stochastic Unit Commitment

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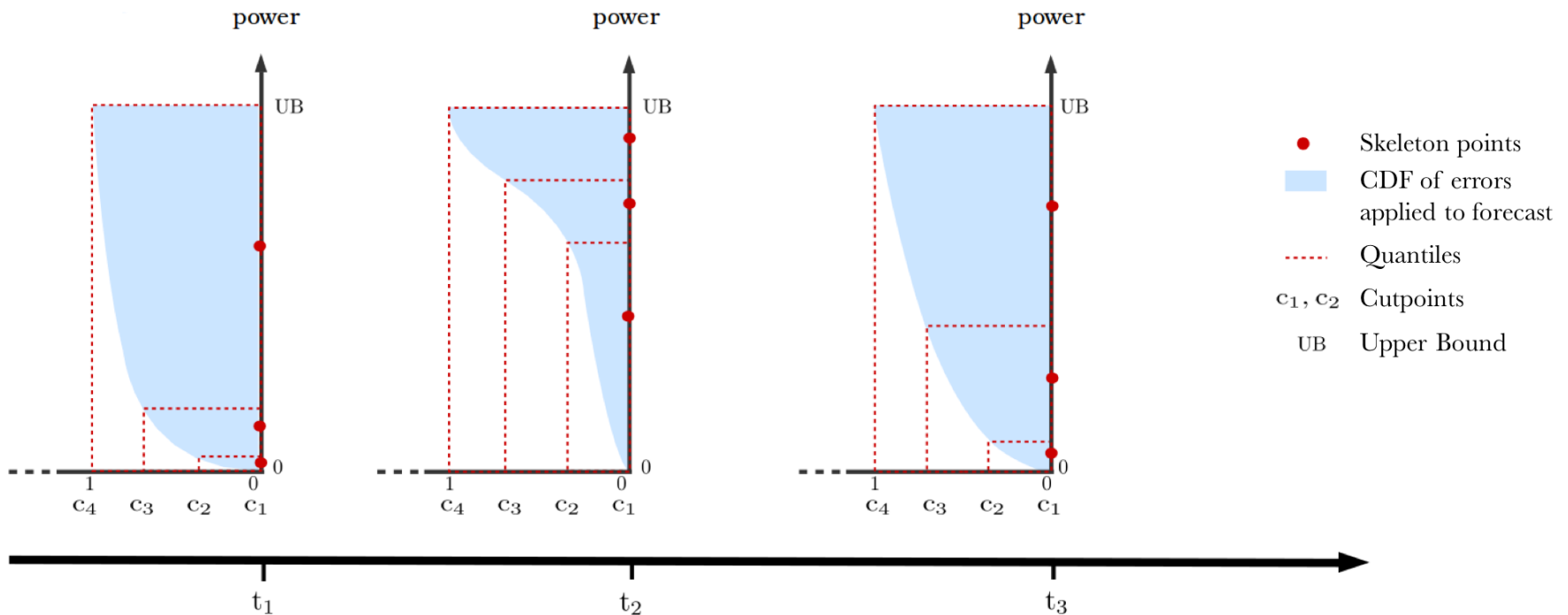FERC Technical Conference

June 27, 2017

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

Stochastic Unit Commitment

- Power system unit commitment must incorporate variable generation resources (i.e., wind power)

- To account for the uncertainty of wind power, we can model this variable generation stochastically, using scenarios

- We perform day-ahead two-stage unit commitment, with scenarios created to represent the plausible range of wind power uncertainty throughout the day

  - Wind is *not* modeled as must-take, allowing for curtailment without penalty

Epi-Spline Scenario Creation

- For a subset of hours in day (i.e., hours 1, 12, 24), calculate empirical **forecast error** CDF from relevant* historical forecast/actual pairs
  - Correlations in forecast error drop off quickly with time, allowing for independent calculations
- Divide distribution at cut points, and calculate the weighted average of the distribution between each cut point pair
- Apply error value to next-day forecast to obtain scenario value

Legend:
- Skeleton points
- CDF of errors applied to forecast
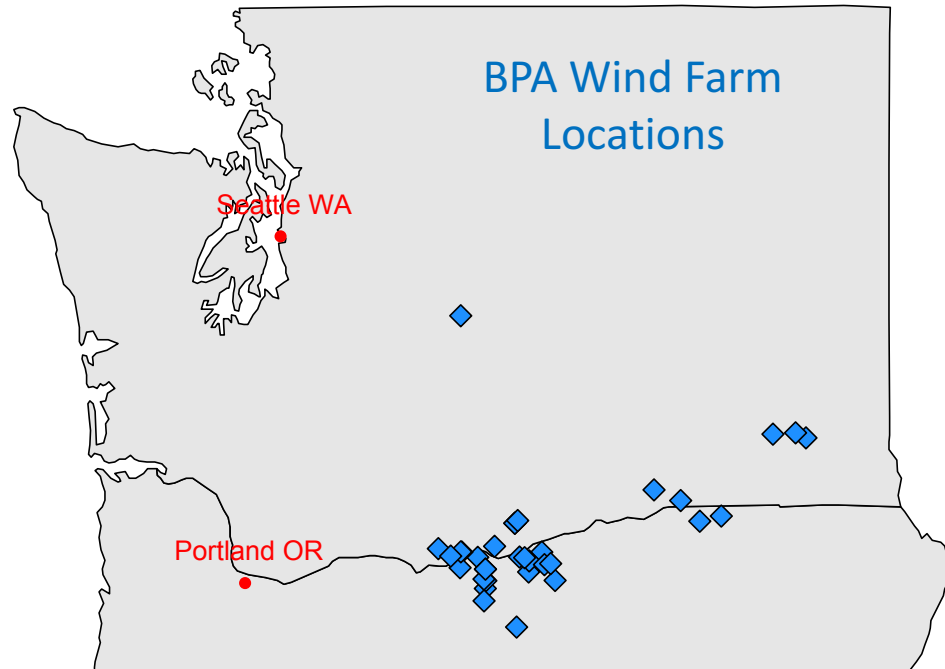- Quantiles
- c_1, c_2 Cutpoints
- UB Upper Bound

Scenario Set Comparison

- Current state-of-the-art method for scenario generation proposed by Pinson *et al.* uses quantile regression to produce a probabilistic forecast and samples from a Gaussian multivariate random variable

- We compare this to Epi-Spline scenarios using a range of cut point sets with increasing focus on 'tail' events

  - Cut points: 0 – 0.33 – 0.66 – 1
  - Cut points: 0 – 0.1 – 0.9 – 1
  - Cut points: 0 – 0.05 – 0.5 – 0.95 – 1
 - Cut points: 0 – 0.01 – 0.5 – 0.99 – 1
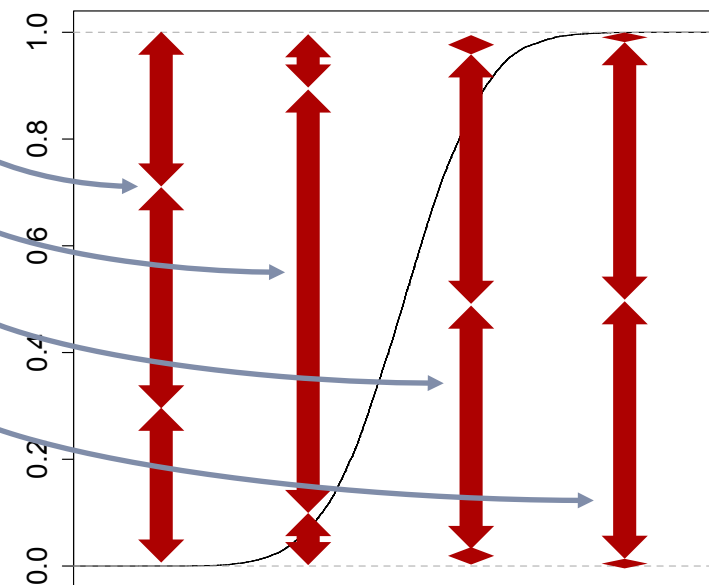
Application and Data

- Generate wind power scenarios using data from Bonneville Power Administration (BPA)

  - BPA has 33 wind farms, with a total capacity of 4782 MW

  - Using vendor-issued forecast data and actual power measurements from November 2015 through May 2017

  - Create day-ahead scenarios of aggregated wind power for balancing area using forecasts issued at 11am on previous day

  - Rolling horizon scenario creation, starting February 1, 2017 (with previous data used for training)
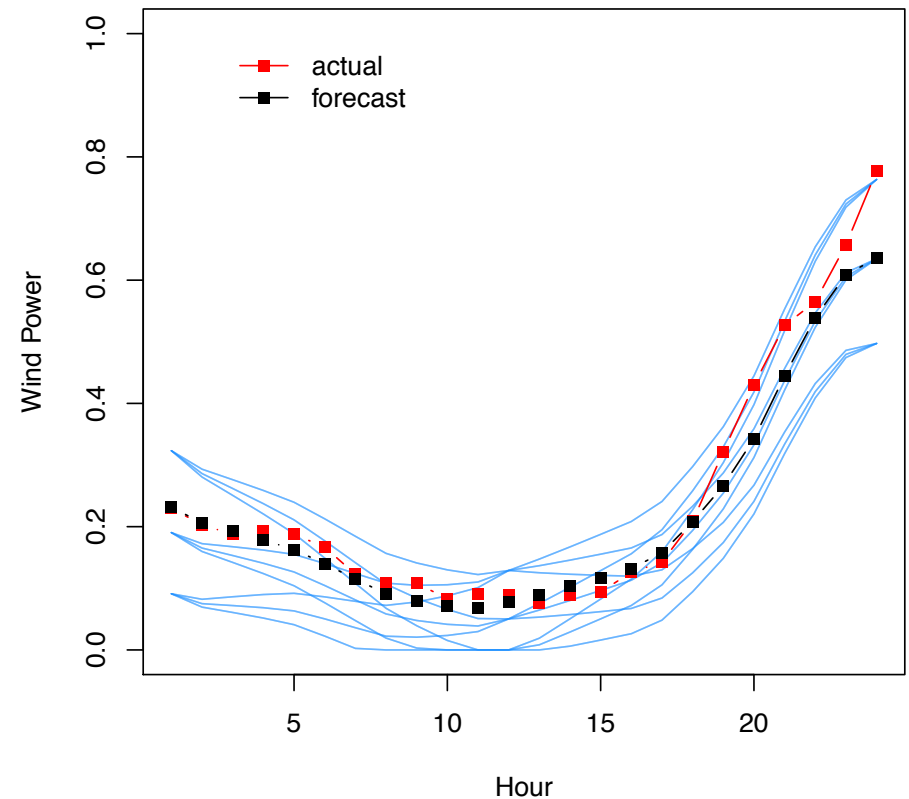
BPA Wind Farm Locations

Seattle WA

Portland OR

Scenario Comparison:
On a 'Good' Forecast Day...

Quantile Regression
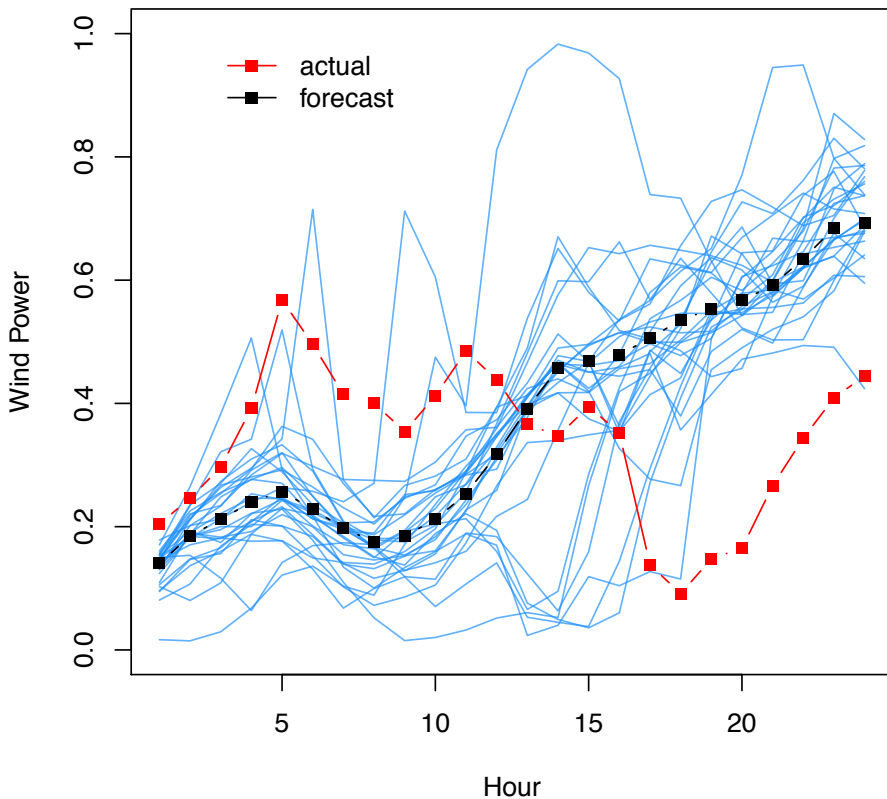March 7, 2017
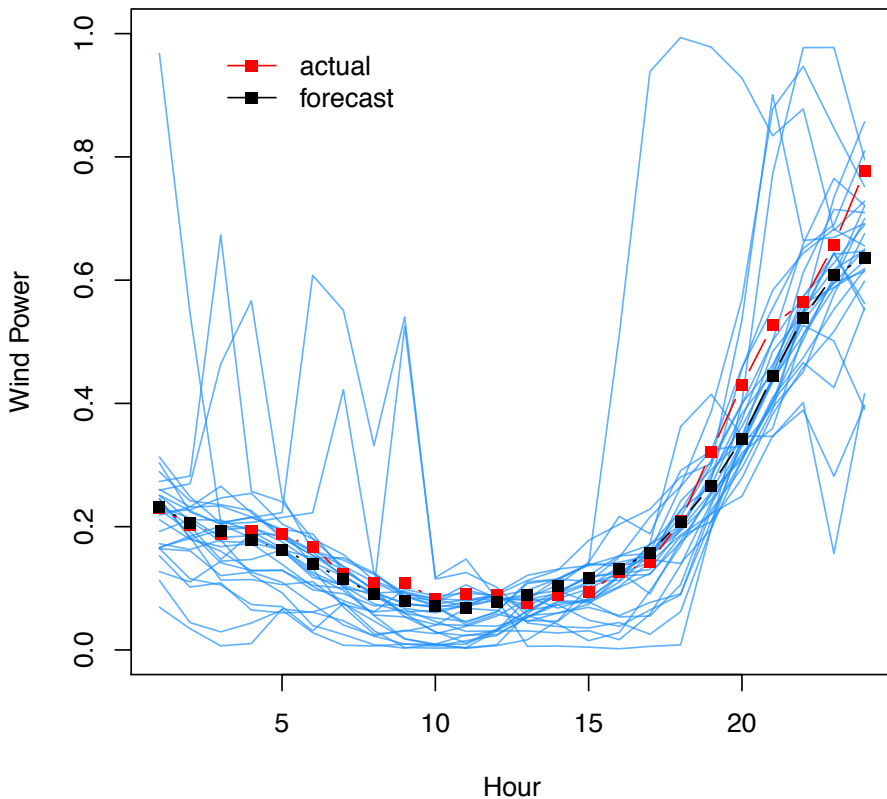
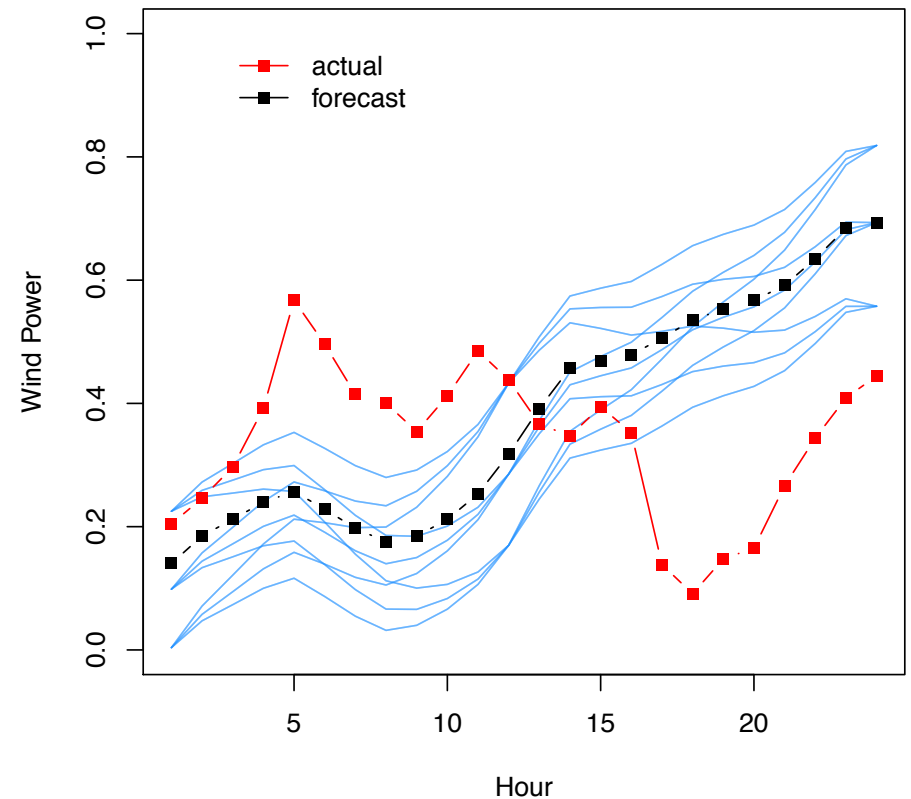Epi-Spline, CP: 0-0.33-0.66-1
March 7, 2017

Scenario Comparison:
And on a 'Bad' Forecast Day...

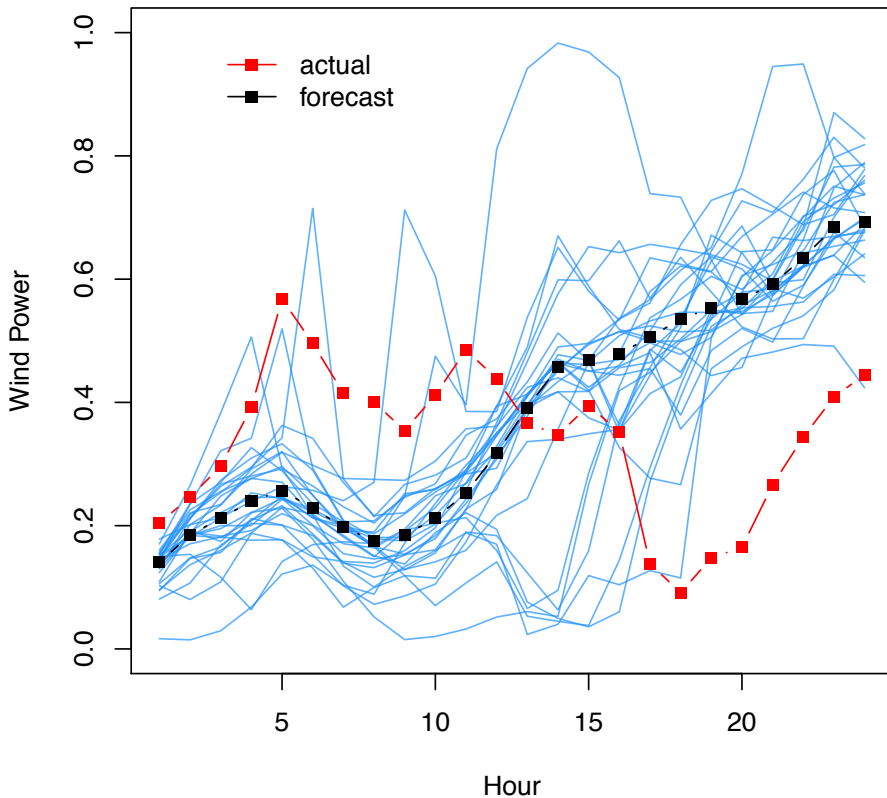Quantile Regression
March 5, 2017

Epi-Spline, CP: 0-0.33-0.66-1
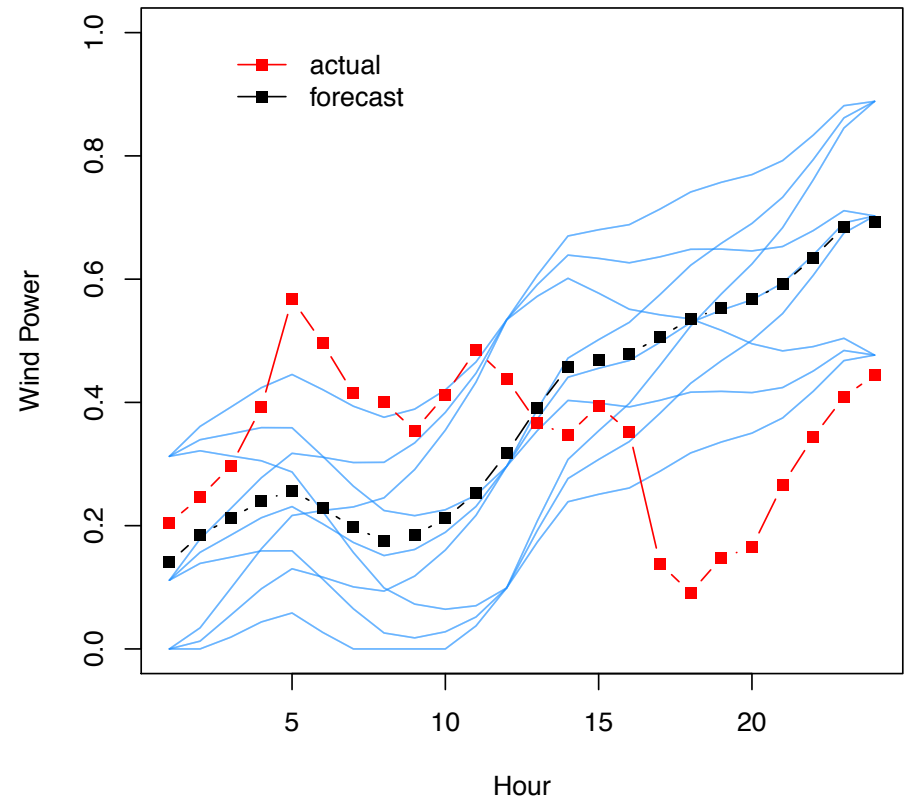March 5, 2017

Scenario Comparison:
And on a 'Bad' Forecast Day...
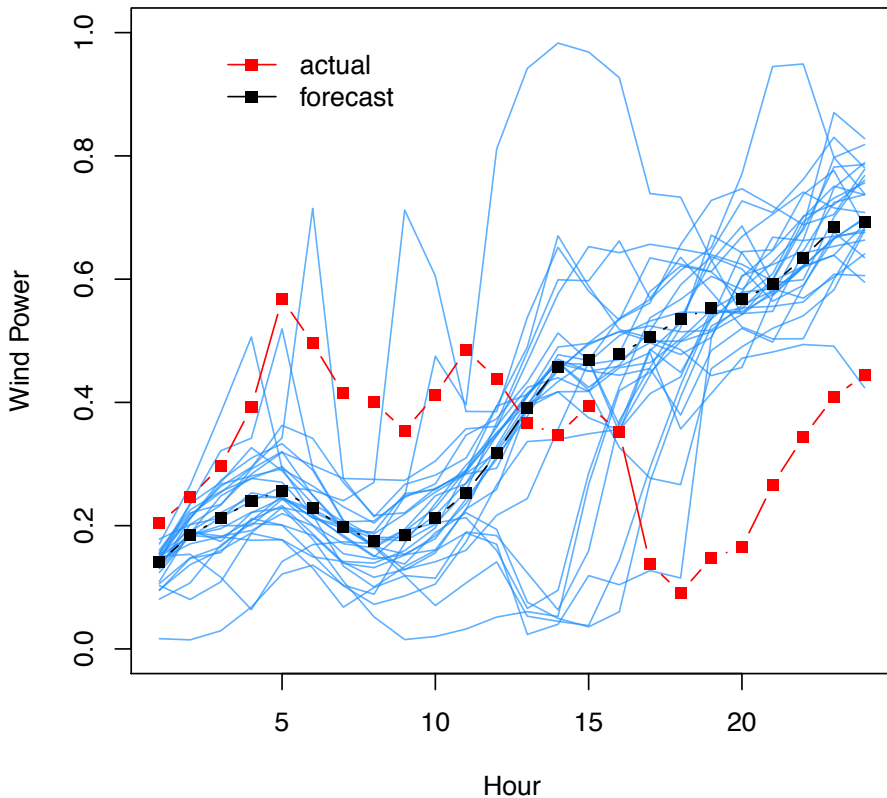

Quantile Regression
March 5, 2017

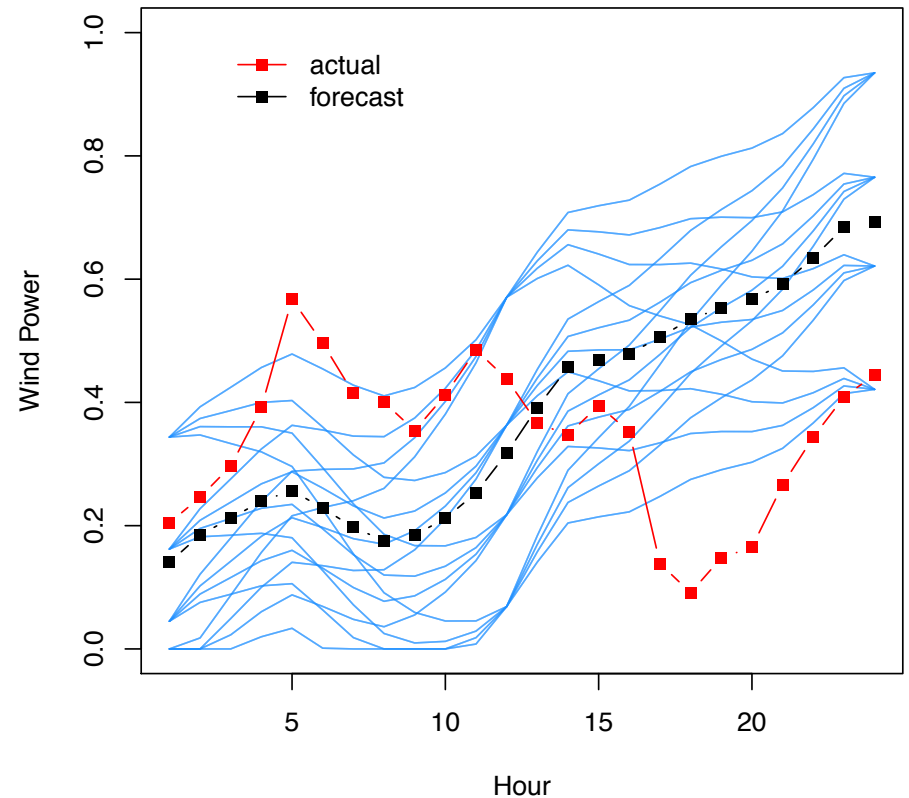Epi-Spline, CP: 0-0.1-0.9-1
March 5, 2017

Scenario Comparison:
And on a 'Bad' Forecast Day...
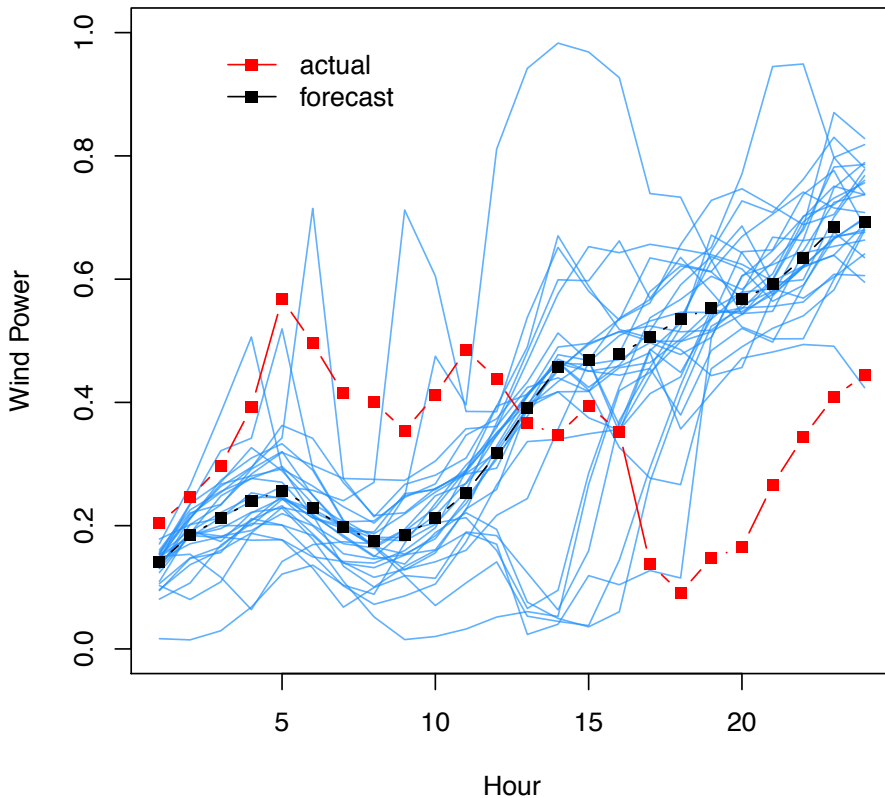

Quantile Regression
March 5, 2017

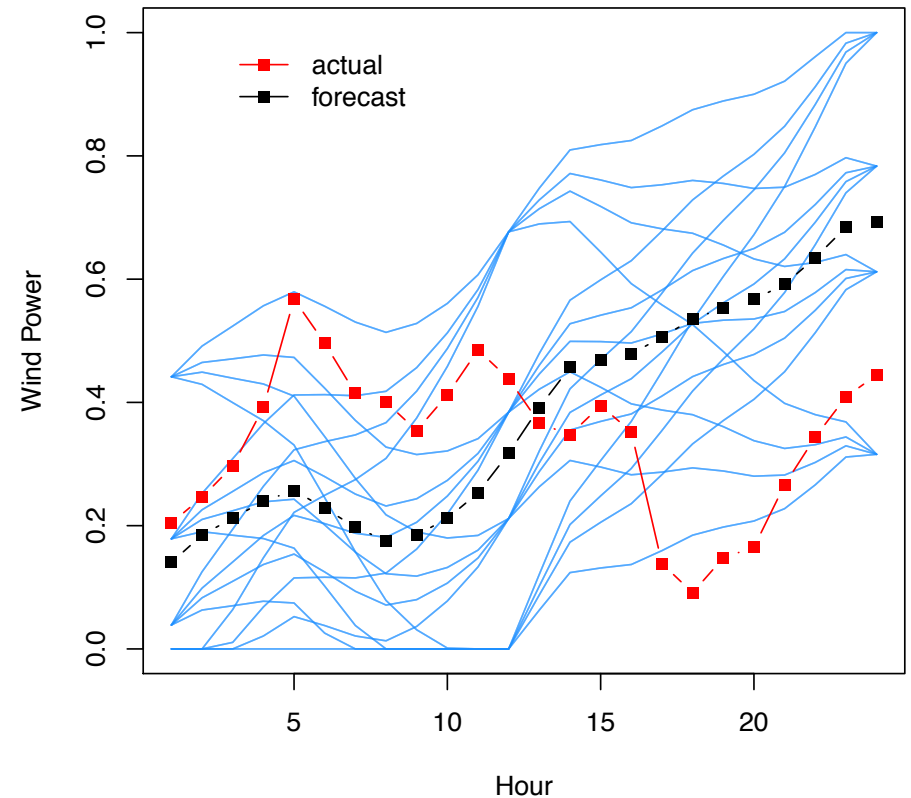Epi-Spline, CP: 0-0.05-0.5-0.95-1
March 5, 2017

Scenario Comparison:
And on a 'Bad' Forecast Day...
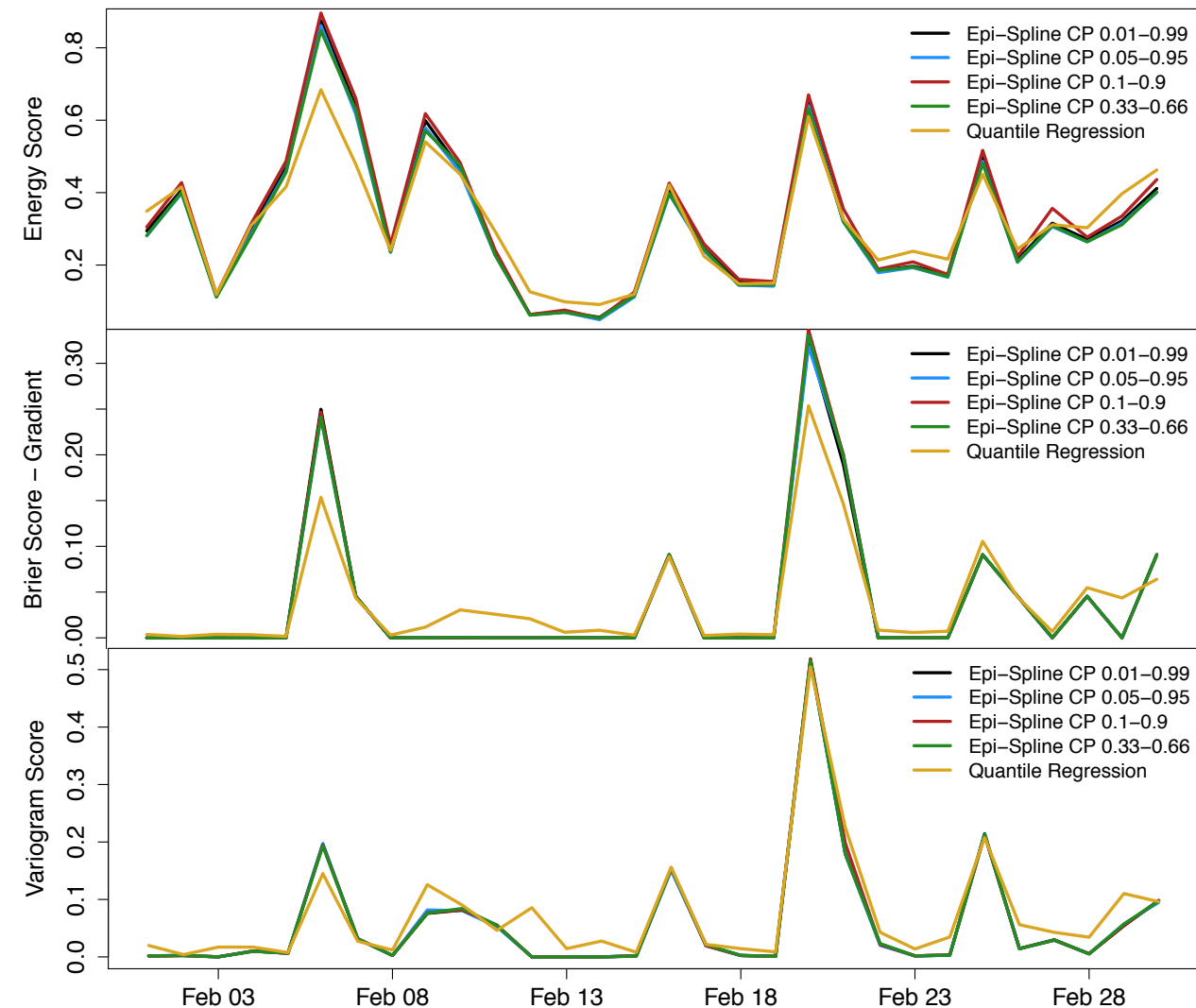

Quantile Regression
March 5, 2017

Epi-Spline, CP: 0-0.01-0.5-0.99-1
March 5, 2017

Assessing Scenario Quality

- Visual comparisons only get you so far…

- There are a number of proper scoring rules used to evaluate probabilistic forecasts and scenarios
    - Energy Score (has known discrimination issues)
    - Brier Score (event-based, need to know what you care about upfront)
    - Variogram Score (improved discrimination using pairwise differences)

- However, ultimate test of quality is performance in a real-world system
    - We simulate 'real-world' using unit-commitment optimization
    - Scenarios should represent a wide enough range of plausible wind power realizations to ensure a feasible solution as the future unfolds
    - However, too wide of a range will drive costs up unnecessarily

Plots/Results of Metrics

- Slight, but inconsistent differences between Epi-Spline and Quantile Regression scenarios
- Virtually *no discrimination* among cut point sets of Epi-Spline scenarios
- The best metrics cannot tell us much about scenario quality

Re-enactment Methodology

- Stochastic day-ahead unit commitment optimization model applied to small, five-generator network (Max demand ~1400 MW)
  - Copper plate model, ignoring network flows
  - Hourly, rolling-horizon simulation with economic dispatch on the hour
  - Not carrying additional reserves, as scenarios should capture required flexibility
- Stochastic wind power scenarios use real data from BPA
  - Scale wind power to assess different wind penetration levels
  - Create day-ahead scenarios based on vendor-issued forecast, determine generator commitments, simulate system performance on realized actual wind power values
- Evaluate different scenario sets and wind penetration levels
  - Comparing cost (fixed and variable), renewables used and curtailed, over-generation, and out-of-market load
- Have started work on larger test systems, but full results are pending
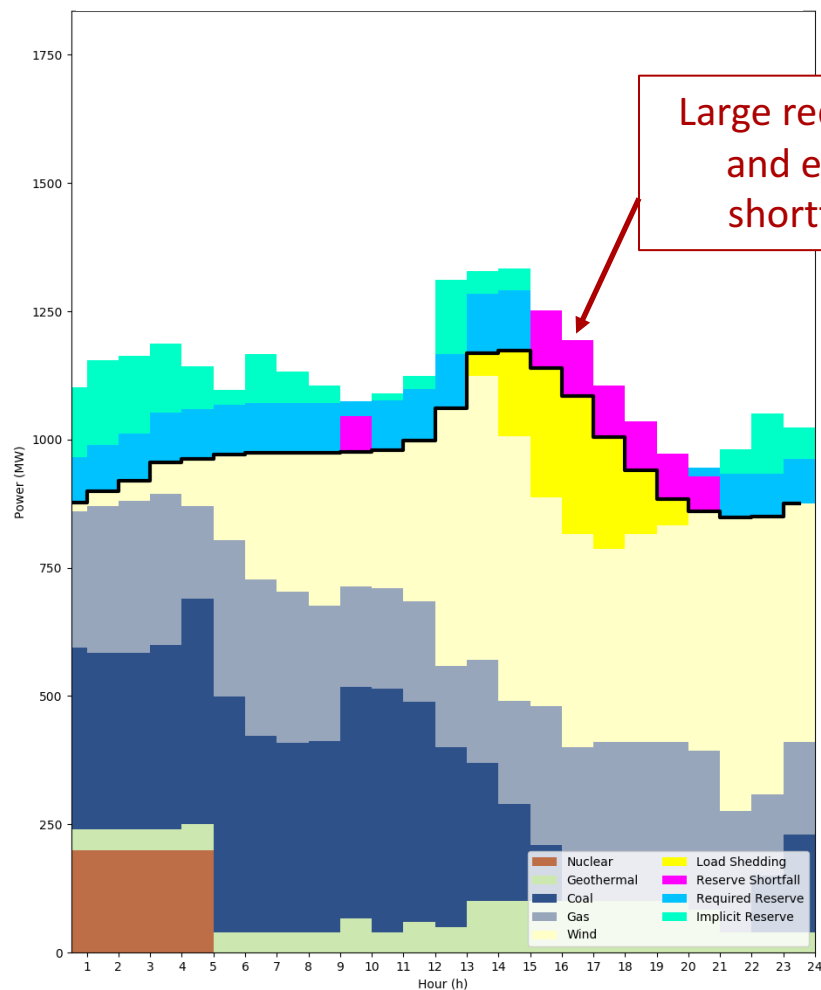
Unit Commitment Performance

- Costs are comparable in deterministic and stochastic solutions
- However, we do not account for the cost of procuring additional generation in real-time to serve the out-of-market load (not met in day-ahead market)
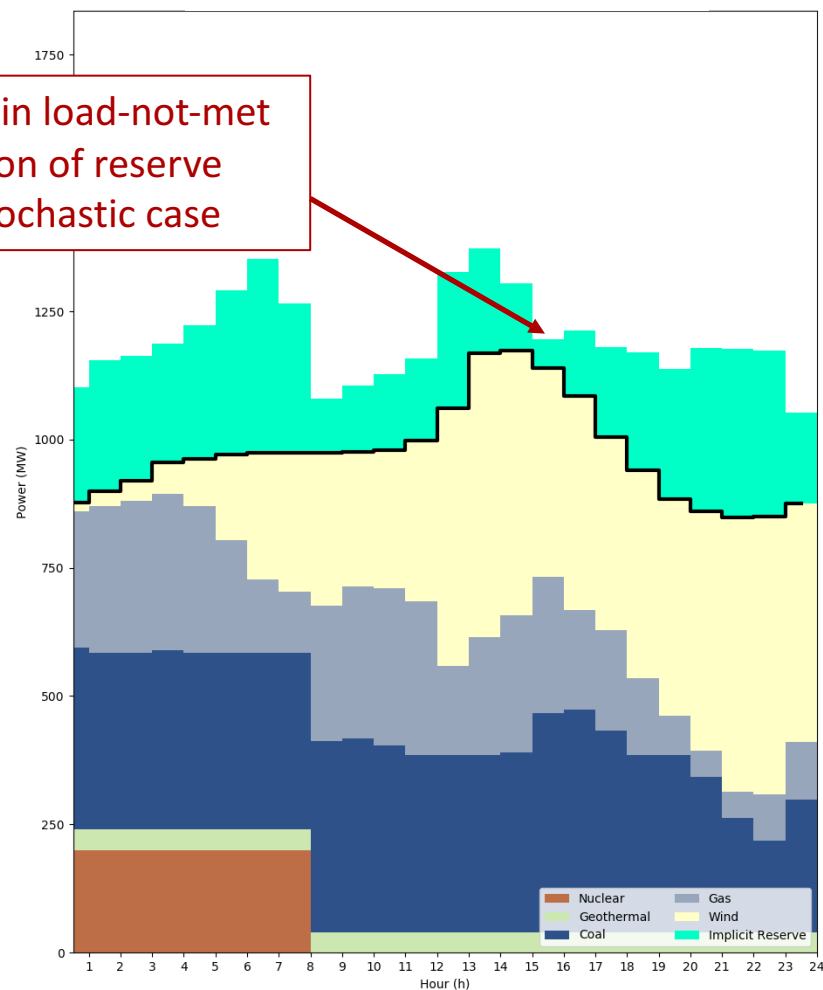
Total System Costs
Wind Penetration 0.2, Cut Point 0.1 – 0.9

Out-of-Market Load
Wind Penetration 0.2, Cut Point 0.1 – 0.9
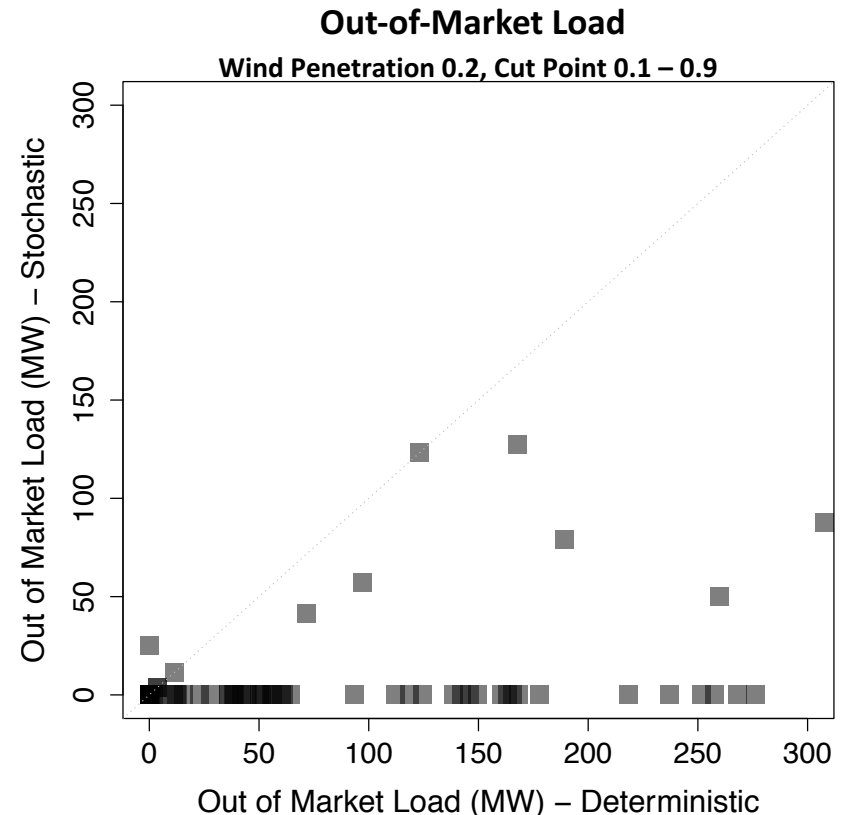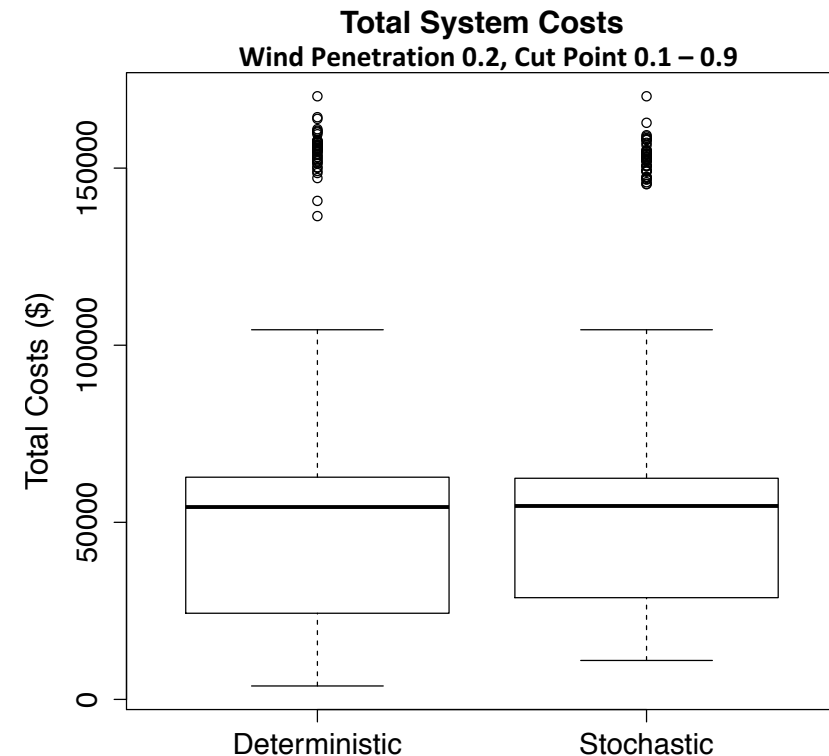
Stochastic vs Deterministic

Deterministic: 2017-03-18
CP: 0 − 0.01 − 0.5 − 0.99 − 1

Stochastic: 2017-03-18
CP: 0 − 0.01 − 0.5 − 0.99 − 1

Large reduction in load-not-met and elimination of reserve shortfall in stochastic case

Variable costs: 227111.27
Fixed costs: 445983.41
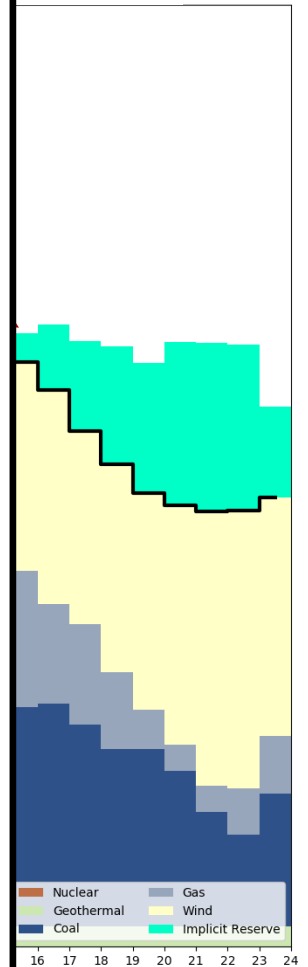Renewables penetration rate: 33.03%
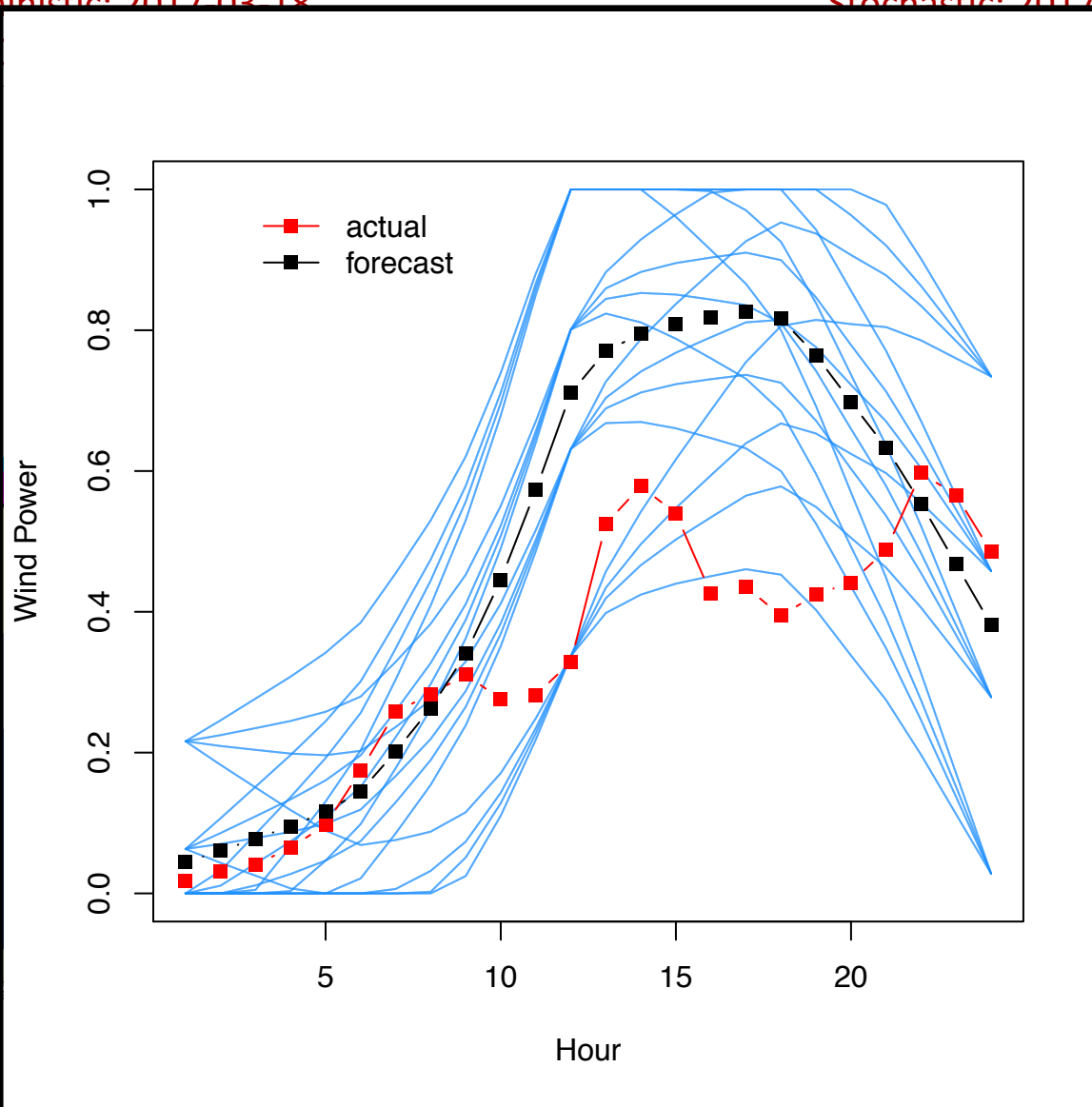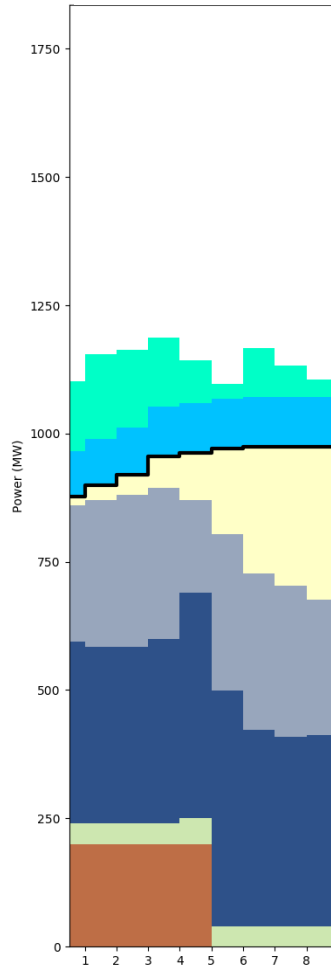
Variable costs: 181086.81
Fixed costs: 571981.60
Renewables penetration rate: 32.88%
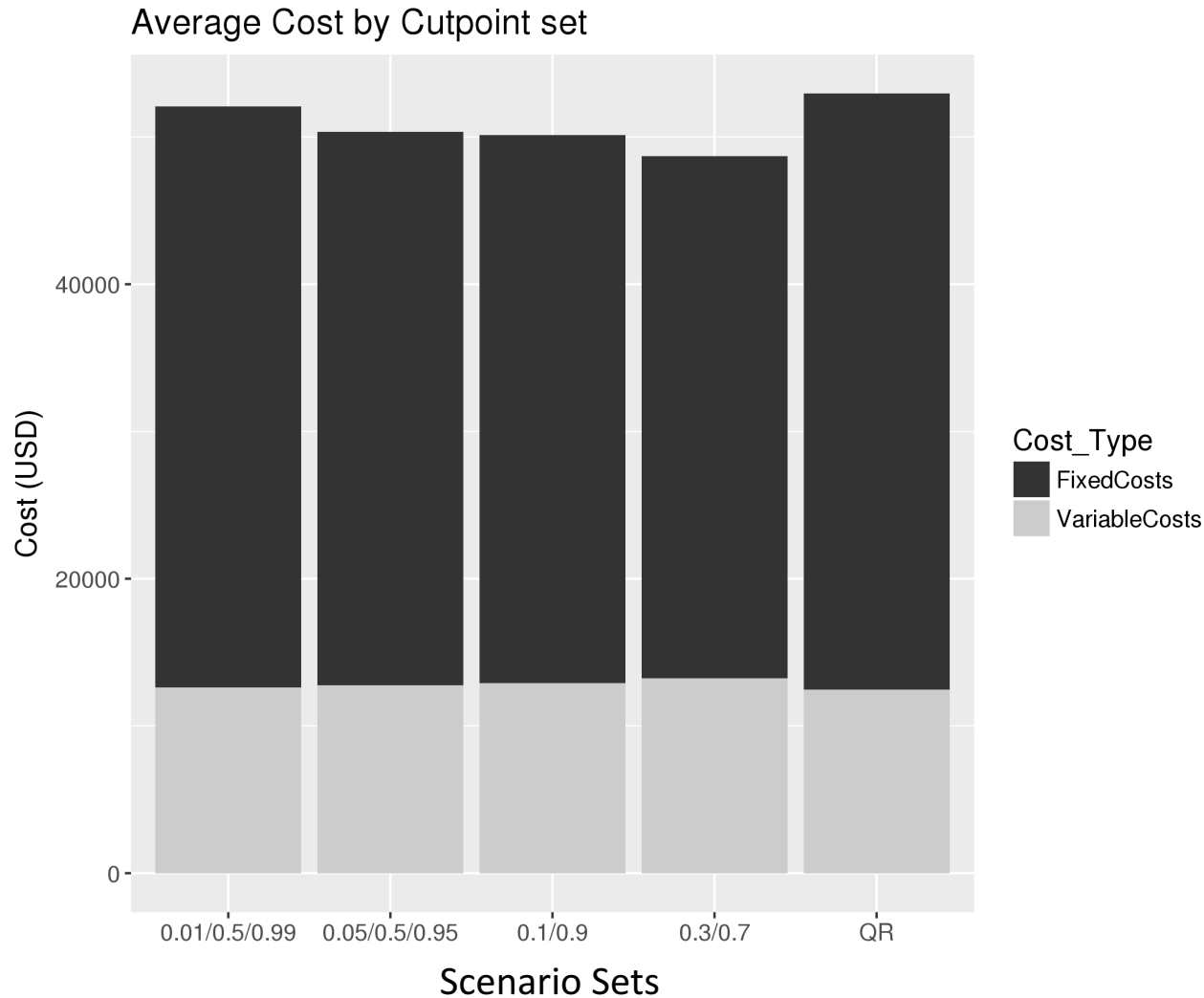
Stochastic vs Deterministic

Compare Scenario Sets: Cost

Average Cost by Cutpoint set

- Slight generation cost variation among scenario sets

- Wider sets have higher costs, to deal with the increased variability

- However, this doesn't account for the cost of procuring additional generation that isn't met in day-ahead scheduling

Compare Scenario Sets: Curtailment

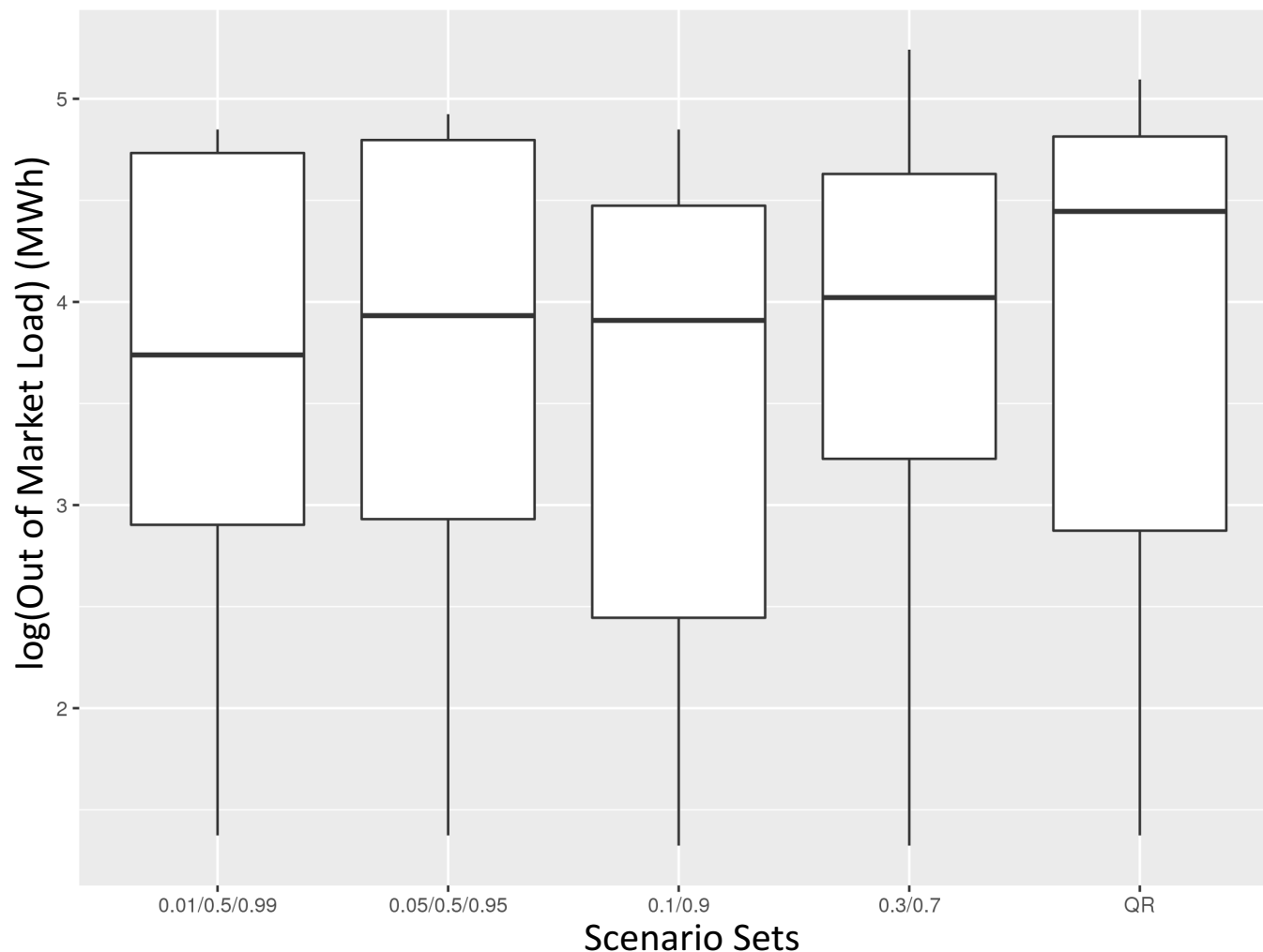Renewable curtailment by cutpoint set

note log scaling on y-axis
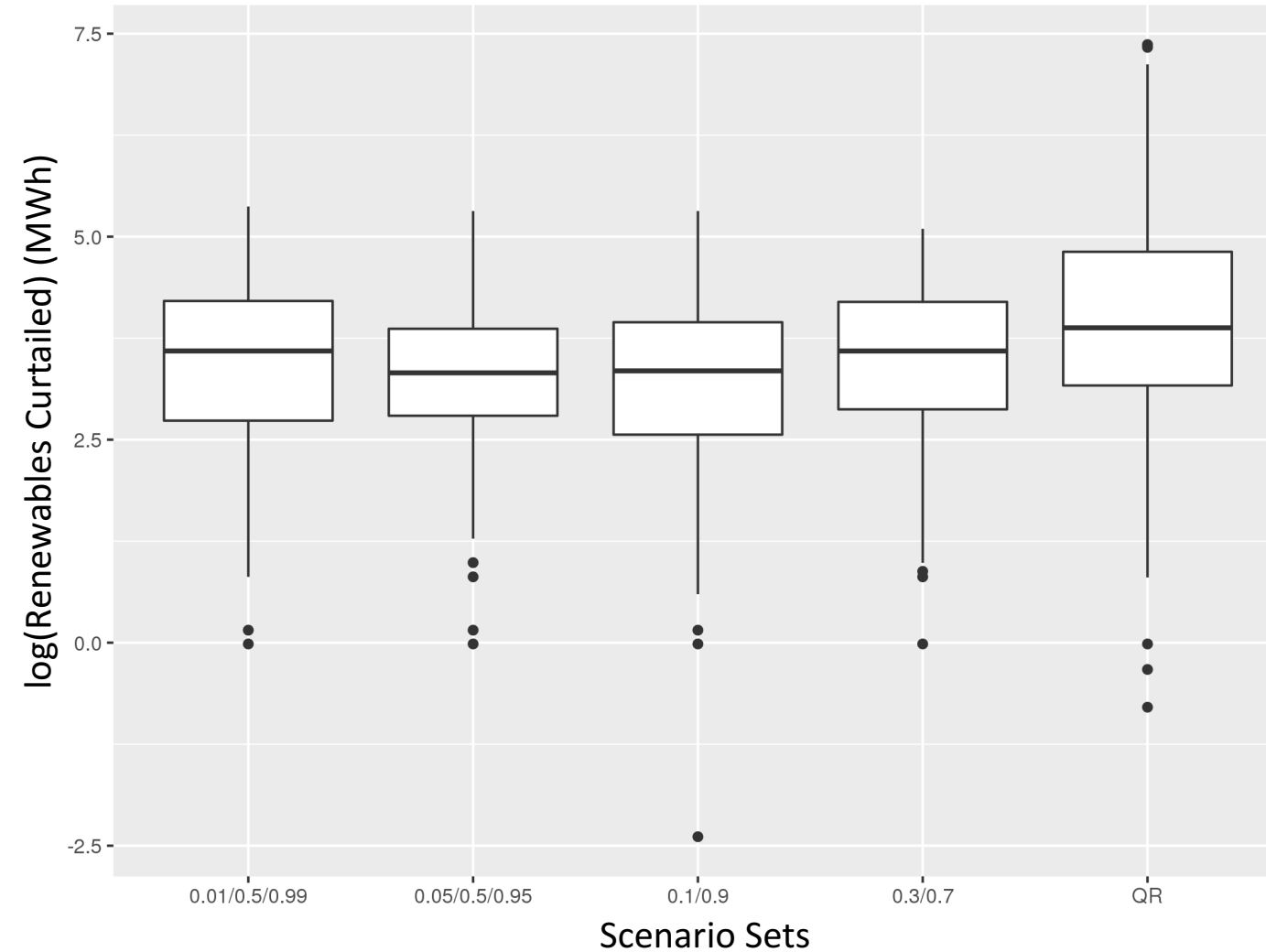
- More curtailment with quantile regression scenarios
- Thermal generation often cannot respond fast enough for extreme ramps in wind

Compare Scenario Sets:
Out-of-Market Load – All Penetration Levels

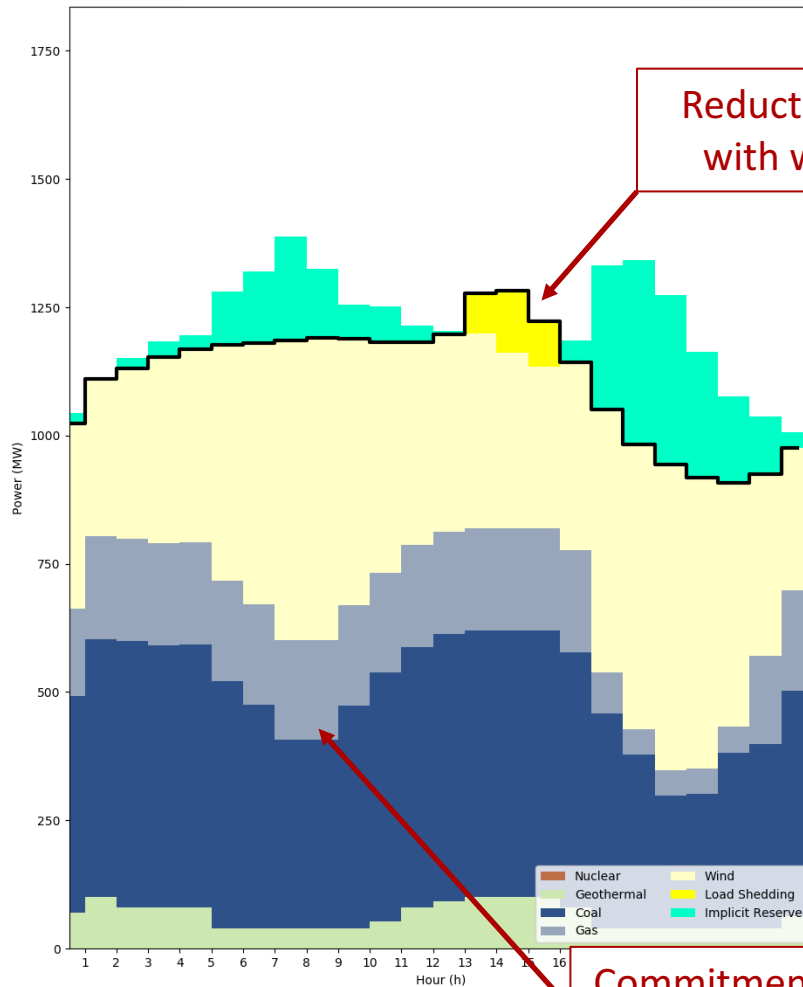Out of Market Load by Scenario Set
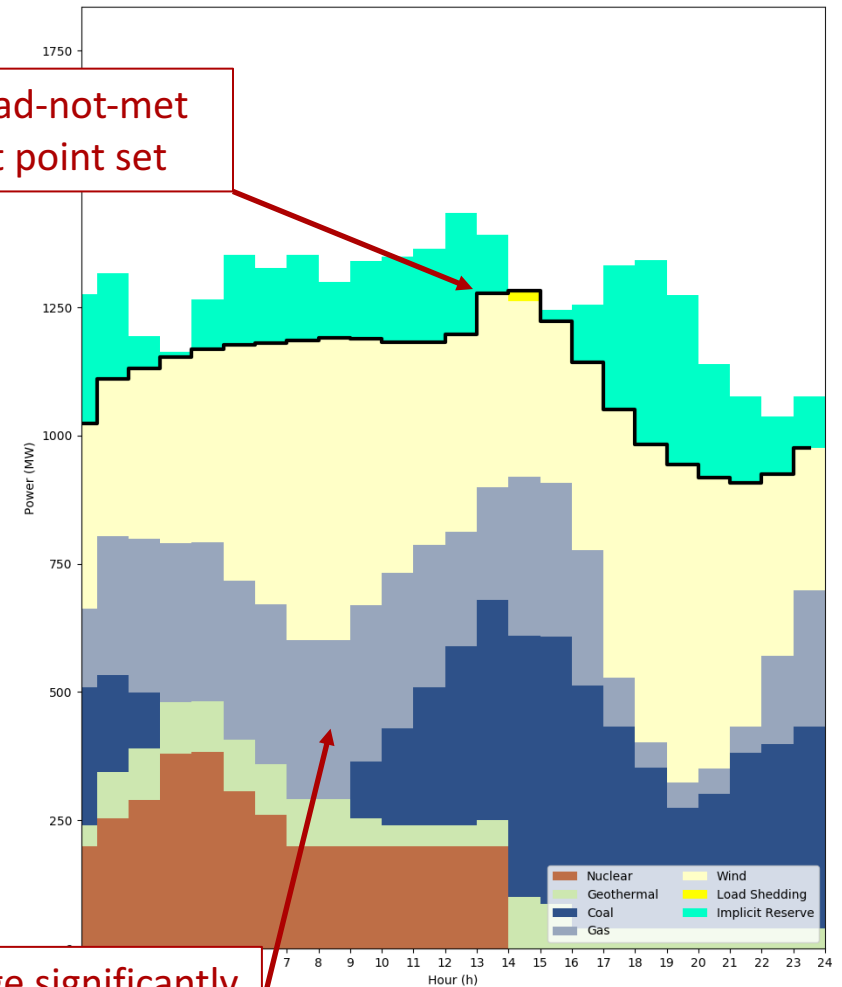
note log scaling on y-axis

- More out-of-market load with quantile regression scenarios
- Mean value is lowest for the widest cut point set, as the scenarios are able to capture more potential variability

Single Day Commitments

2017-04-02
CP: $0 - 0.33 - 0.66 - 1$

2017-04-02
CP: $0 - 0.01 - 0.5 - 0.99 - 1$
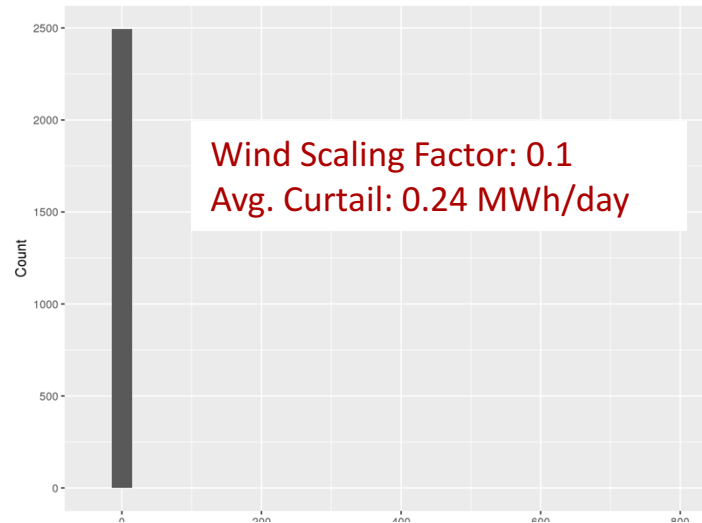
Reduction in load-not-met with wider cut point set

Commitments change significantly between cut point sets

Variable costs: 298129.21
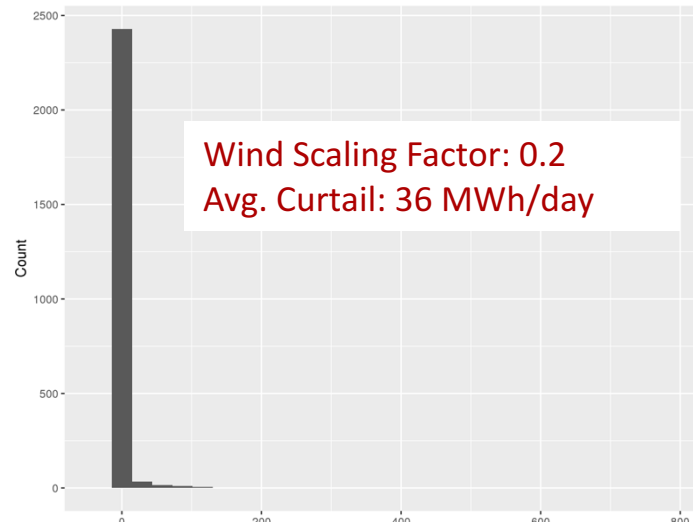Fixed costs: 307123.20
Renewables penetration rate: 38.83%
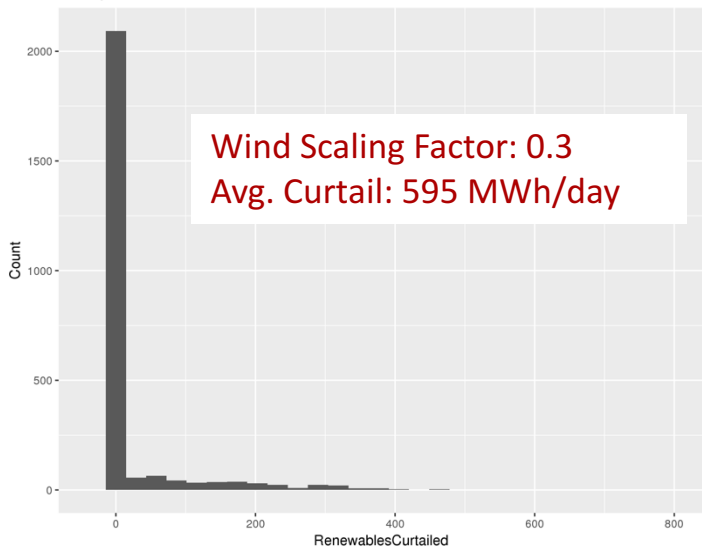
39.05%

Wind Penetration Level: Curtailment

Hourly Wind Curtailment: Scale 0.1

Wind Scaling Factor: 0.1
Avg. Curtail: 0.24 MWh/day

Hourly Wind Curtailment: Scale 0.2

Wind Scaling Factor: 0.2
Avg. Curtail: 36 MWh/day

Hourly Wind Curtailment: Scale 0.3

Wind Scaling Factor: 0.3
Avg. Curtail: 595 MWh/day

Hourly Wind Curtailment: Scale 0.4

Wind Scaling Factor: 0.4
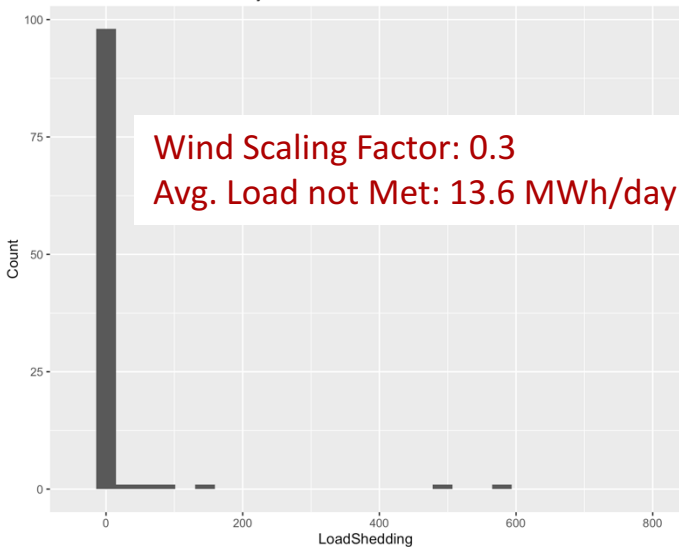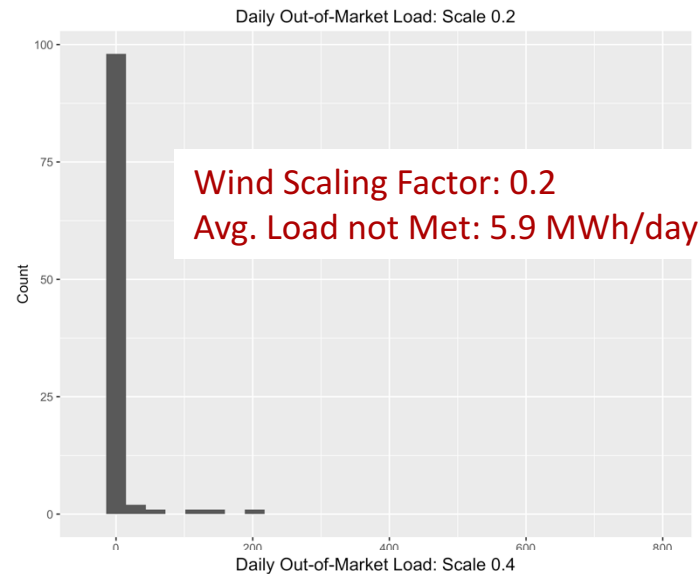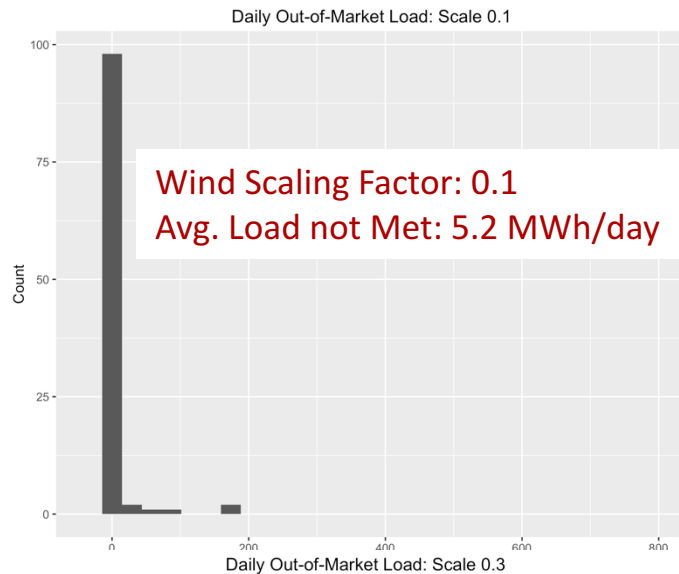Avg. Curtail: 1885 MWh/day
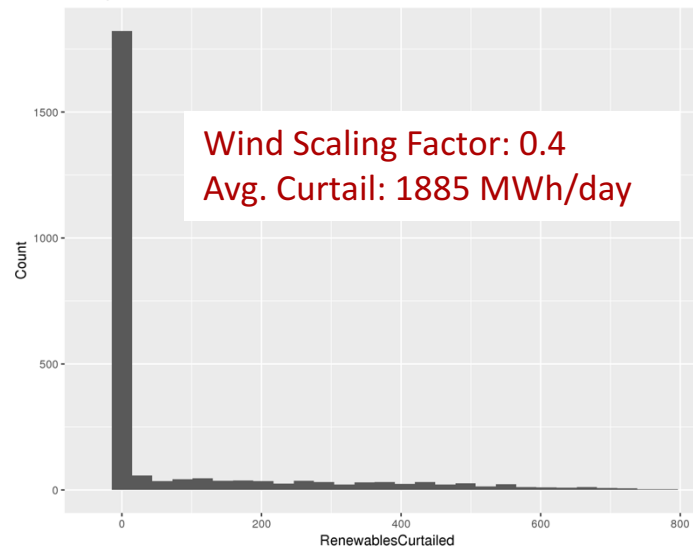
- Scaling factor is in relation to total capacity of BPA system
- Renewable penetration is 11, 22, 31, and 38%, respectively
- Curtailment increases sharply with increased renewable penetration

Wind Penetration Level: Out-of-Market Load

Daily Out-of-Market Load: Scale 0.1

Wind Scaling Factor: 0.1
Avg. Load not Met: 5.2 MWh/day

Daily Out-of-Market Load: Scale 0.2

Wind Scaling Factor: 0.2
Avg. Load not Met: 5.9 MWh/day

Daily Out-of-Market Load: Scale 0.3

Wind Scaling Factor: 0.3
Avg. Load not Met: 13.6 MWh/day

Daily Out-of-Market Load: Scale 0.4

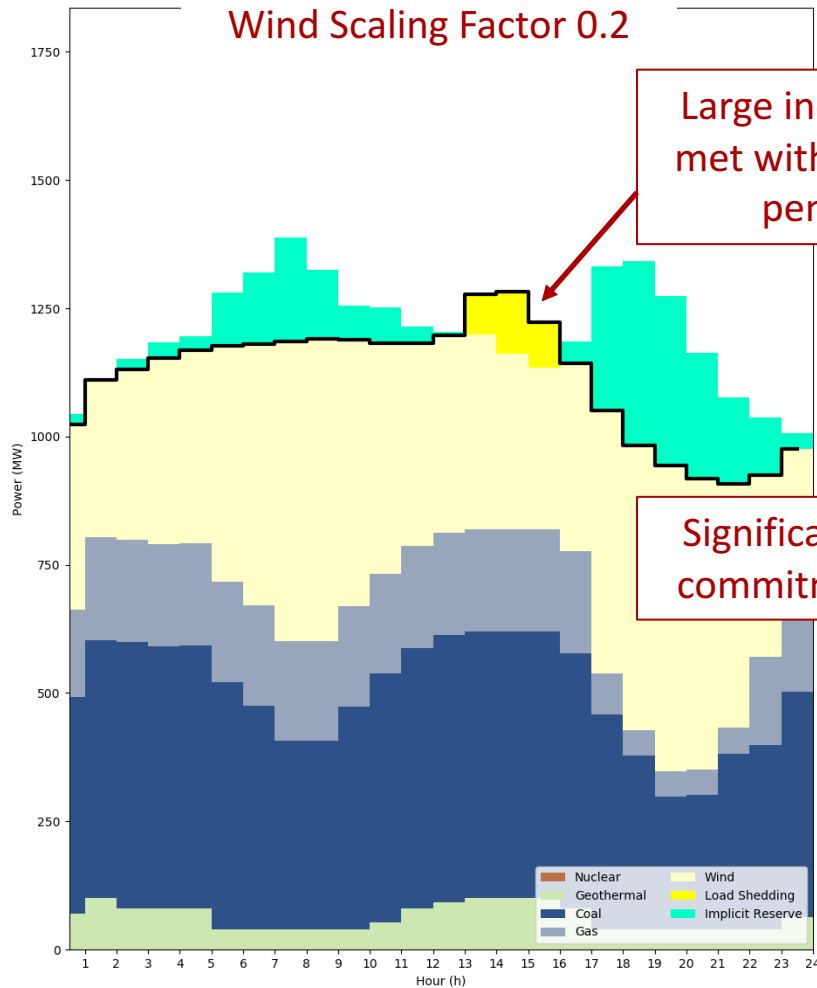Wind Scaling Factor: 0.4
Avg. Load not Met: 23.9 MWh/day
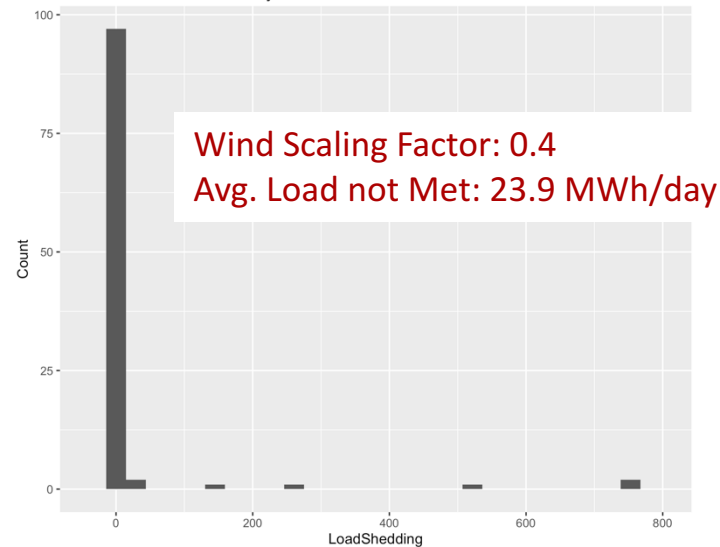
- Increased wind results in more out-of-market load, but the differences are small
- Still only see this happen on very few days overall

Single Day Commitments

2017-04-02
CP: 0 − 0.33 − 0.66 − 1
Wind Scaling Factor 0.2

2017-04-02
CP: 0 − 0.33 − 0.66 − 1
Wind Scaling Factor 0.4
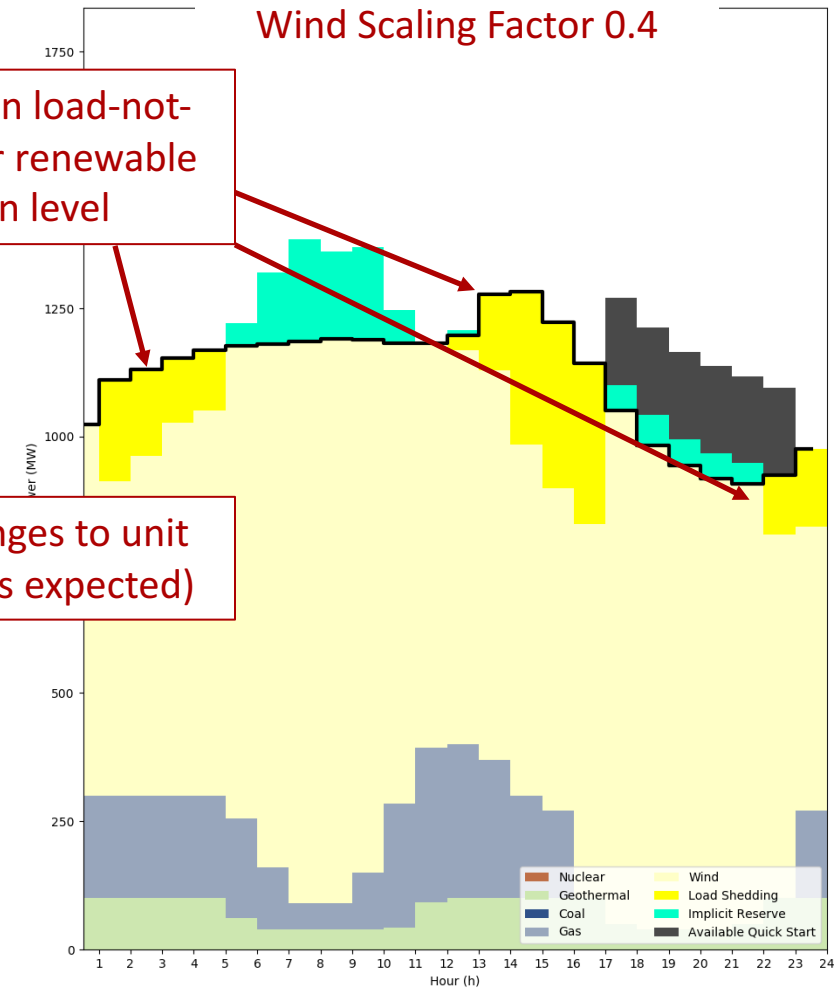
Large increase in load-not-met with higher renewable penetration level

Significant changes to unit commitment (as expected)

Variable costs: 298129.21
Fixed costs: 307123.20
Renewables penetration rate: 38.83%

Variable costs: 103376.18
Fixed costs: 96262.60
Renewables penetration rate: 74.00%

Future Work

- Evaluation of additional scenario sets

  - Assess value of scenarios that explicitly incorporate wind power ramp events

  - Look at performance of simple methods used in literature, compare to methods presented here

- Run re-enactment on larger test cases

  - Have started on WECC 240 case, with results pending

  - Increase wind penetration levels to assess scenario performance at high renewable levels

- Assess performance over a longer date range

  - Incorporate more variability, both in seasonal wind and load

- Different wind dataset, if possible

  - Evaluate scenario creation methodology on additional wind sites, as ramp behavior and wind variability vary by location

Questions?

- Contact:
  - Andrea Staid, astaid@sandia.gov

- Acknowledgements
  - Bonneville Power Administration for providing access to their data and for partial funding of this work
  - U.S. Department of Energy's ARPA-E, Green Energy Network Integration (GENI) Project Portfolio