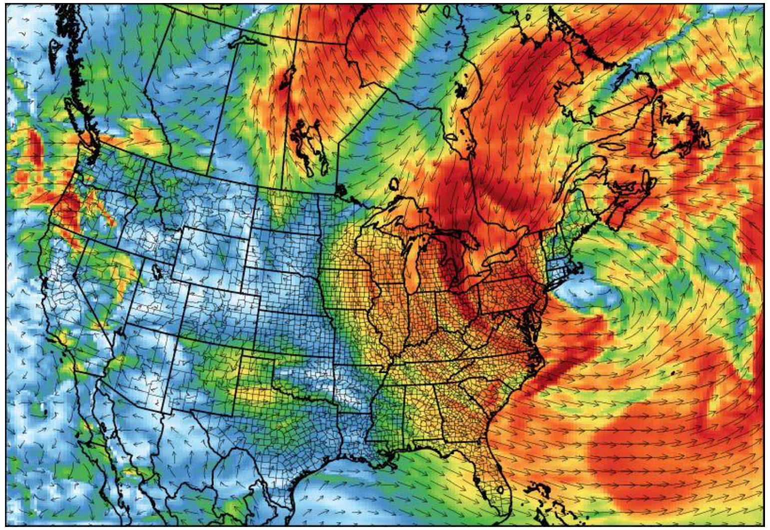
Wind and Power Time Series Modeling of ISO-NE Wind Plants

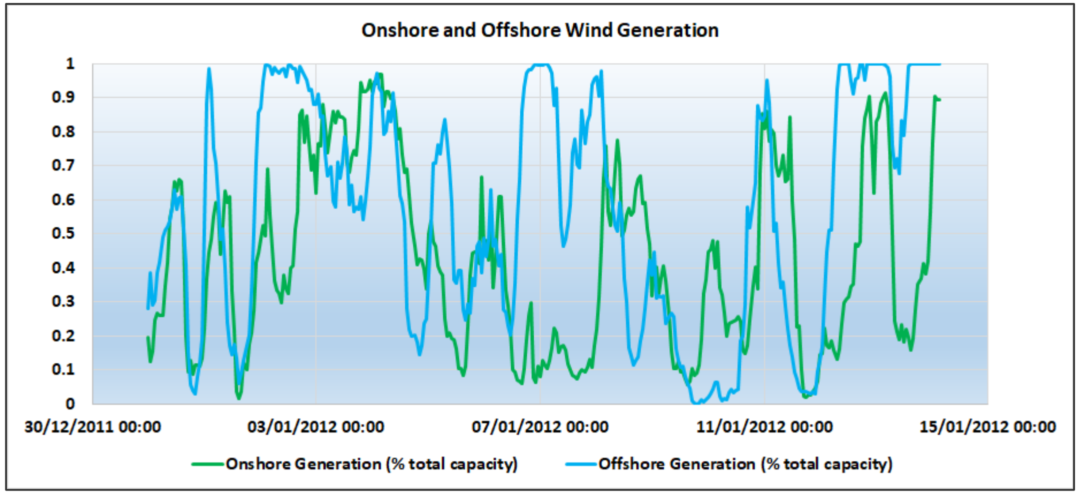
Methodology and Analysis of Results

Planning Advisory Committee – February 20, 2020

Outline and General Approach

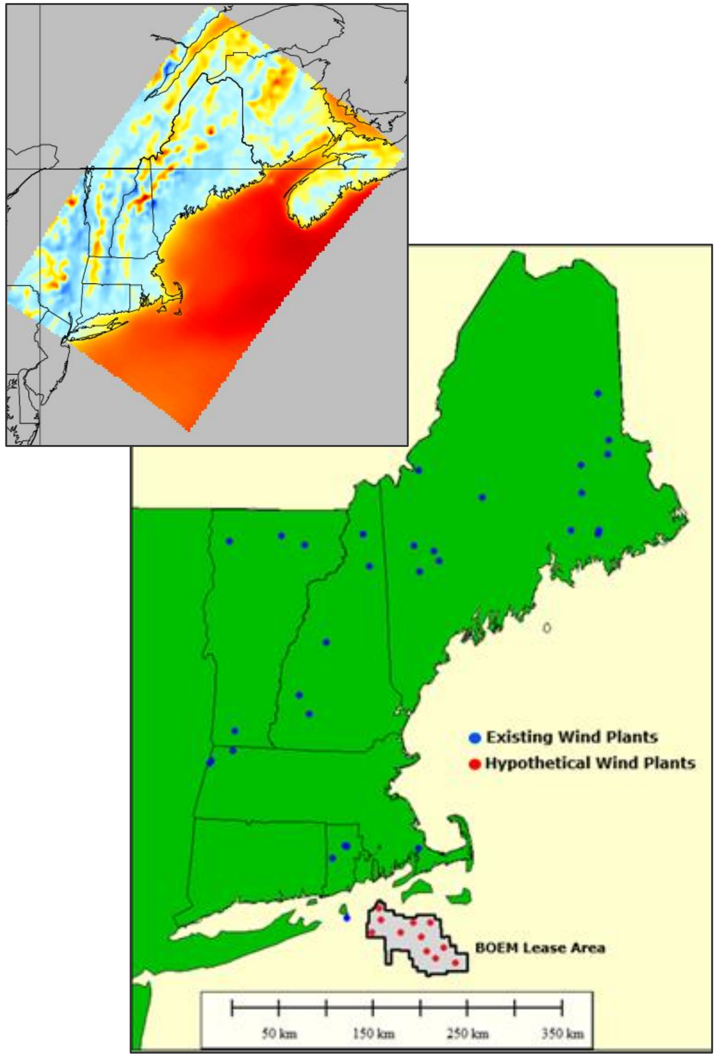
- DNV GL Wind Mapping System (WMS)
  - ➢ A dynamic downscaling system developed to generate high-resolution mesoscale wind maps and virtual time series data for any location in the world.
  - ➢ Datasets are considered client confidential and not made publicly available.
- Wind speed time series calibration
  - ➢ Using measurements collected by DNV GL Forecaster system.
- Selection of offshore locations
  - ➢ Located within Bureau of Ocean Energy Management (BOEM) lease area (required turbine spacing of 1 nautical mile).
- Power time series modeling
  - ➢ Existing wind plants use DNV GL Forecaster power models.
  - ➢ Future offshore plants modeled using WindFarmer software.
- Analysis of onshore and offshore variability
  - ➢ Greater range in offshore generation variability.





Mesoscale wind flow modeling and time series calibration

- DNV GL Wind Mapping System used to generate historical meteorological data.
  - ➢ Weather Research and Forecasting (WRF) model using NASA's MERRA-2 reanalysis data.
  - ➢ Hourly time series at 38 existing and 11 future locations for 2012 -2018.
- Wind observations at existing plants taken from DNV GL Forecaster service.
- Wind observations at "future/hypothetical" wind plants taken from floating LiDAR devices.
- Modeled wind speed data at each *existing* wind plant location were calibrated using a combination of diurnal and monthly correction factors and an analog ensemble calibration method.
- Modeled wind speed data at each *future* wind plant were bias adjusted after comparison to LiDAR measurements collected within the BOEM lease area.



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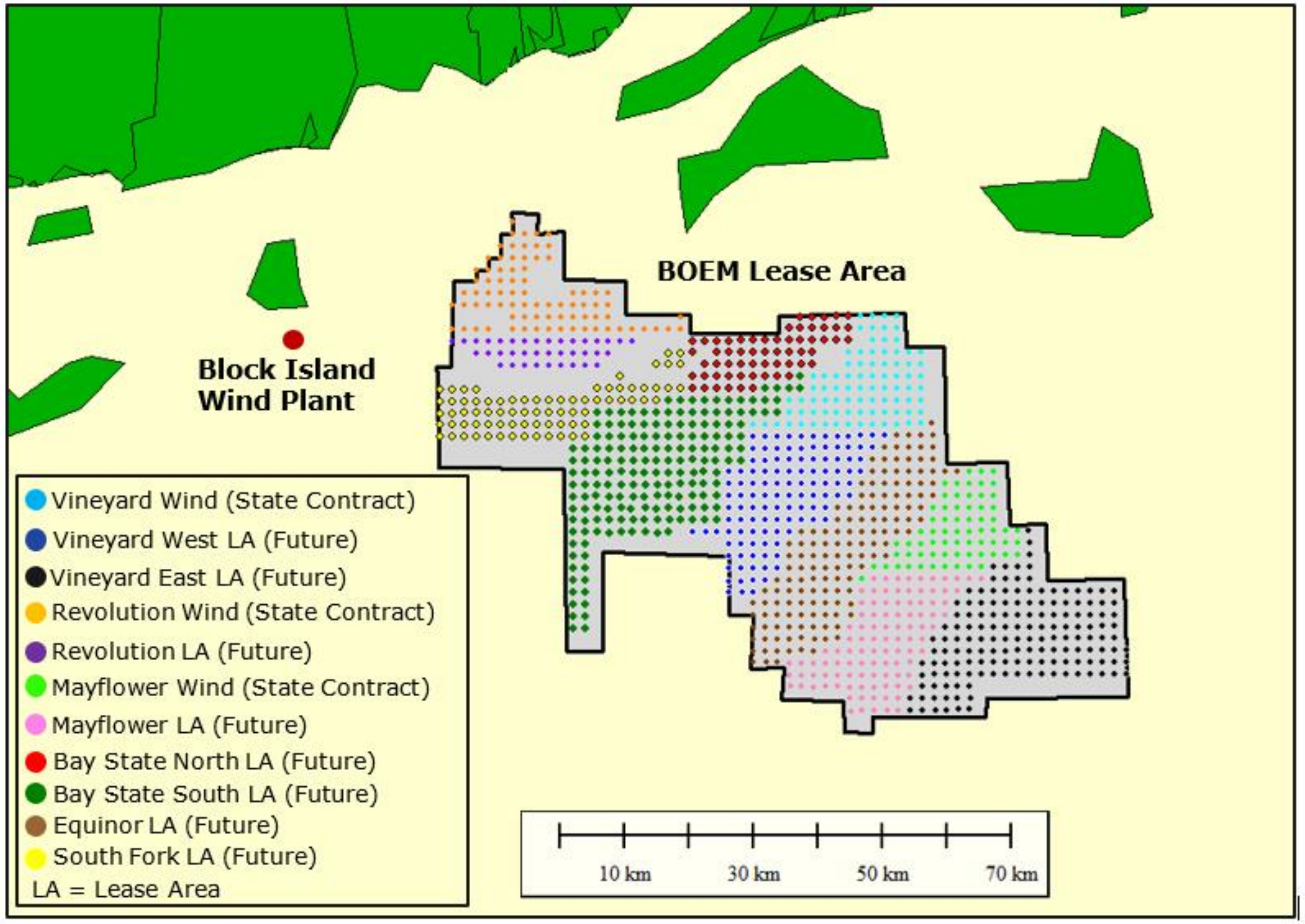
Offshore Wind Plant Layouts

- Three wind plants with long-term contracts by state RFP’s.
  - Vineyard Wind (State Contract)
  - Revolution Wind (State Contract)
  - Mayflower Wind (State Contract)
- 1 nautical mile spacing between turbines.
- All contracted and future wind plant layouts have been estimated by DNV GL.
  - Turbine layouts determined by spacing and total BOEM capacity estimation for 12 GW of generation.
- Lidar units within BOEM lease area used for bias correction of modeled offshore wind speed time series.



Power Time Series Modeling

Existing Wind Plants

- Existing wind to power conversion models for the 38 operational wind plants taken from DNV GL forecasting service.
  - Models routinely trained and updated for past several years.
- Approximately 1,320 MW of existing onshore wind plants and 30 MW of existing offshore.

Future Wind Plants

- DNV GL has modeled a total of 12,124 MW of offshore wind generation in the BOEM lease area.
- Hypothetical layouts with a minimum turbine spacing of 1 nautical mile and hub heights ranging from 119 m to 150 m based on publicly available information.
- Turbine options chosen to meet desired wind plant capacities for the 11 hypothetical wind plants.
- Power modeling using DNV GL WindFarmer software
  - Captures turbine and wind plant wake interactions

Power Time Series Modeling

- Three wind plants with long-term contracts by state RFP's.
  - Vineyard Wind (840 MW)
  - Revolution Wind (663.6 MW)
  - Mayflower Wind (804 MW)
- Eight additional future wind plants for a total of 9,816 MW of additional generation.
  - Turbine layouts and model determined by spacing and total BOEM capacity estimation requirements[1].
- 2 of 3 offshore turbine power curves supplied by ISO-NE. The final power curve was created as a proxy from the two supplied power curves.

Wind Plant Name	Capacity (MW)
Vineyard Wind (State Contract)	840
Revolution Wind (State Contract)	636.6
Mayflower Wind (State Contract)	804
Bay State North LA (Future)	504
Vineyard East LA (Future)	1836
Vineyard West LA (Future)	1160
Revolution LA (Future)	444
Mayflower LA (Future)	1224
Bay State South LA (Future)	2124
Equinor LA (Future)	1764
South Fork LA (Future)	760

1) Proposed+1x1+layout+from+RI-MA+Leaseholders+1+Nov+19+%281%29.pdf

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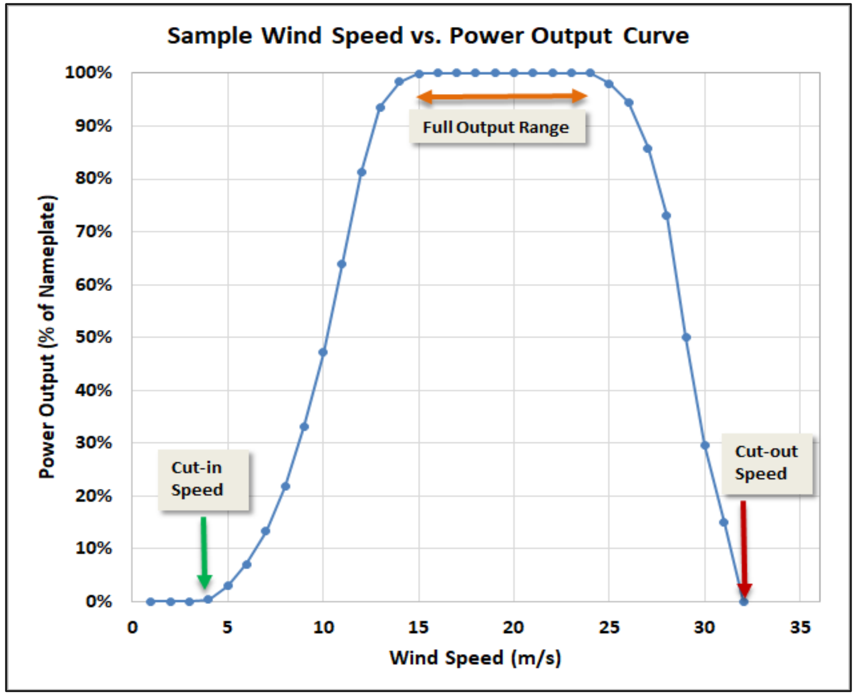
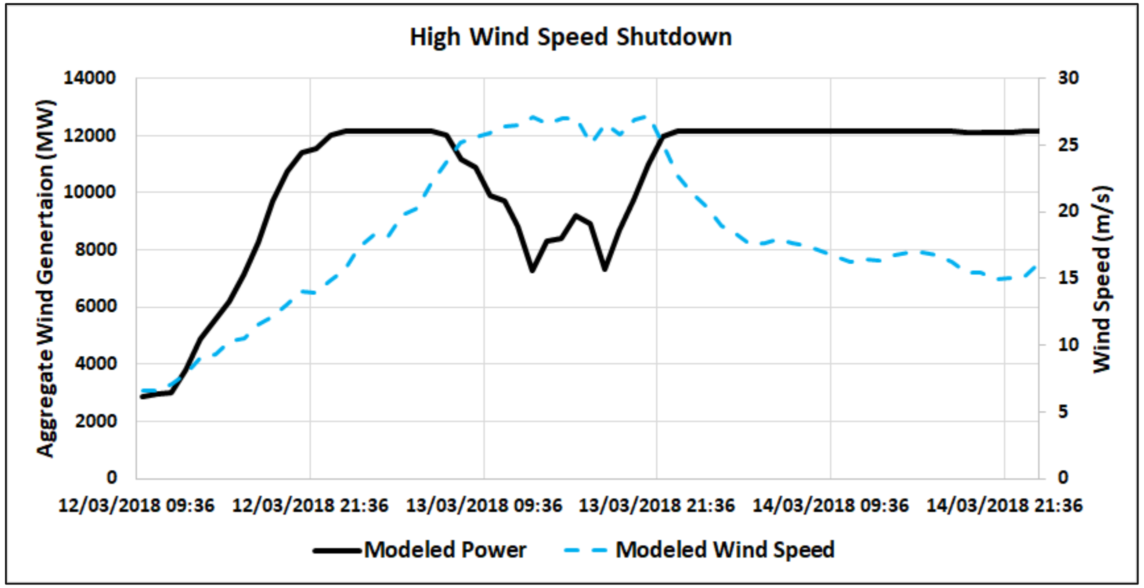
Wind turbine power curve basics

Wind Speed (m/s)	Percent of Nameplate Power
0	0.0%
1	0.0%
2	0.0%
3	0.4%
4	3.0%
5	7.1%
6	13.3%
7	21.8%
8	33.1%
9	47.2%
10	63.9%
11	81.3%
12	93.6%
13	98.4%
14	100.0%
15	100.0%
16	100.0%
17	100.0%
18	100.0%
19	100.0%
20	100.0%
21	100.0%
22	100.0%
23	100.0%
24	98.0%
25	94.6%
26	85.8%
27	73.0%
28	50.0%
29	29.6%
30	15.0%
31	0.0%



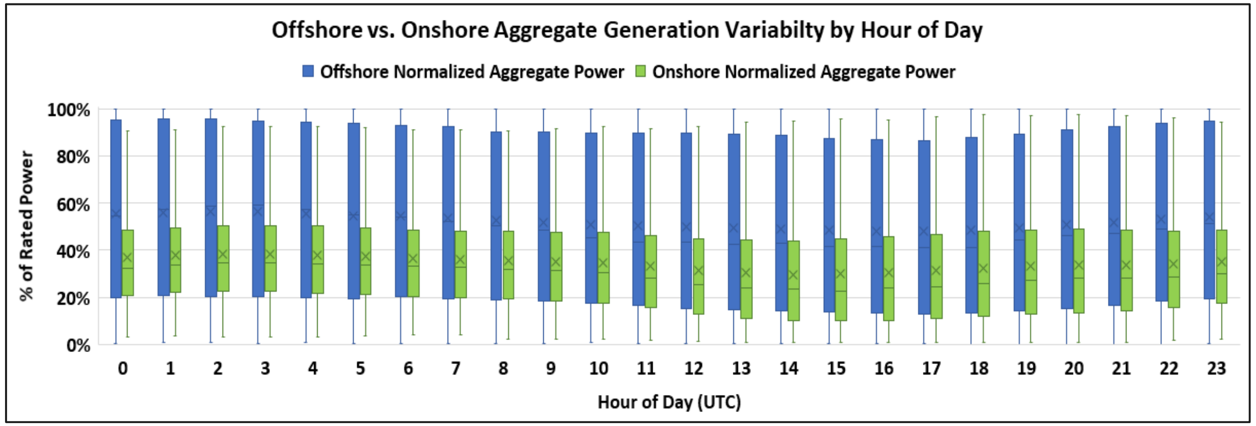


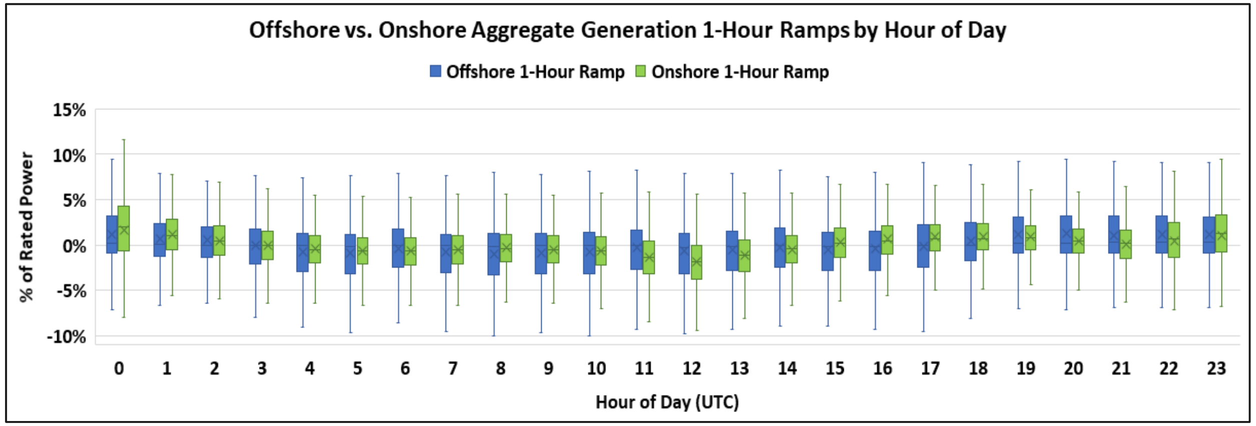
Power Time Series

- Three modeled power time series created for each wind plant.
  - **Gross power**
    - Encompasses losses due to internal and external wake effects.
  - **Gross power minus estimated electrical losses**
    - Estimated electrical efficiency of 97.5% applied as bulk loss.
  - **Gross power minus estimated electrical and availability losses**
    - Estimated electrical efficiency of 97.5%.
    - Estimated wind plant availabilities of 94.5% and 93.0% for onshore and offshore, respectively.
      - Accounts for the expected turbine availability, balance of plant and grid availability.
      - Applied randomly throughout production time series.
- Electrical efficiency and availability losses chosen based on DNV's review of pre-construction estimates throughout New England.
- Losses not applied include: turbine performance, environmental (including icing and temperature losses) and curtailment.

Preliminary evaluation of wind generation variability

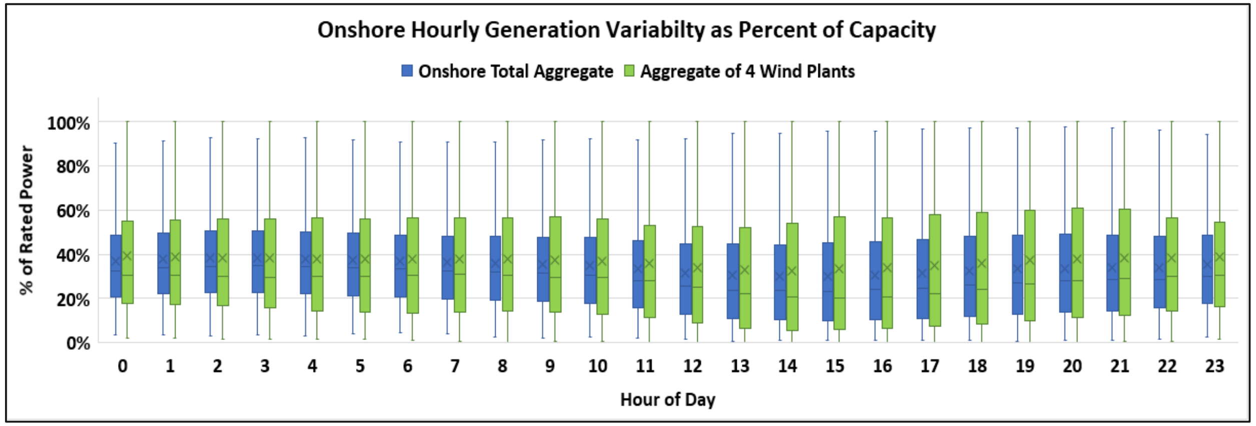
- Model results show greater variability (range) in the offshore vs onshore power generation, in aggregate, for each hour of the day.
- Hour-to-hour wind generation ramps appear to be similar in magnitude to those onshore.
  - Not very common to have hour-to-hour changes of more than a few percent of the total capacity for both onshore and offshore wind generation.
  - Accurate forecasting of wind ramps will be important to capture timing
- Three primary contributors to increased variability include
  - Portfolio Effect
  - Wind speed variability
  - Wind speed frequency distribution

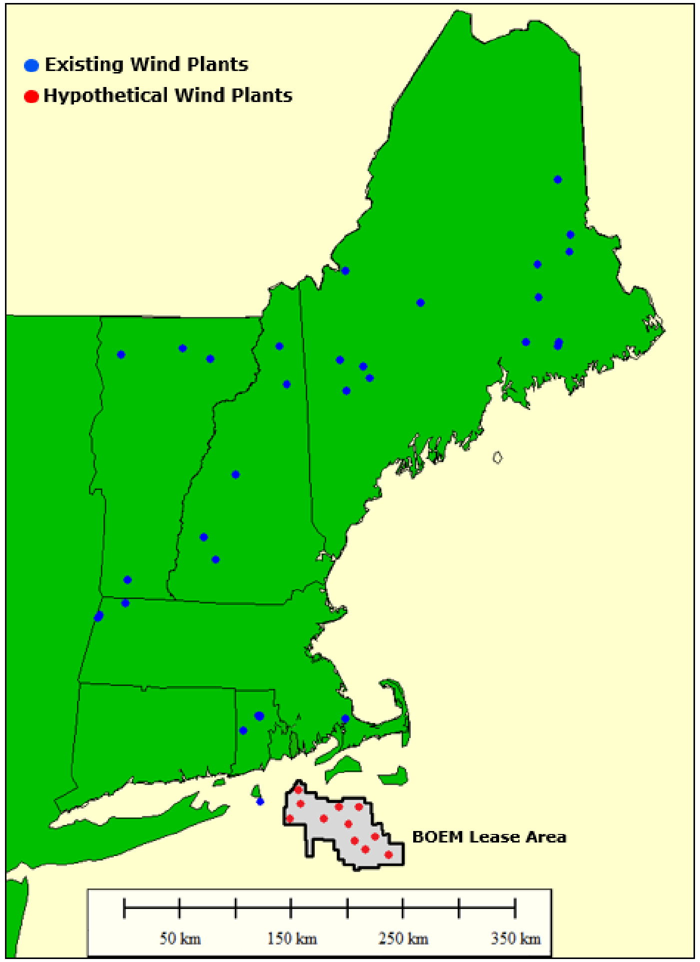




Portfolio Effect

- Increased geographic dispersion of onshore wind plants results in decreased variability of aggregate generation
  - Reduces the risk that a single weather system will impact the generation of all plants in the region at the same time.
- Example of portfolio effect for onshore plants shown below
  - Comparison of aggregate of four nearby wind plants with the aggregate of all plants.





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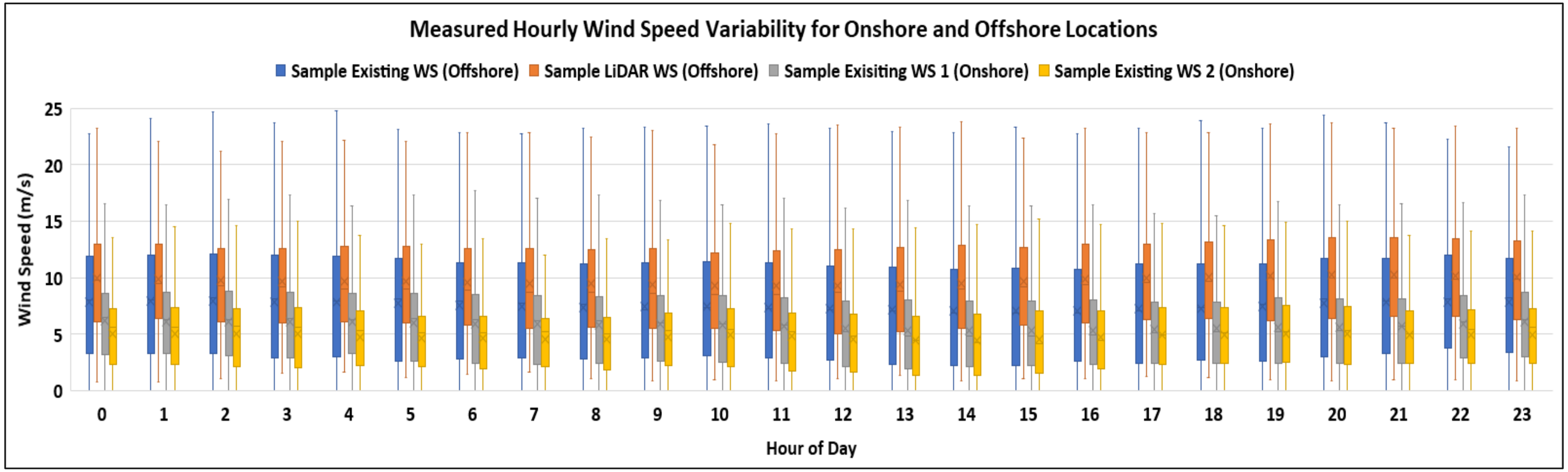
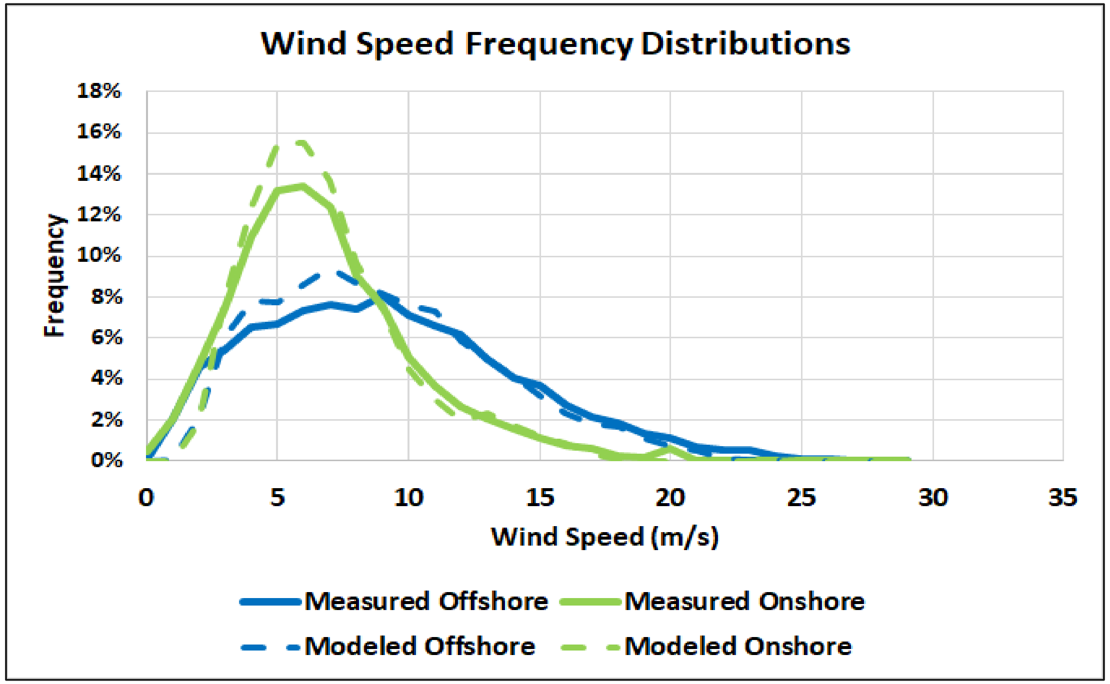
Wind Speed Variability Differences

- Analysis of onshore and offshore wind speed measurements indicates larger variation with the offshore winds for each hour of the day.
- Likely due to fact that the offshore winds can be much higher and so this allows for a larger range between the weak and strong winds.



Wind Speed Frequency Distributions

- Offshore wind speed distribution is not only shifted toward higher wind speeds but is also more broadly spread out than that for onshore.
  - Offshore wind speed distribution from floating lidar.
  - Onshore wind speed distribution from existing wind plant.
- Both modeled and measured distributions are in reasonable agreement.



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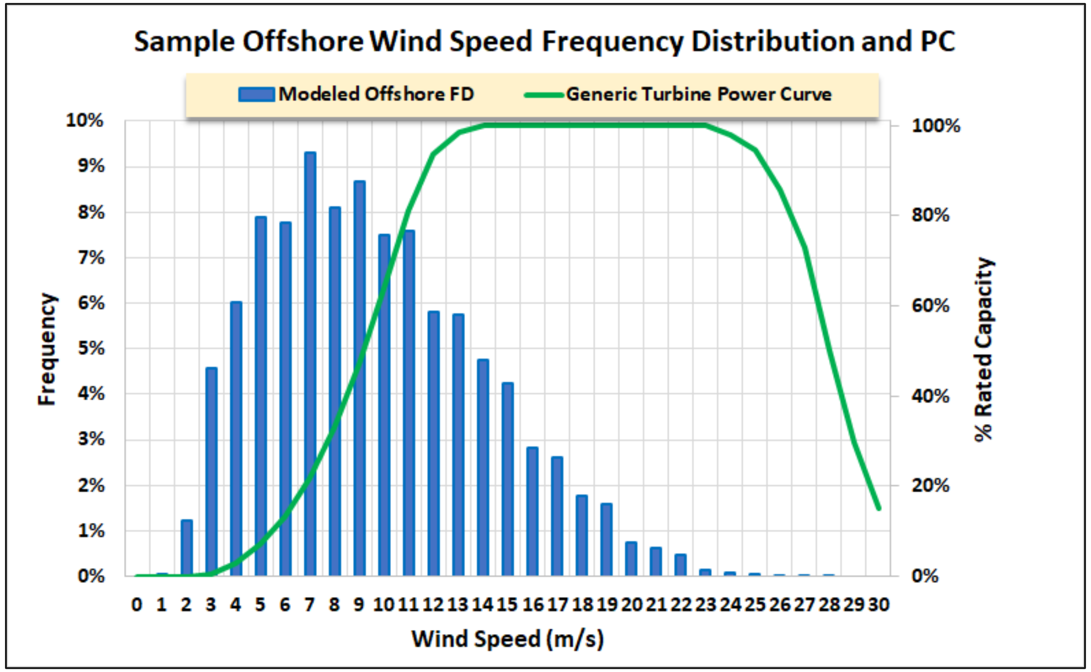
Wind Speed Frequency Distribution in Relation to Power Curve

- Increased spread in wind speeds throughout the range of the offshore power curve
  - Increases the range of possible power generation values throughout the time series.
- Offshore turbines achieve rated power at a higher wind speed. Therefore, the turbine spends more time below rated power, where power output is sensitive to small changes in wind speed.



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Summary

- DNV GL has combined its mesoscale and power time series modeling capabilities to produce simulated wind plant time series for 38 existing and 11 future/hypothetical (offshore) wind plant locations.
- Modeled wind speed data were calibrated to available wind speed measurements
- Investigated the increased variability in the offshore wind power time series and it appears to be due to a combination of the portfolio effect, increased variability due to stronger winds and a broader shape to the wind speed frequency distribution.
- Work will continue in 2020 to improve and expand modeling of offshore wind