Stochastic Time Series Modeling for ISO-NE

Results and Next Steps

Revision 2

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Revision History

- Revision 1 (2021-02-16)
  - Slide 43: Updated pressure percentile values
  - Slides 63-68: Updated to higher quality images
- Revision 2: (2021-03-02)
  - Slide 43: Corrected error in all percentile values, instead of only excluding leap day (2/29), all of February was excluded. Now corrected to show 365 days’ worth of data with leap day excluded. Realization example also updated to reflect new percentile values.

Purpose

- Provide stakeholders a summary of the DNV GL report detailing results of the stochastic time series analysis of variable energy resources (VER)
- Describe 2021 update to the VER time series data

Overview

- Background
  - 2020 ISO-NE VER Data Set
- Stochastic Time Series Analysis
  - Expansion of 2020 ISO-NE VER Data Set
  - Stochastic Engine (SE)
  - Key Performance Indicators (KPI) Analysis
    - Reliability of VER during cold snaps / heat waves
    - Probability of wind and solar droughts/lulls
    - Correlation of load, wind, and solar
    - Representative 8760s
    - Distributions of wind at peak(min) gross(net) load
    - Intra-day variability of VER (ramping)
- 2021 VER Data Series
  - Historical 2020 Data Update
  - New Facility Additions

Background

- During 2019 it became apparent to ISO-NE that a new consistent dataset of offshore wind was needed to serve as inputs to multiple studies across the organization
  - 2019 Economic Studies
  - Transmission Planning Study Assumptions
  - Energy Security Analysis

- We hired DNV GL at the end of 2019 to use their weather modeling software and develop a historical data set of all existing wind plants and future offshore wind plants from 2012-2018. This work was presented to PAC in February 2020 with two presentations
  - ISO-NE presentation and DNV GL presentation

- In early 2020, DNV GL updated the data set with an additional year of historical data and recalibrated the models to create an updated 8 year data set from 2012-2019

- In Summer of 2020, the ISO hired DNV to create a stochastic data set from an expanded historical modeled data set from which the results of that study are being presented today
  - July 22, 2020 ISO-NE PAC scope of work presentation
  - 2020 ISO-NE Variable Energy Resource (VER) Data Series (2000-2019) Rev.3

- In Fall of 2020, the ISO hired DNV to expand and recalibrate the historical data set to include 2020 historical data and additional hypothetical wind/solar plants
  - 2021 ISO-NE VER Data Series (2000-2020) to be posted in Mar-Apr 2021

2020 ISO-NE VER Data Set

- Revision 2 of the 2020 ISO-NE VER data set contained hourly time series data for wind resources in New England for 8 years (2012-2019)
- This data set was created using NASA satellite information and advanced modeling software from DNV GL to create historical time series profiles based on New England weather conditions
- The data set was then calibrated with available recorded data to get the best fit possible
  - NOTE: The data set will not match historical values hour-by-hour, since it is based on a model, but the data should still follow overall weather trends and magnitudes and be statistically similar to recorded values
- The data set included the following information
  - 37 existing onshore and 1 existing offshore wind plant wind speed profiles
  - 12 future offshore wind plant wind speed profiles (4 state contracted and 8 hypothetical in BOEM lease area south of Cape Cod)
  - Aggregate wind power profiles (1 onshore and 1 offshore)
    - NOTE: Individual wind plant power profiles are considered market sensitive under the ISO Info Policy
- This data set was posted to the PAC website on May 1, 2020

STOCHASTIC TIME SERIES ANALYSIS

Expansion of 2020 VER Data Set and Stochastic Engine

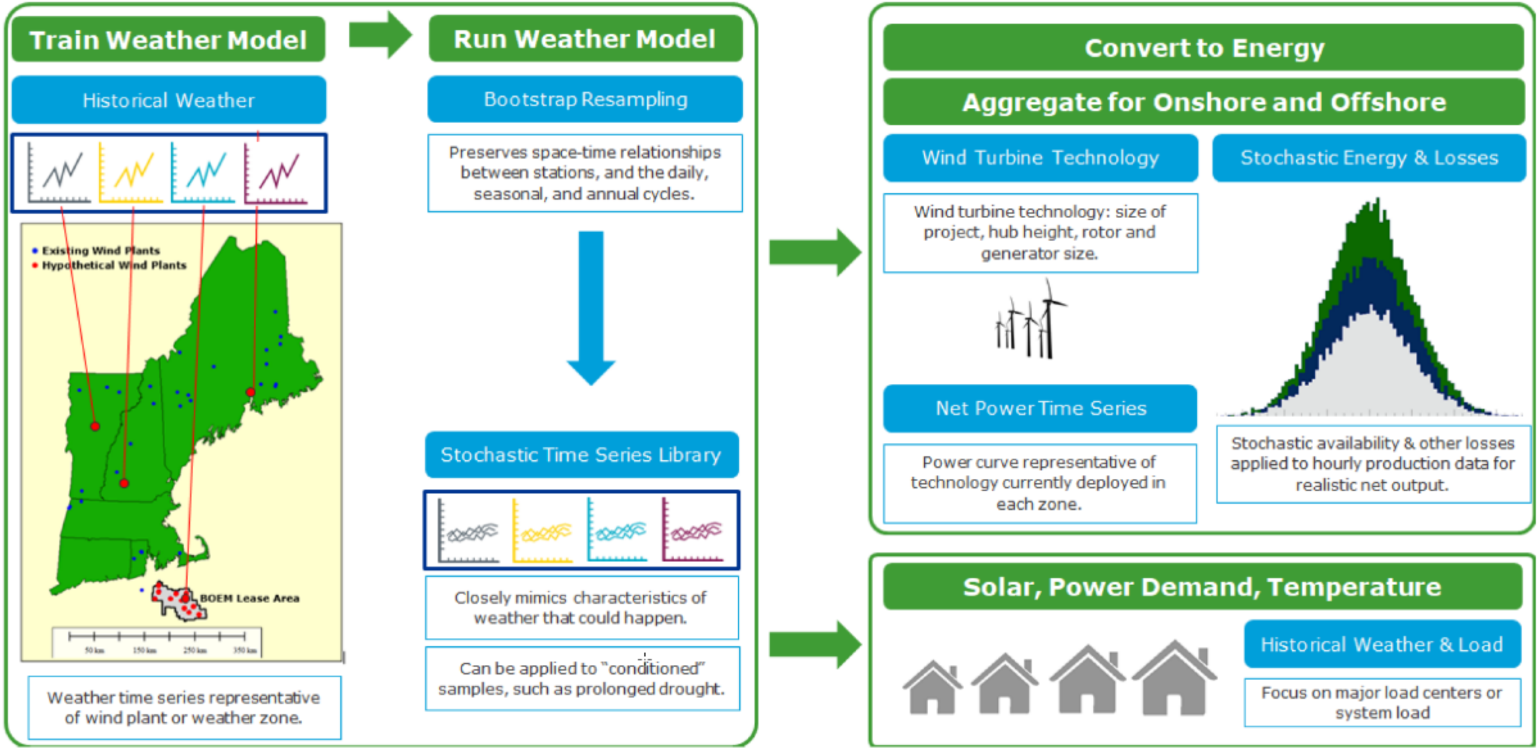
Expansion of 2020 ISO-NE VER Data Set

- In order to provide enough historical weather events for the Stochastic Engine, DNV GL recommend the historical VER data set should be expanded to 20 years
- The historical data set also needed to include solar and load profiles for the full 20 years to provide the co-dependencies between wind, solar, and load
- Revision 3 of the 2020 ISO-NE VER data set was posted on September 21, 2020 and contains hourly time series data for variable energy resources, load, and weather data in New England for a full 20 years (2000-2019)
- The expanded data set added the following information
  - All previous data from Revision 2 expanded to a full 20 years (2000-2019)
  - Aggregate behind-the-meter solar photovoltaic (PV) power profiles by Load Zone
  - Load (gross minus energy efficiency) and weather (temperature, relative humidity [RH], and global horizontal irradiance [GHI]) profiles by Load Zone

Stochastic Engine

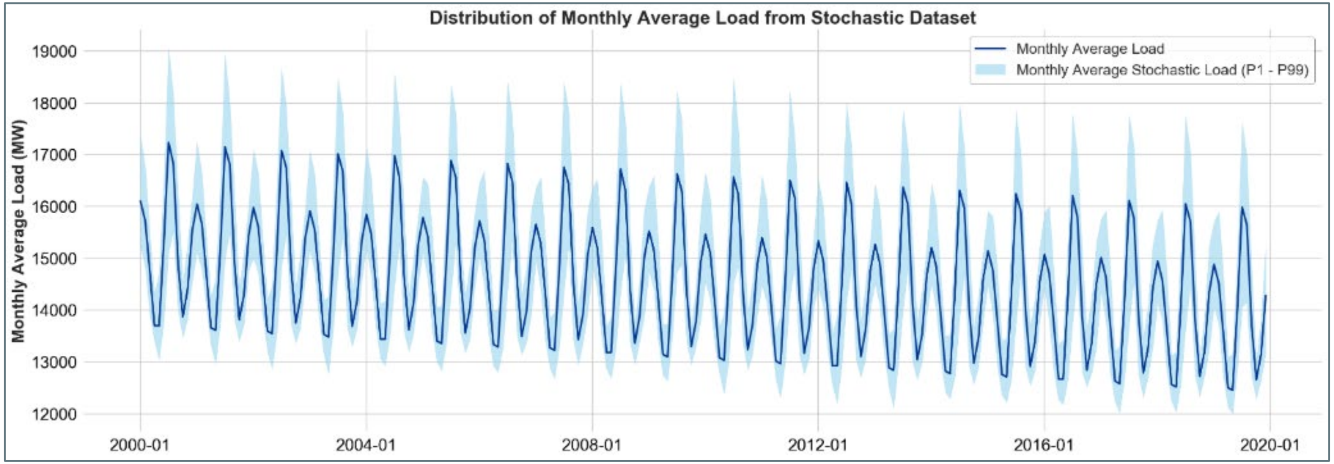
- The Stochastic Engine (SE) is a tool developed by DNV GL to statistically tackle time-series-based problems at scale. It can resample any time series (wind speed, irradiance, price, load) into parallel, plausible, scenarios while preserving all the relationships within the data and between the signals.
- The weather-to-generation models will then simulate the expected power production for each weather scenario, creating at least 20,000 years worth (1,000 20-year simulations) of hourly time series of weather and power outputs for each wind plant, zonal solar, and zonal load.
- Each time series will preserve the correlations from year-to-year, month-to-month, temperature-to-load, and zone-to-zone.
- Each 20-year simulation (also referred to as a realization) can be thought of as an alternate reality of weather conditions that have the same overall climate of New England.
- The stochastic data set is LARGE. It contains **175.2 million hours** worth of data and is **512 GB** in size.

Stochastic Engine, cont.



Stochastic Engine, cont.

- The SE preserves all trends present in the original data set. The figure below presents the distribution of monthly mean load values calculated from the 20,000-year stochastic data set. The original 20 years of input gross load data exhibited a downward trend, in part due to the implementation of energy efficiency programs in recent years. The stochastic data set preserves this trend.



Load and Resources Quantities

- Load:
  - For the purposes of this data set, load is defined as gross load minus energy efficiency (i.e., the load seen in the control room after behind-the-meter solar PV is reconstituted)
- Wind: (4,457.25 MW total nameplate capacity)
  - Onshore: (1,319.65 MW total nameplate capacity)
    - 37 existing wind plants
    - Note: does not include Weaver Wind (ISD in 2020)
  - Offshore: (3,137.6 MW total nameplate capacity)
    - 1 existing wind plant
      - Block Island 30 MW, POI – RI
    - 4 state contracted wind plants
      - Vineyard Wind: 840.0 MW, POI – SEMA
      - Mayflower Wind: 804.0 MW, POI – SEMA
      - Revolution Wind: 663.6 MW, POI – RI
      - Park City Wind: 800.0 MW, POI – SEMA
- Solar PV: (7,725.9 MW total nameplate capacity)
  - Based on the draft 2020 PV forecast for 2029
  - Note: The draft forecast was ~1% less than the final 2020 PV forecast

STOCHASTIC ANALYSIS RESULTS

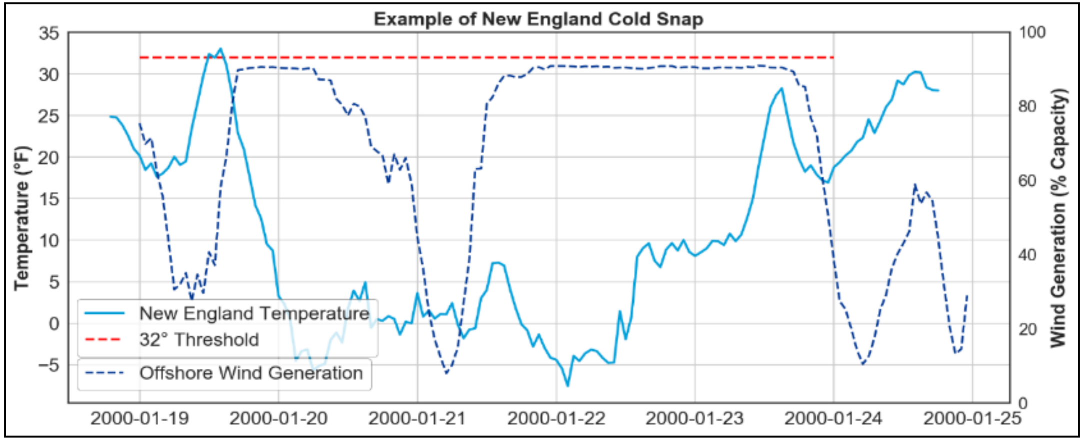
Key Performance Indicators

Key Performance Indicators

- The ISO prioritized the following KPIs for DNV GL to analyze in the stochastic data set
  1. Reliability of VER during cold snaps / heat waves
  2. Probability of wind and solar droughts/lulls
  3. Correlation of load, wind, and solar
  4. Representative 8760s
  5. Distributions of wind at peak(min) gross(net) load
  6. Intra-day variability of VER (ramping)
- The ISO had also proposed analyzing the following KPIs, but did not have enough budget in this round to complete
  – Storage requirements for VER to reduce resource variability
  – The probability of high-wind shutdown events for offshore wind
  – Analysis of impacts of upcoming 2024 solar eclipse
- This presentation will focus on results for the aggregate New England region. Similar results for each Load Zone are included in the final DNV GL report.
  – The report will be posted on the PAC website after this presentation

1. Reliability During Cold Snaps / Heat Waves

- Methodology
  - Cold snaps and heat waves were defined as a span of weather for ≥3 days that met two types of temperature criteria



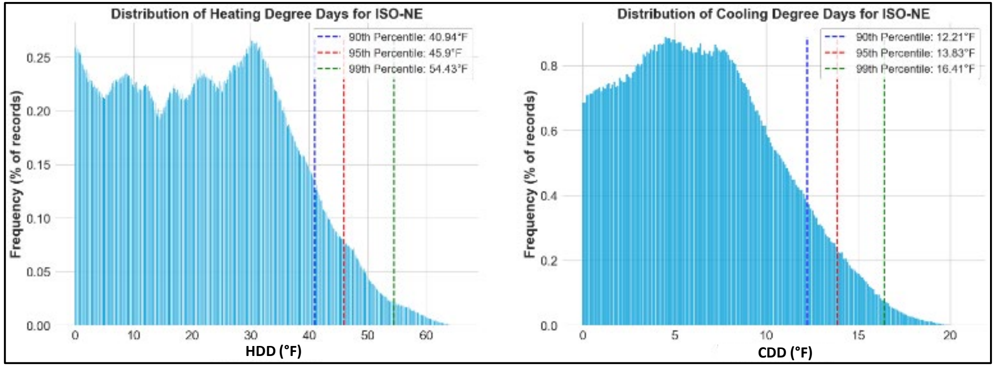
  - Method 1 (Max Daily Temp)
    - Peak daily New England average temperature above/below a threshold
    - Cold snap thresholds: <32°F, <20°F, <15°F, and <10°F
    - Heat wave thresholds: >85°F, >90°F, and >95°F

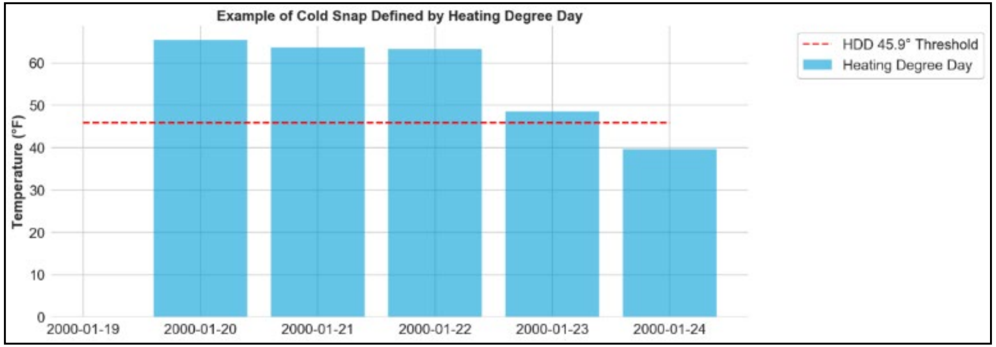
1. Reliability During Cold Snaps / Heat Waves

- Methodology, cont.
  - Method 2 (HDD/CDD)
    - New England heating/ cooling degree day (HDD/CDD) values above/below a threshold
    - Selection of 90th, 95th, and 99th percentiles used as thresholds

$$HDD = 65°F - \text{mean daily temperature}$$

$$CDD = \text{mean daily temperature} - 65°F$$





1. Reliability During Cold Snaps / Heat Waves

- Summary of cold snaps and heat waves for New England using Method 1

Statistic	Temperature Threshold						
	<10°F	<15°F	<20°F	<32°F	>85°F	>90°F	>95°F
Average events per year	0.0	0.1	0.4	4.2	2.4	0.4	0.0
Maximum events per year	1	2	4	10	9	5	2
Minimum events per year	0	0	0	0	0	0	0
Total number of events	14[1]	1,060	7,094	84,912	48,279	7,192	91[1]
Average event duration (days)	3.0	3.1	3.3	4.8	4.3	3.5	3.0
Maximum event duration (days)	3	6	7	24	14	10	4
Average daily maximum temperature (°F)	8.7	11.8	15.0	25.7	88.4	92.4	96.1
Average temperature at time of daily peak load hour (°F)	5.8	8.0	10.6	20.4	87.1	90.8	94.1
Average daily peak load (MW)	21,748	21,024	20,359	19,159	23,082	24,232	24,458
Maximum daily peak load (MW)	22,276	22,725	22,725	22,725	28,198	27,911	26,726
Temperature at time of maximum peak load hour (°F)	3.5	5.1	5.1	5.1	87.0	92.2	95.3
Average onshore wind generation during daily peak load (% Capacity)	78%	62%	54%	47%	22%	22%	14%
Average offshore wind generation during daily peak load (% Capacity)	76%	67%	62%	59%	36%	33%	19%
Onshore wind generation at time of maximum peak load (% Capacity)	86%	67%	67%	67%	31%	24%	10%
Offshore wind generation at time of maximum peak load (% Capacity)	91%	57%	57%	57%	66%	52%	4%
Average solar generation during daily peak load hour (MW)	0%	3%	3%	8%	48%	50%	50%
Solar generation at time of maximum peak load (% Capacity)[2]	0%	0%	0%	0%	71%	79%	67%

1. A sample size of <100 is very small within a data set of 7.3M days and the results should be considered accordingly
2. The sun had gone down prior to the winter peak load hour

1. Reliability During Cold Snaps / Heat Waves

- Summary of onshore wind output expectations using Method 1

Temperature (°F)	Onshore Wind (% Capacity)							
	Min	P1	P5	P50	P95	P99	Max	Average Daily Peak Load (MW)
<10	61%	61%	63%	81%	88%	88%	88%	21,748
<15	6%	7%	9%	69%	87%	89%	91%	21,017
<20	5%	7%	9%	63%	86%	88%	91%	20,365
<32	2%	7%	13%	45%	84%	88%	93%	19,212
>85	2%	4%	5%	19%	45%	58%	79%	23,096
>90	2%	4%	6%	18%	51%	64%	77%	24,157
>95	7%	7%	8%	12%	26%	31%	37%	24,442

1. Reliability During Cold Snaps / Heat Waves

- Summary of offshore wind output expectations

Temperature (°F)	Offshore Wind (% Capacity)							
	Min	P1	P5	P50	P95	P99	Max	Average Daily Peak Load (MW)
<10	37%	38%	39%	90%	93%	94%	94%	21,748
<15	2%	13%	18%	74%	93%	94%	96%	21,017
<20	0%	2%	12%	67%	93%	94%	97%	20,365
<32	0%	1%	5%	69%	92%	94%	97%	19,212
>85	0%	1%	2%	26%	87%	92%	96%	23,096
>90	0%	1%	2%	21%	88%	92%	96%	24,157
>95	1%	2%	2%	7%	66%	87%	93%	24,442

1. Reliability During Cold Snaps / Heat Waves

- Summary of solar output expectations

Temperature (°F)	Solar (% Capacity)							
	Min	P1	P5	P50	P95	P99	Max	Average Daily Peak Load (MW)
<10	0%	0%	0%	0%	0%	0%	0%	21,748
<15	0%	0%	0%	0%	0%	41%	52%	21,017
<20	0%	0%	0%	0%	0%	40%	52%	20,365
<32	0%	0%	0%	0%	27%	49%	78%	19,212
>85	0%	11%	20%	49%	73%	79%	85%	23,096
>90	0%	11%	22%	54%	73%	79%	83%	24,157
>95	0%	10%	20%	57%	74%	77%	79%	24,442

1. Reliability During Cold Snaps / Heat Waves

- Summary of cold snaps and heat waves for New England using Method 2

Statistic	Cold Snap (heating degree day)			Heat Wave (cooling degree day)		
	>54.4°F	>45.9°F	>40.9°F	>12.2°F	>13.8°F	>16.4°F
Average events per year	0.2	1.6	3.6	1.5	0.7	0.0
Maximum events per year	3	8	10	7	5	3
Minimum events per year	0	0	0	0	0	0
Total number of events	4,633	31,752	72,261	30,966	14,784	949
Average event duration (days)	3.2	3.9	4.7	4.2	3.8	3.2
Maximum event duration (days)	7	15	28	15	9	6
Average daily degree day (°F)	58.4	52.2	47.9	14.6	15.8	17.7
Average temperature at time of peak load hour (°F)	9.8	15.1	19.2	87.9	89.3	91.8
Average daily peak load hour (MW)	20,484	19,644	19,236	23,836	24,430	24,854
Maximum daily peak load hour (MW)	22,725	22,725	22,725	28,198	28,102	27,577
Temperature at time of maximum peak load hour (°F)	5.1	5.1	5.1	87.0	86.5	91.6
Average onshore wind generation during daily peak load hour (% Capacity)	52%	50%	47%	22%	24%	23%
Average offshore wind generation during daily peak load hour (% Capacity)	61%	58%	58%	40%	41%	35%
Onshore wind generation at time of maximum peak load hour (% Capacity)	67%	67%	67%	31%	27%	61%
Offshore wind generation at time of maximum peak load hour (% Capacity)	57%	57%	57%	66%	70%	90%
Average solar generation during daily peak load hour (% Capacity)	4%	15%	12%	50%	52%	53%
Solar generation at time of maximum peak load hour (% Capacity)*	0%	0%	0%	71%	71%	57%

* The sun had gone down prior to the winter peak load hour

1. Reliability During Cold Snaps / Heat Waves

- Summary of onshore wind output expectations

HDD/CDD	Onshore Wind (% Capacity)							
	Min	P1	P5	P50	P95	P99	Max	Average Daily Peak Load (MW)
54.43	4.8%	6.8%	8.5%	60.2%	85.7%	88.2%	90.9%	20,479
45.90	2.3%	7.6%	16.1%	50.1%	84.5%	88.0%	92.4%	19,688
40.94	2.3%	7.8%	14.3%	45.2%	83.6%	87.5%	92.4%	19,297
12.21	1.7%	3.3%	5.2%	20.1%	45.7%	59.2%	77.4%	23,792
13.83	1.8%	3.3%	5.4%	22.0%	50.7%	63.2%	77.4%	24,397
16.41	1.9%	3.2%	6.7%	22.4%	50.7%	61.5%	73.8%	24,819

1. Reliability During Cold Snaps / Heat Waves

- Summary of offshore wind output expectations

HDD/CDD	Offshore Wind (% Capacity)							
	Min	P1	P5	P50	P95	P99	Max	Average Daily Peak Load (MW)
54.43	0.8%	8.5%	14.5%	61.4%	92.2%	93.8%	96.5%	20,479
45.90	0.2%	1.6%	6.6%	66.6%	92.4%	94.0%	96.9%	19,688
40.94	0.2%	1.5%	5.6%	66.7%	92.4%	93.9%	97.1%	19,297
12.21	0.2%	1.2%	2.5%	32.4%	87.2%	91.4%	96.0%	23,792
13.83	0.2%	1.3%	2.7%	32.4%	88.0%	91.6%	95.8%	24,397
16.41	0.4%	1.3%	2.2%	24.6%	88.3%	91.6%	95.8%	24,819

1. Reliability During Cold Snaps / Heat Waves

- Summary of solar output expectations

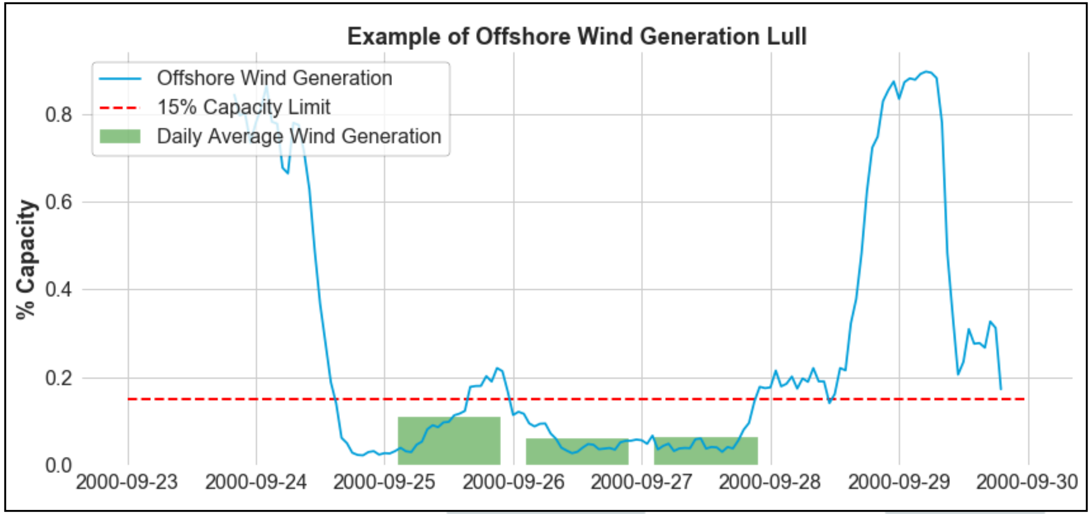
HDD/CDD	Solar (% Capacity)							
	Min	P1	P5	P50	P95	P99	Max	Average Daily Peak Load (MW)
54.43	0.0%	0.0%	0.0%	0.0%	0.1%	42.3%	52.2%	20,479
45.90	0.0%	0.0%	0.0%	0.1%	33.7%	52.6%	73.3%	19,688
40.94	0.0%	0.0%	0.0%	0.1%	32.7%	55.9%	77.7%	19,297
12.21	0.0%	12.1%	23.3%	52.7%	73.5%	79.0%	85.1%	23,792
13.83	0.0%	12.6%	24.5%	54.9%	74.6%	79.4%	84.7%	24,397
16.41	0.2%	12.6%	24.6%	56.6%	74.4%	78.5%	81.3%	24,819

1. Reliability During Cold Snaps / Heat Waves

- Observations
  - Method 2 (HDD/CDD) seems to provide better statistical sampling of extreme temps than in Method 1 (Max Daily Temps)
  - As cold snap intensity increases, so does wind generation
    - A review of the weather data indicates this is due to passing cold fronts associated with strong low-pressure systems
  - As heat wave intensity increases, wind generation tends to decrease
    - A review of the weather data indicates this is due to a high-pressure ridge that sets up over New England and suppresses wind speeds
  - During heat waves, the formation of the upper-level ridge also tends to reduce cloud cover which generally increases solar generation

2. Probability of Wind and Solar Droughts/Lulls

- Methodology
  - A wind and solar "drought" or "lull" is defined as a specified 3 or more consecutive days where the average daily generation (wind or solar) is below a specified percentage of max capacity during the month.
  - The figure presents an example of a wind generation lull where daily average offshore wind generation remained below 15% capacity for 3 days.



2. Probability of Wind and Solar Droughts/Lulls

- Average yearly wind lulls by generation type

Period	Daily Average Onshore Wind Generation Capacity Thresholds		
	< 15% Capacity	< 20% Capacity	< 25% Capacity
≥3 days	5.7 lulls	13.6 lulls	20.4 lulls
≥4 days	3.1 lulls	7.9 lulls	12.4 lulls
≥5 days	1.4 lulls	4.5 lulls	8.2 lulls

Period	Daily Average Combined Wind Generation Capacity Thresholds		
	< 15% Capacity	< 20% Capacity	< 25% Capacity
≥3 days	3.5 lulls	7.2 lulls	11.8 lulls
≥4 days	1.4 lulls	3.1 lulls	6.1 lulls
≥5 days	0.5 lulls	1.5 lulls	2.9 lulls

Period	Daily Average Offshore Wind Generation Capacity Thresholds		
	< 15% Capacity	< 20% Capacity	< 25% Capacity
≥3 days	3.9 lulls	7.1 lulls	11.1 lulls
≥4 days	1.7 lulls	2.9 lulls	5.3 lulls
≥5 days	0.6 lulls	1.3 lulls	2.4 lulls

Period	Daily Average Solar Generation Capacity Thresholds		
	< 15% Capacity	< 20% Capacity	< 25% Capacity
≥3 days	0.1 lulls	0.5 lulls	1.2 lulls
≥4 days	0.0 lulls	0.0 lulls	0.3 lulls
≥5 days	0.0 lulls	0.0 lulls	0.1 lulls

2. Probability of Wind and Solar Droughts/Lulls

- Overlapping wind/solar lulls with cold snaps / heat waves
  - An event was considered to be overlapping if at least one of the cold snap / heat wave days was coincident with one of the wind/solar lull days
  - Note: There are 7.3 million days in the stochastic data set

	Cold Snap		Heat Wave	
Offshore Wind Lull	451 days	0.0062%	4,035 days	0.0552%
Onshore Wind Lull	213 days	0.0029%	1,534 days	0.0210%
Total Wind Lull	1 day	<0.0001%	4,113 days	0.0563%
Solar Lull	383 days	0.0052%	0 days	0.0000%
Wind & Solar Lull	0 days	0.0000%	0 days	0.0000%

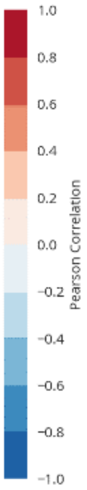
2. Probability of Wind and Solar Droughts/Lulls

- Observations
  - Wind lulls of 3 or more days with daily average wind generation below 15% of capacity occur approximately 4 times/year for offshore and 6 times/year for onshore wind
  - Onshore wind lulls are more common than offshore, most likely due to lower average onshore wind speeds and onshore generation capacity factor
  - Wind lulls are more likely during summer than winter months but can occur at any time of year
  - Combined offshore and onshore wind reduces the amount of lulls
  - Solar lulls are very uncommon, <2 times/year for any metric evaluated
  - It is very uncommon to have a combined cold snap and wind lull, which could compound energy security concerns
  - Wind lulls are more common during heat waves, but still rare when looking at the overall data set

3. Correlation of Load, Wind, and Solar

Quality of Correlation	Pearson Coefficient
Perfect	± 1.00
High	±0.50 to ±0.99
Moderate	±0.30 to ±0.49
Low	±0.01 to ±0.29
None	0.00

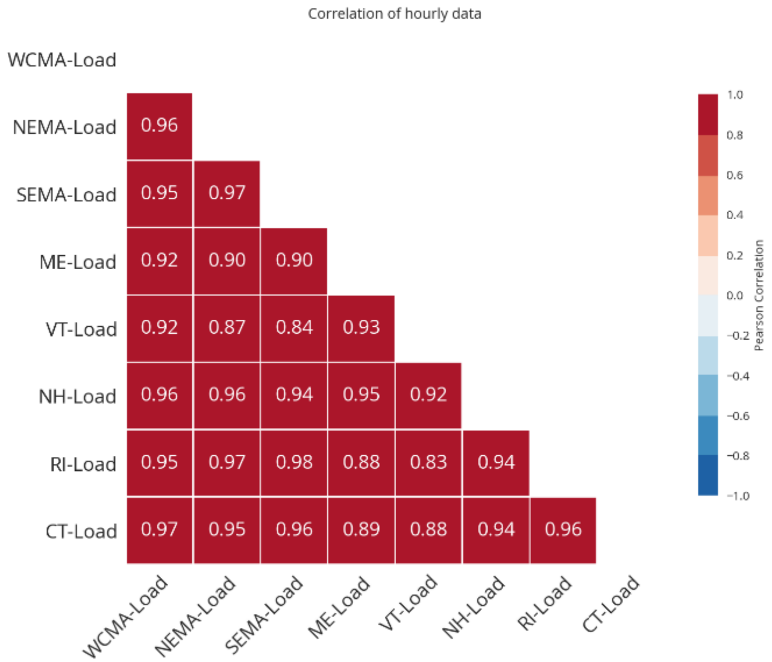
- Pearson correlation coefficients* were computed based on hourly, monthly, and annual values.
- A Pearson correlation coefficient measures the statistical relationship between two continuous variables and is based on the method of covariance. It gives information about both the magnitude and direction of correlation between two variables.
- A negative correlation coefficient means the two variables are negatively correlated (one goes up when the other goes down) while a positive coefficient indicates the variables are positively correlated (both go up at same time).
- The table above presents a description of the degree of correlation quality as it relates to the Pearson coefficient. The tables on the following slides are also color coded with dark red indicating strong positive correlation, pale red/blue indicating weak correlation, and dark blue indicating strong negative correlation.

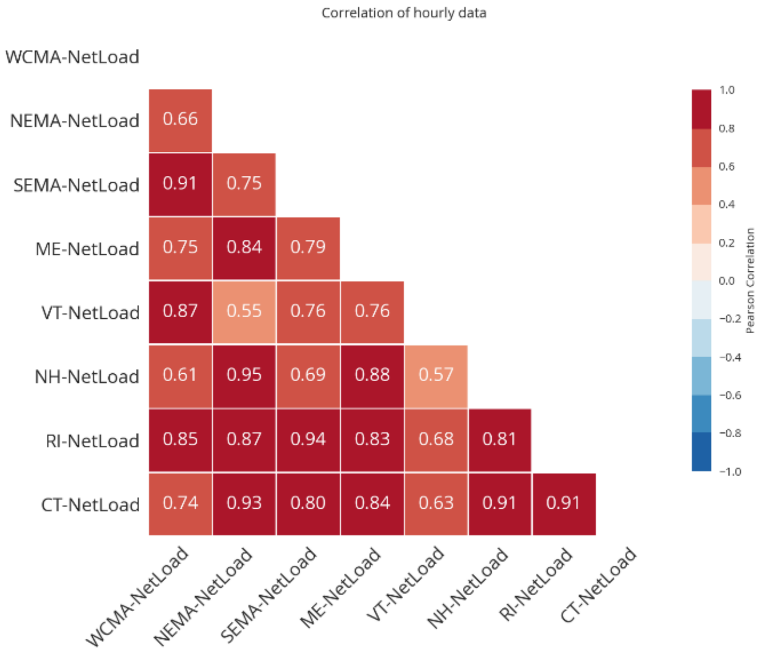


* "Statistics Solutions," [Online]. Available: https://www.statisticssolutions.com/pearsons-correlation-coefficient/. [Accessed 2021].

3. Correlation of Load, Wind, and Solar

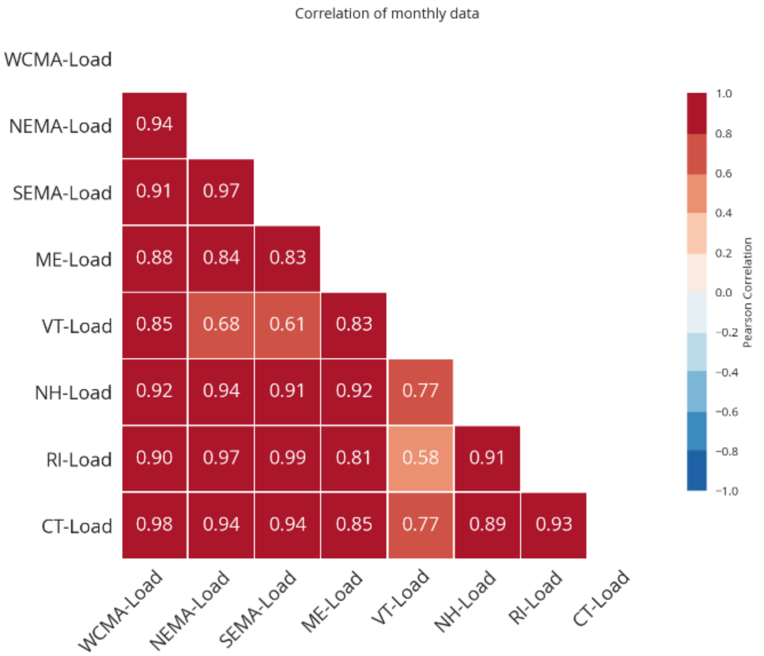
- Hourly load – gross and net

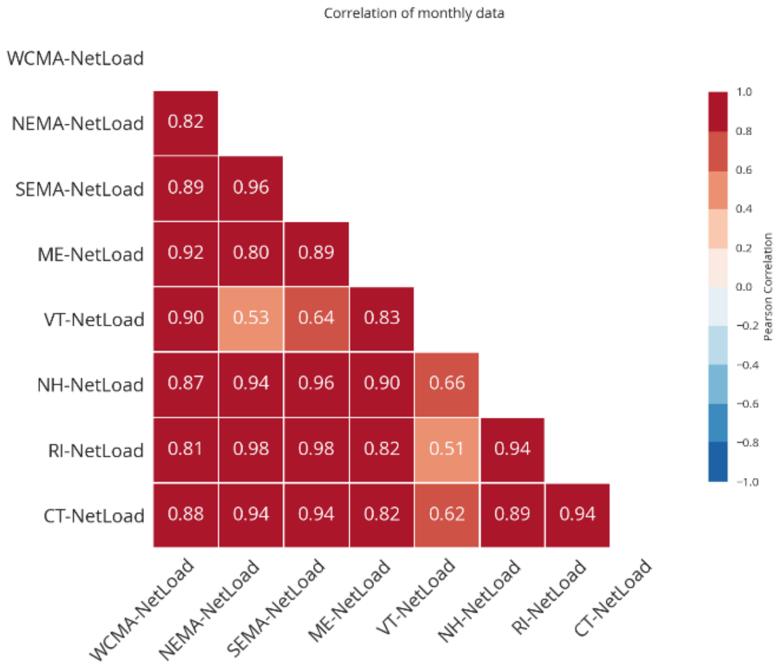




3. Correlation of Load, Wind, and Solar

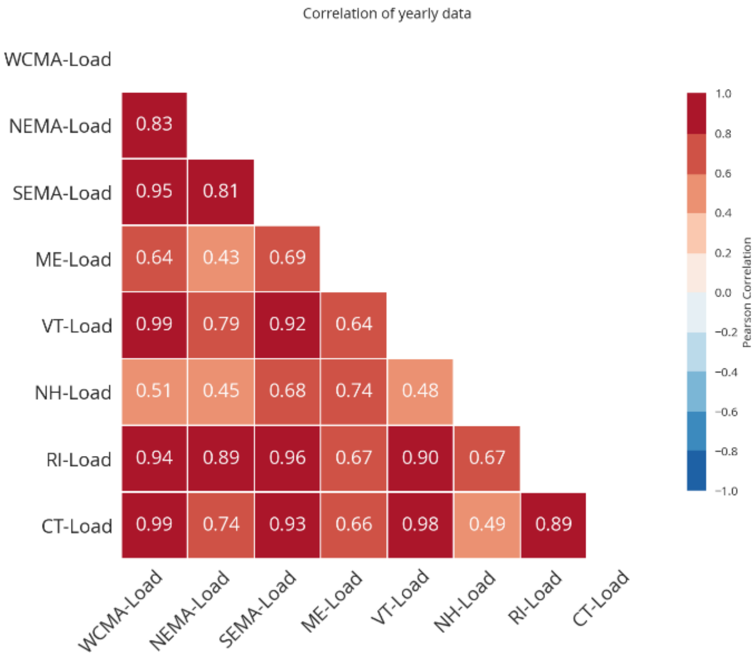
- Monthly average load – gross and net

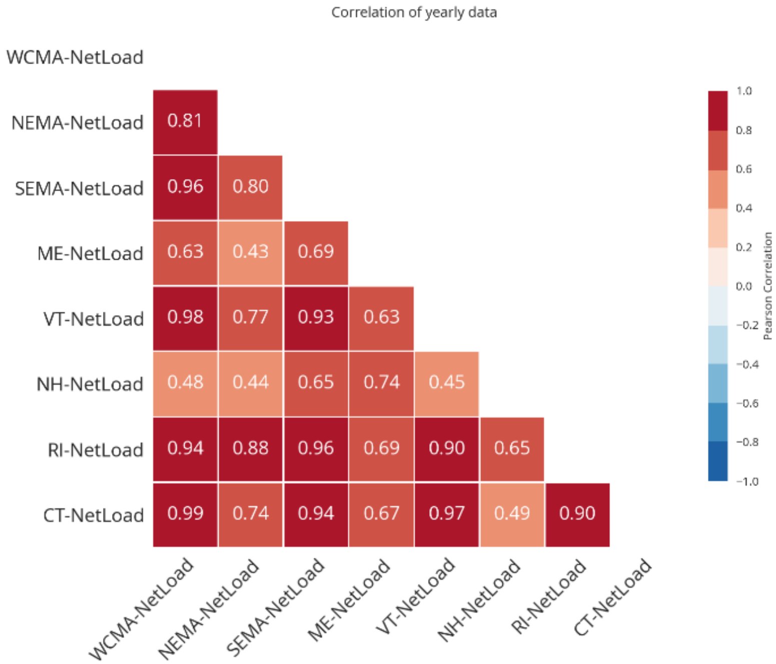




3. Correlation of Load, Wind, and Solar

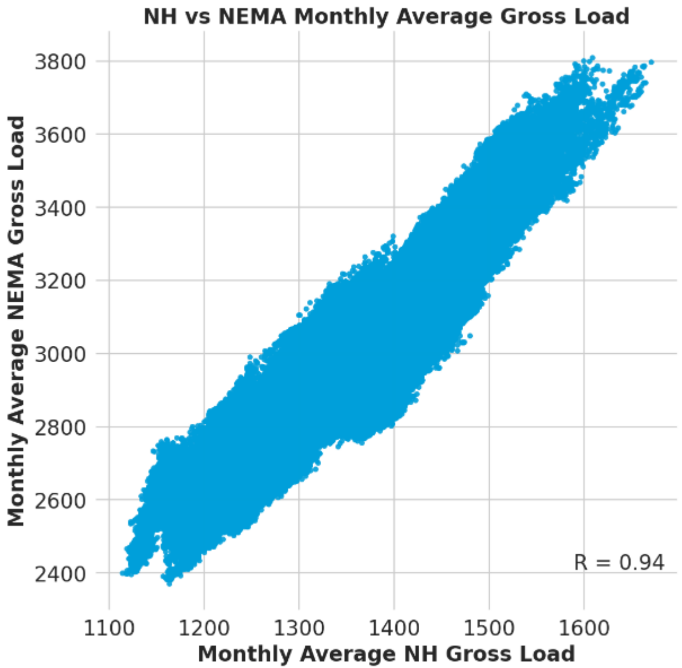
- Yearly average load – gross and net

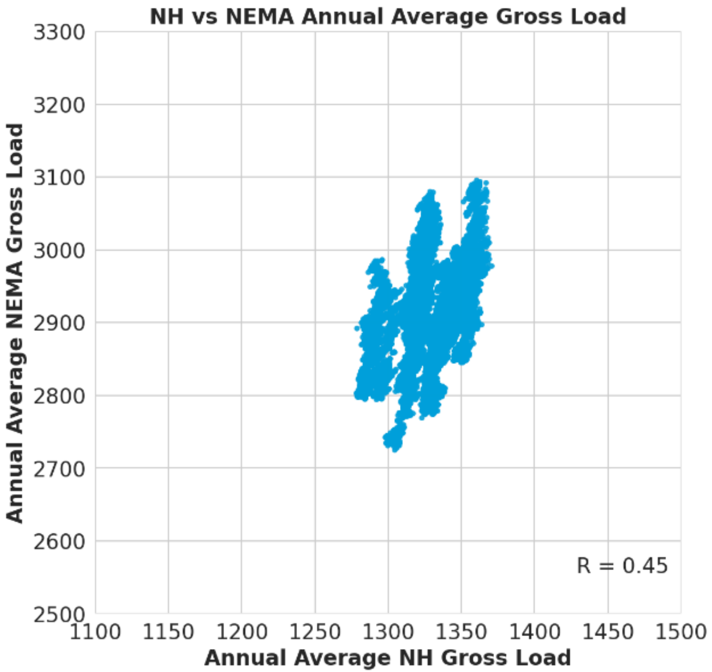




3. Correlation of Load, Wind, and Solar

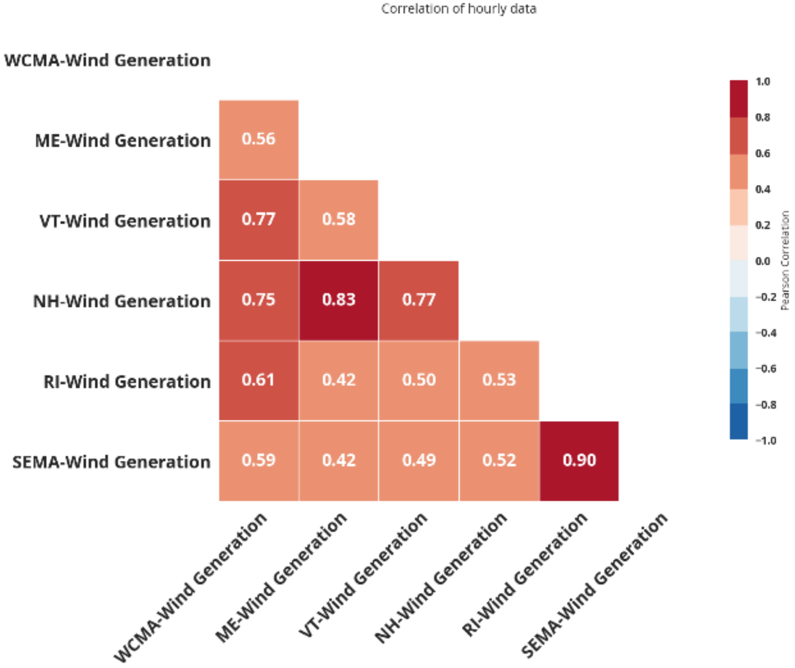
- Monthly vs. annual correlation between two Load Zones

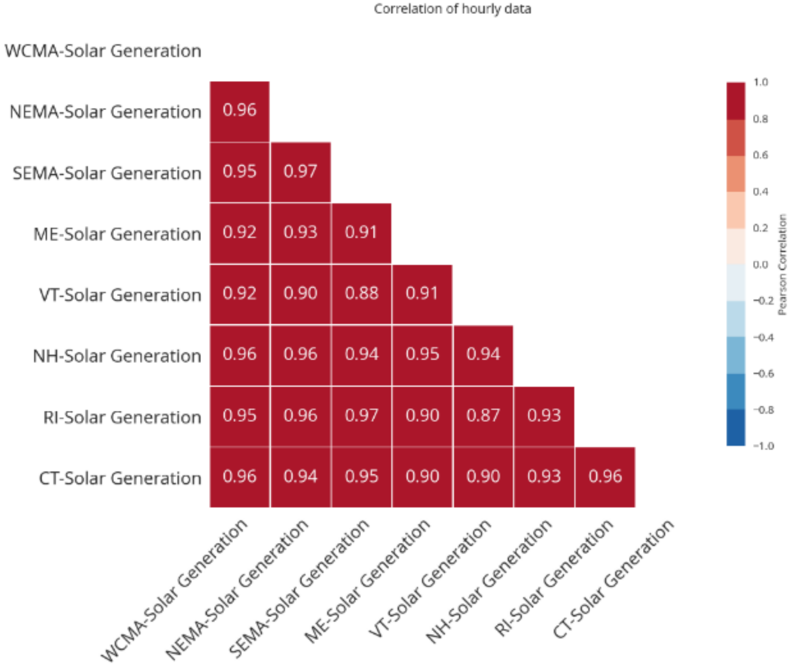




3. Correlation of Load, Wind, and Solar

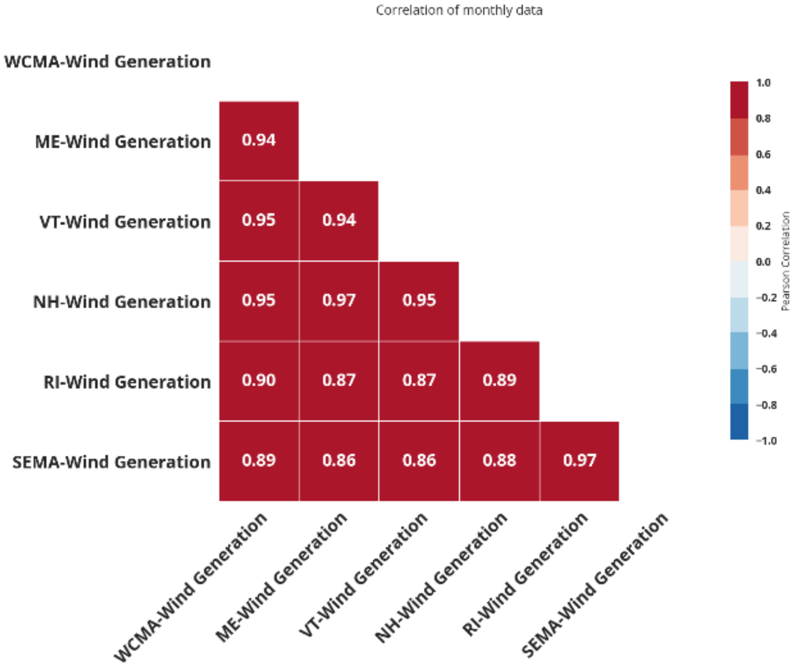
- Hourly wind and solar
  - Note: Wind is net output (includes electric and availability losses)

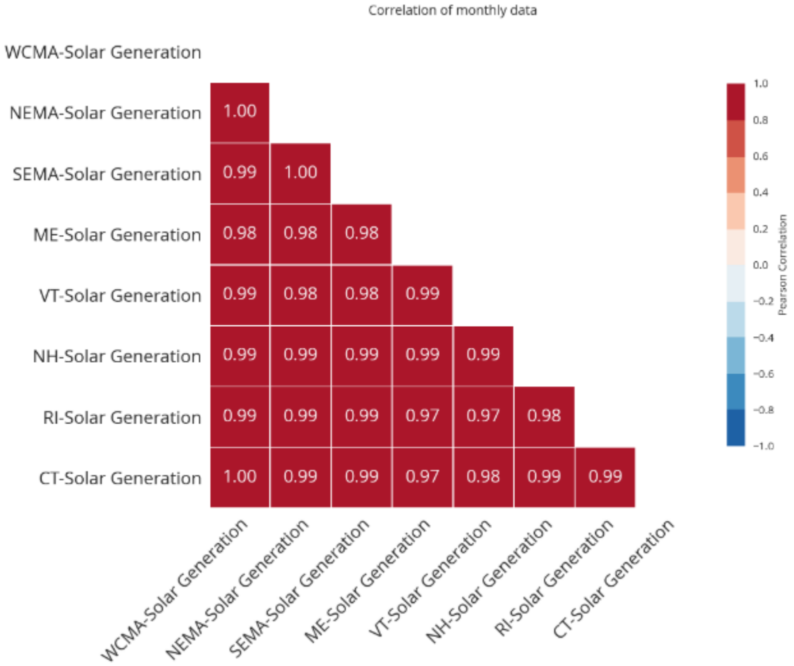




3. Correlation of Load, Wind, and Solar

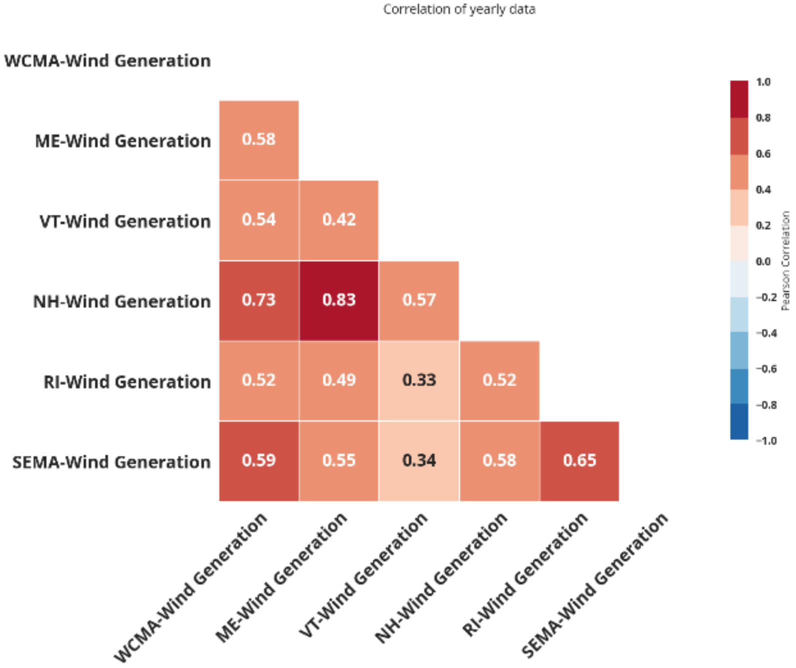
- Monthly wind and solar
  - Note: Wind is net output (includes electric and availability losses)

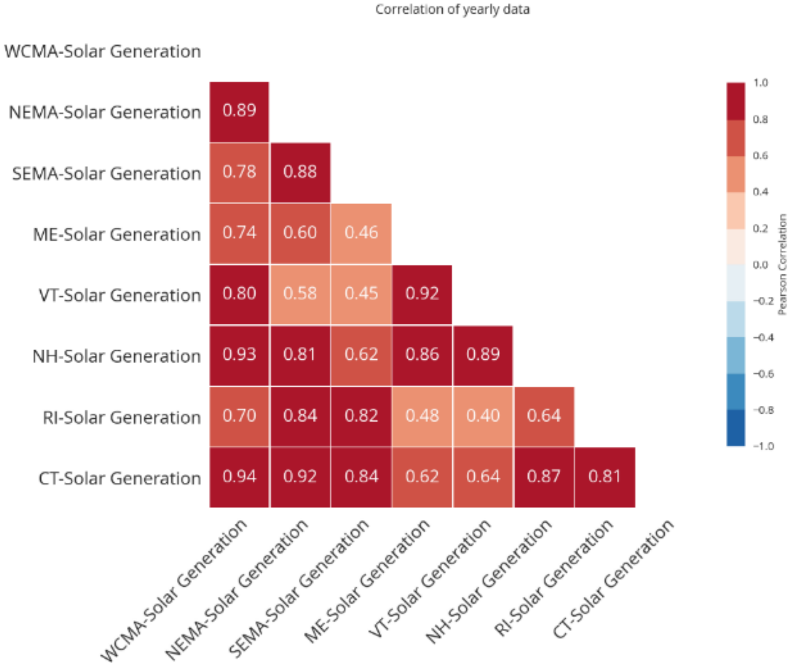




3. Correlation of Load, Wind, and Solar

- Yearly wind and solar
  - Note: Wind is net output (includes electric and availability losses)





3. Correlation of Load, Wind, and Solar

- Hourly load, wind, and solar by Load Zone

	ME	NH	VT	CT	RI	SEMA	WCMA	NEMA	ISO-NE
Load - Wind	-0.01	0.00	0.01		-0.03	-0.03	-0.04		-0.02
Net Load - Wind	0.05	0.02	0.22		0.09	0.11	0.14		0.10
Solar - Wind	-0.12	-0.08	-0.24		-0.18	-0.16	-0.19		-0.18
Load - Solar	0.36	0.37	0.30	0.36	0.38	0.36	0.36	0.39	0.39
Net Load - Solar	-0.20	0.14	-0.66	-0.03	-0.32	-0.54	-0.65	0.08	-0.23
Load - Solar+Wind	0.18	0.31	0.31		0.18	0.13	0.36		0.34
Net Load - Solar+Wind	-0.06	0.13	-0.62		-0.09	-0.14	-0.65		-0.15
Load - Offshore Wind									-0.00
Net Load - Offshore Wind									0.10
Solar - Offshore Wind									-0.17
Onshore Wind - Offshore Wind									0.51

3. Correlation of Load, Wind, and Solar

- Monthly load, wind, and solar by Load Zone

	ME	NH	VT	CT	RI	SEMA	WCMA	NEMA	ISO-NE
Load - Wind	0.07	-0.08	0.32		-0.42	-0.43	-0.08		-0.24
Net Load - Wind	0.28	0.01	0.59		-0.24	-0.15	0.33		-0.03
Solar - Wind	-0.73	-0.66	-0.78		-0.66	-0.65	-0.80		-0.70
Load - Solar	-0.24	-0.08	-0.51	0.08	0.25	0.23	-0.03	0.13	0.06
Net Load - Solar	-0.51	-0.22	-0.81	-0.09	-0.03	-0.20	-0.53	-0.03	-0.24
Load - Solar+Wind	-0.02	-0.19	-0.52		-0.40	-0.43	-0.04		-0.26
Net Load - Solar+Wind	0.13	-0.21	-0.80		-0.31	-0.26	-0.53		-0.33
Load - Offshore Wind									-0.25
Net Load - Offshore Wind									-0.05
Solar - Offshore Wind									-0.66
Onshore Wind - Offshore Wind									0.88

3. Correlation of Load, Wind, and Solar

- Yearly load, wind, and solar by Load Zone

	ME	NH	VT	CT	RI	SEMA	WCMA	NEMA	ISO-NE
Load - Wind	0.42	0.21	-0.02		0.02	0.01	0.12		0.09
Net Load - Wind	0.42	0.22	0.01		0.03	0.04	0.12		0.10
Solar - Wind	-0.05	0.01	-0.18		-0.09	-0.21	-0.07		-0.11
Load - Solar	0.05	0.37	-0.16	0.20	0.40	0.45	0.16	0.36	0.24
Net Load - Solar	-0.02	0.32	-0.28	0.17	0.30	0.35	0.06	0.33	0.18
Load - Solar+Wind	0.42	0.32	-0.16		0.08	0.06	0.17		0.16
Net Load - Solar+Wind	0.42	0.31	-0.25		0.07	0.07	0.08		0.15
Load - Offshore Wind									0.06
Net Load - Offshore Wind									0.07
Solar - Offshore Wind									-0.18
Onshore Wind - Offshore Wind									0.63

3. Correlation of Load, Wind, and Solar

- Observations
  - On an hourly basis, wind generation within each Load Zone did not appear to be correlated to solar generation, gross load, or net load. There was a moderate positive relationship between hourly gross load and solar generation, likely due to their very diurnally dependent profiles.
  - On a monthly level, SEMA, RI, and ISO-NE exhibited a moderate negative relationship between gross load and wind, while VT exhibited a moderate positive relationship. The solar and wind relationship showed a fairly strong negative correlation for all regions while for gross load and solar there was no consistent trend across all regions.
  - Annually, gross load and solar have a moderate positive correlation for most regions, with the exception of VT. ME had a positive correlation between gross load and wind, while NH, SEMA, RI, and NEMA had moderate positive correlations between gross load and solar.
  - Hourly wind generation is moderately correlated across adjacent Load Zones but weakly correlated between further apart Load Zones. The correlation of wind across Load Zones improves with monthly averaging periods, but not annual averaging periods.

4. Representative 8760s

- Methodology
  - Distributions of the total annual energy production values for wind capacity, solar capacity, and total annual load were created for each aggregated data set.
  - The P1, P5, P10, P50, P90, P95, and P99 single year hourly (8760) time series were identified within the 20,000-year data set, such that their total energy production or load was equivalent to the specified probability of exceedance.
  - Note: The 8760s do not represent the probabilistic (PXX) values for each hourly record, rather the total annual value.
    - For example, a P99 wind generation time series represents the year where the total annual energy production of that time series falls in the 99th percentile of all 20,000 annual wind energy production values.

4. Representative 8760s

- Methodology, cont.
  - The following table presents the percentile values for each variable independently to show the range of data contained in the stochastic data

Percentile	Onshore Wind Gross (TWh)	Offshore Wind Gross (TWh)	Total Wind Gross (TWh)	Solar (TWh)	Gross Load (TWh)	Avg Wind Speed (m/s)	Avg Temp (°F)	Avg RH (%)	Avg Pressure (mb)	Avg GHI (W/m²)
P1	3.641	12.356	16.001	9.191	119.752	6.737	48.186	65.544	999.172	160.427
P5	3.686	12.522	16.193	9.431	121.871	6.776	48.584	65.901	999.324	163.883
P10	3.743	13.117	16.874	9.567	122.961	6.837	48.924	66.257	1000.173	165.155
P50	3.957	13.889	17.792	9.759	127.720	7.024	50.311	67.068	1000.881	169.684
P90	4.175	14.446	18.526	10.119	132.449	7.217	52.105	68.013	1001.426	173.973
P95	4.257	14.520	18.703	10.192	133.692	7.277	52.392	68.358	1002.692	175.633
P99	4.299	14.619	18.861	10.329	136.167	7.316	53.165	68.752	1002.973	176.508

  - Then the user could select the P1 onshore gross wind year and it would equate to realization 339 and the year 2006. The details of that 8760 are shown below

Realization 339 Year 2006	Onshore Wind Gross (TWh)	Offshore Wind Gross (TWh)	Total Wind Gross (TWh)	Solar (TWh)	Gross Load (TWh)	Avg Wind Speed (m/s)	Avg Temp (°F)	Avg RH (%)	Avg Pressure (mb)	Avg GHI (W/m²)
Value	3.641	12.540	16.170	9.910	128.411	6.738	52.031	67.414	1000.933	171.064
Percentile (%)	1.000	5.395	4.505	76.290	54.565	1.030	88.360	69.175	59.705	64.710

4. Representative 8760s

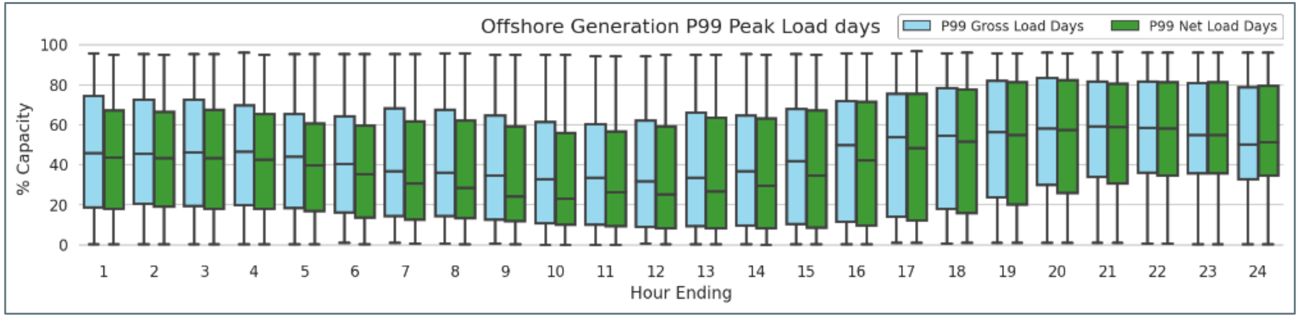
- Observations
  - Using representative 8760s for economic study analyses can provide a future alternative to using historical weather years
  - Studies can bracket system response using high(low) wind years, high(low) solar years, or high(low) load years
  - This can help provide insight to how robustly a given system design and resource mix will hold up to different types of overall yearly weather
  - Further metrics could be examined such as ranking years by resource variability using an average daily mileage metric

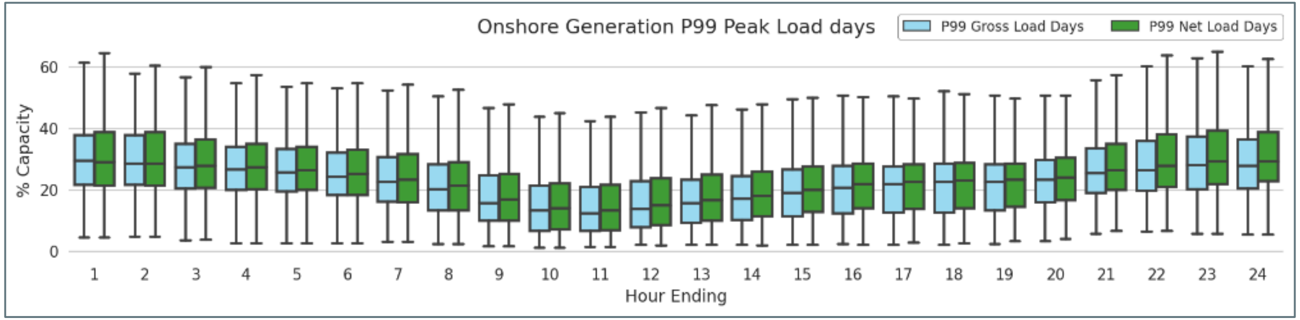
5. Wind PDFs at Peak(Min) Gross(Net) Load

- Methodology
  - Determine the upper 5th (P95) and top 1st (P99) percentiles of daily peak gross load.
  - Determine the bottom 1st (P1) and lower 5th (P5) percentiles of minimum daily gross load.
  - Find the upper 5th (P95) and top 1st (P99) percentiles of daily peak net load (gross load – energy efficiency and solar).
  - Determine the bottom 1st (P1) and lower 5th (P5) percentiles of minimum daily net load (gross load – energy efficiency and solar).
  - For the four different groups, create probability distribution functions (PDFs) for each hour of the day for onshore aggregate wind generation and the corresponding PDFs for the offshore aggregate.

5. Wind PDFs at Peak(Min) Gross(Net) Load

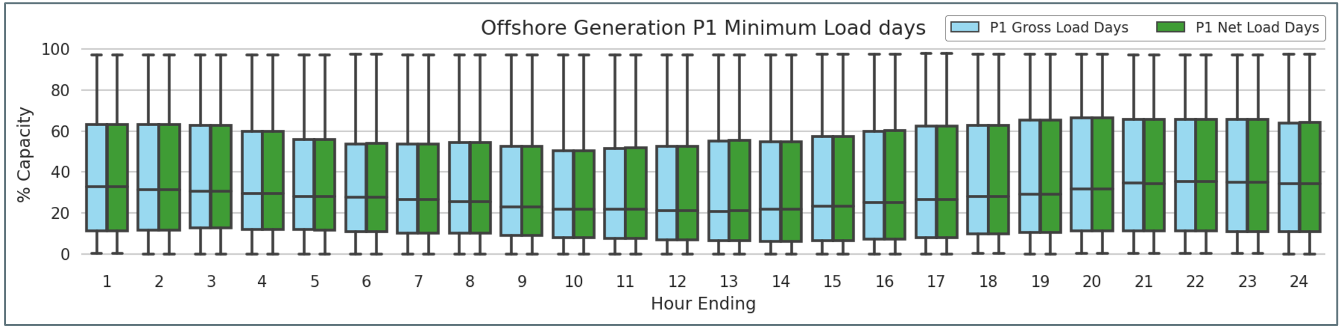
- 99th Percentile Gross and Net Peak Load Days

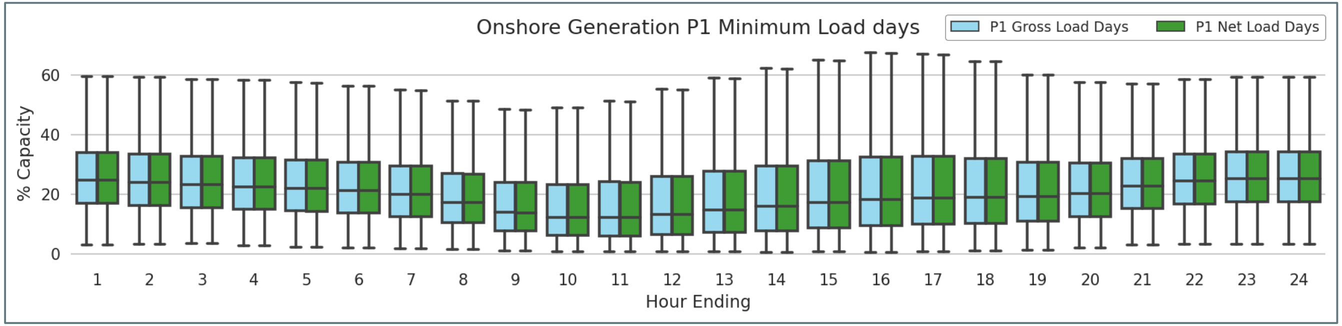




5. Wind PDFs at Peak(Min) Gross(Net) Load

- 1^{st} Percentile Gross and Net Minimum Load Days





5. Wind PDFs at Peak(Min) Gross(Net) Load

- Transmission Planning for Clean Energy Transition (TPCET)
  - The TPCET work reviewed 2019 ISO-NE VER historical data set (2012-2018) that contained 7 years worth of data (2,555 days)
  - It filtered the data by specific times of day, when specific load conditions were met, during certain months of the year (Sept 2020 PAC presentation)
    - This was a very small sample size compared to the 7.3 million day stochastic data set
  - The following slides show the stochastic data set P99 (top 73,000 days) for gross peak load and P1 (bottom 73,000 days) for min net load with their corresponding wind output values as a sanity check to TPCET values
    - Wind values did not vary significantly when filtering by gross or net loads as seen on the previous box plots
    - The stochastic data set did not further filter by months of year, or solar conditions so this is like comparing red delicious apples to granny smith apples, not quite the exact same apple, but still helpful to gain insight into the data

5. Wind PDFs at Peak(Min) Gross(Net) Load

- The TPCET wind assumptions for peak load are within the stochastic data set wind values

Base Case	Time of Day	On-Shore Wind	Off-Shore Wind
Summer Weekday Evening (July-August)	7:00 PM (HE20)	5%	5%
Summer Weekday Mid-Day Peak – Low Renewables (July-August)	5:00 PM (HE18)	5%	5%
Summer Weekday Mid-Day Peak – High Renewables (July-September)	2:00-3:00 PM (HE15-16)	30%	90%

Hour Ending	Onshore Wind During P99 Gross Load Days (% Capacity)							
	P1	P5	P10	Median	Mean	P90	P95	P99
14	4.9%	6.1%	7.1%	17.2%	19.3%	33.8%	44.3%	57.8%
15	5.4%	6.9%	8.3%	19.1%	21.1%	34.7%	48.2%	63.8%
16	5.1%	7.6%	8.8%	20.8%	22.5%	36.0%	51.8%	67.1%
17	5.2%	8.0%	9.1%	22.0%	22.8%	36.3%	52.3%	64.1%
18	4.8%	6.9%	8.3%	22.7%	22.9%	37.0%	49.9%	62.5%
19	4.7%	6.9%	8.2%	22.7%	22.9%	36.2%	50.1%	58.7%
20	5.6%	7.1%	8.2%	23.3%	23.8%	37.7%	47.4%	54.8%
21	7.9%	8.9%	10.1%	25.4%	26.3%	41.3%	48.7%	53.5%

Hour Ending	Offshore Wind During P99 Gross Load Days (% Capacity)							
	P1	P5	P10	Median	Mean	P90	P95	P99
14	1.0%	2.5%	3.5%	36.7%	39.3%	80.8%	86.8%	91.2%
15	1.0%	2.2%	3.3%	41.9%	41.7%	83.7%	88.4%	91.7%
16	1.3%	2.7%	4.1%	49.8%	45.1%	85.7%	89.3%	92.2%
17	2.3%	3.5%	4.9%	54.0%	48.0%	87.6%	90.3%	92.7%
18	2.6%	4.1%	5.6%	54.4%	49.8%	88.4%	90.6%	92.9%
19	2.1%	3.7%	5.8%	56.3%	52.1%	89.5%	91.1%	93.0%
20	2.2%	3.5%	6.3%	58.1%	53.9%	89.9%	91.4%	93.2%
21	2.1%	3.3%	6.2%	59.3%	54.8%	89.6%	91.2%	93.2%

5. Wind PDFs at Peak(Min) Gross(Net) Load

- The TPCET wind assumptions for minimum load are within the stochastic data set wind values

Base Case	Time of Day	On-Shore Wind	Off-Shore Wind
Spring Weekend Nighttime Minimum – Low Renewables (April, May, September)	3:00-5:00 AM (HE4-HE6)	5%	5%
Spring Weekend Nighttime Minimum – High Renewables (April, May, September)	3:00-5:00 AM (HE4-HE6)	65%	90%
Spring Weekend Mid-Day Minimum (April, May, September)	12:00-3:00 PM (HE13-HE16)	55%	60%

Hour Ending	Onshore Wind During P1 Net Load Days (% Capacity)							
	P1	P5	P10	Median	Mean	P90	P95	P99
3	6.2%	8.6%	10.5%	23.2%	25.1%	42.2%	49.0%	61.4%
4	5.6%	8.0%	10.0%	22.3%	24.5%	41.6%	48.4%	61.3%
5	5.2%	7.7%	9.6%	21.8%	24.0%	41.4%	48.2%	61.4%
6	4.7%	7.2%	9.1%	21.2%	23.4%	41.1%	48.1%	61.8%
7	4.1%	6.5%	8.2%	20.0%	22.4%	40.4%	47.7%	62.2%
-	-	-	-	-	-	-	-	-
12	1.6%	2.5%	3.5%	13.3%	18.1%	40.1%	50.2%	66.4%
13	1.7%	2.7%	3.8%	14.6%	19.4%	42.7%	52.3%	68.0%
14	1.9%	3.0%	4.2%	15.9%	20.6%	44.9%	54.2%	69.9%
15	1.9%	3.2%	4.5%	17.1%	21.8%	46.5%	55.9%	72.0%
16	2.0%	3.5%	5.0%	18.1%	22.8%	48.0%	57.7%	73.3%
17	2.2%	3.9%	5.4%	18.8%	23.3%	48.5%	58.1%	73.7%

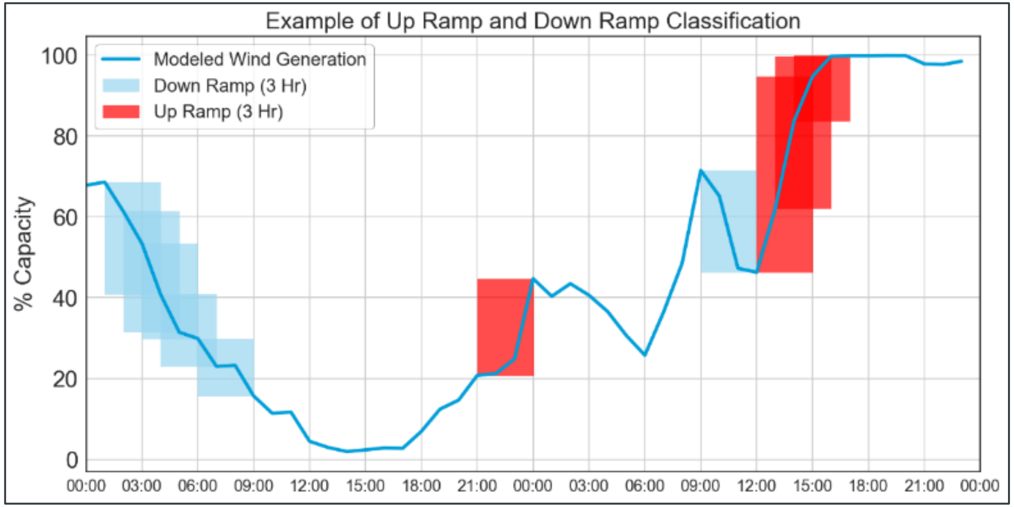
Hour Ending	Offshore Wind During P1 Net Load Days (% Capacity)							
	P1	P5	P10	Median	Mean	P90	P95	P99
3	1.0%	2.6%	4.7%	30.7%	38.1%	84.9%	89.2%	92.3%
4	1.1%	2.8%	4.8%	29.5%	37.1%	84.7%	89.3%	92.3%
5	1.2%	2.7%	4.7%	28.1%	35.8%	83.1%	89.0%	92.3%
6	1.3%	2.6%	4.2%	27.7%	35.0%	83.4%	89.2%	92.4%
7	1.3%	2.7%	4.2%	26.5%	34.6%	84.2%	89.3%	92.4%
-	-	-	-	-	-	-	-	-
12	0.7%	1.6%	2.6%	21.2%	31.8%	83.2%	88.6%	92.0%
13	0.6%	1.3%	2.2%	21.0%	32.1%	82.4%	88.4%	92.0%
14	0.6%	1.2%	2.0%	21.9%	32.1%	82.4%	88.7%	92.2%
15	0.5%	1.1%	1.9%	23.2%	33.3%	84.0%	89.2%	92.3%
16	0.7%	1.4%	2.2%	25.0%	34.7%	84.9%	89.4%	92.4%
17	0.9%	1.8%	2.9%	26.7%	36.0%	85.8%	89.7%	92.6%

5. Wind PDFs at Peak(Min) Gross(Net) Load

- Observations
  - Further refinement in filtering of the data can help provide statistical backup for variable energy resource assumptions in long-term point-in-time transmission planning studies
  - As shown on the box plot graphs, the distributions of onshore and offshore wind generation exhibit little variation during the peak and minimum gross and net load days. This is likely because the peak(min) net load days are often coincident with peak(min) gross load days, so the wind generation will be very similar.

6. Intra-day Variability of Wind and Solar

- Methodology
  - Time spans of 1, 2, 3, and 4 hours were examined. For this study, the units of generation are percent of capacity. To qualify as an up or down ramp, the time changes must be non-decreasing for up ramps (time derivative greater than or equal to zero), and non-increasing for down ramps (time derivative less than or equal to zero) over the specified time interval.
  - An example of a number of 3 hour wind ramps identified within a time series from the stochastic data set is shown in the figure. Up ramps over a 3-hour period are marked in red, and down ramps in blue.



6. Intra-day Variability of Wind and Solar

- VER up ramps by mean/max capacity and % of events over a capacity threshold

Up Ramps (% of nameplate)			
Ramp Span	Type	Mean Ramp (% Capacity)	Max Ramp (% Capacity)
1 hour	Onshore Wind	2.4%	16.6%
	Offshore Wind	4.8%	43.6%
	Solar	7.8%	30.6%
	Wind + Solar	3.4%	20.8%
2 hours	Onshore Wind	5.4%	26.5%
	Offshore Wind	10.6%	63.1%
	Solar	15.4%	49.6%
	Wind + Solar	8.5%	34.6%
3 hours	Onshore Wind	8.7%	35.0%
	Offshore Wind	17.7%	74.4%
	Solar	21.9%	65.8%
	Wind + Solar	14.4%	45.0%
4 hours	Onshore Wind	12.1%	41.6%
	Offshore Wind	25.4%	81.1%
	Solar	26.5%	78.9%
	Wind + Solar	20.2%	53.9%

Ramp Span	Capacity Threshold	Up Ramps (% Events)		
		Onshore	Offshore	Wind + Solar
1 Hour	> 15%	0.0%	6.0%	0.6%
	> 20%	0.0%	2.4%	0.0%
	> 25%	0.0%	0.9%	0.0%
	> 30%	0.0%	0.3%	0.0%
2 Hours	> 15%	2.4%	25.5%	21.0%
	> 20%	0.4%	15.1%	9.8%
	> 25%	0.1%	8.8%	2.3%
	> 30%	0.0%	5.0%	0.2%
3 Hours	> 15%	12.0%	49.2%	44.3%
	> 20%	3.7%	36.0%	30.9%
	> 25%	1.0%	25.6%	19.4%
	> 30%	0.2%	17.7%	9.3%
4 Hours	> 15%	28.4%	68.0%	60.5%
	> 20%	12.2%	56.1%	49.2%
	> 25%	4.7%	45.0%	38.4%
	> 30%	1.6%	35.2%	26.8%

6. Intra-day Variability of Wind and Solar

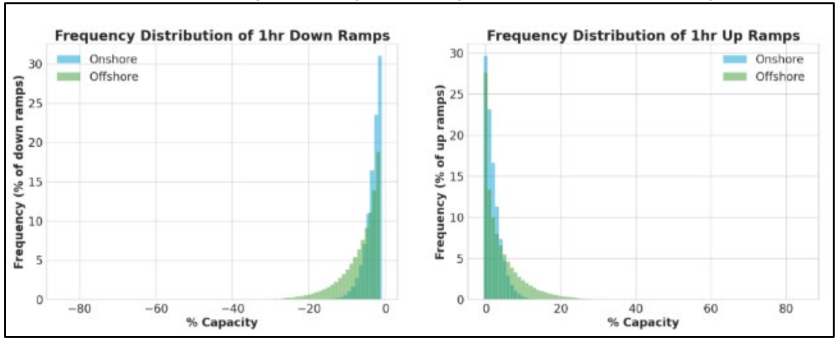
- VER down ramps by mean/max capacity and % of events over a capacity threshold

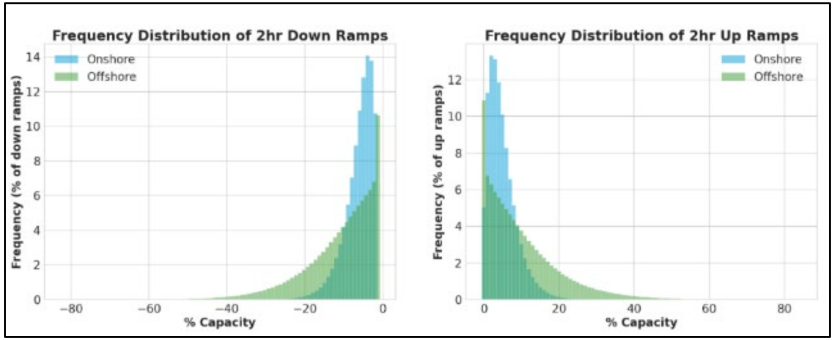
Down Ramps (% of nameplate)			
Ramp Span	Type	Mean Ramp (% Capacity)	Max Ramp (% Capacity)
1 hour	Onshore Wind	-2.4%	-16.6%
	Offshore Wind	-4.7%	-38.9%
	Solar	-7.7%	-29.5%
	Wind + Solar	-3.3%	-20.1%
2 hours	Onshore Wind	-5.4%	-26.8%
	Offshore Wind	-10.1%	-55.7%
	Solar	-15.2%	-49.4%
	Wind + Solar	-8.1%	-34.6%
3 hours	Onshore Wind	-8.6%	-34.2%
	Offshore Wind	-16.6%	-67.7%
	Solar	-21.6%	-65.0%
	Wind + Solar	-13.8%	-47.0%
4 hours	Onshore Wind	-11.9%	-39.6%
	Offshore Wind	-23.6%	-75.3%
	Solar	-26.5%	-78.8%
	Wind + Solar	-19.6%	-56.2%

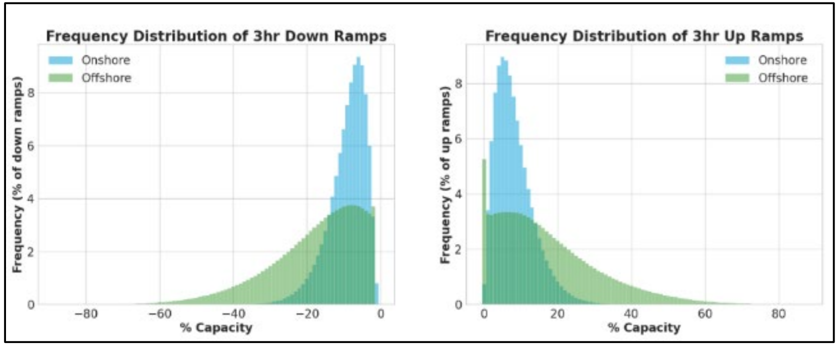
Ramp Span	Capacity Threshold	Down Ramps (% Events)		
		Onshore	Offshore	Wind + Solar
1 Hour	> 15%	0.0%	5.5%	0.6%
	> 20%	0.0%	2.0%	0.0%
	> 25%	0.0%	0.7%	0.0%
	> 30%	0.0%	0.2%	0.0%
2 Hours	> 15%	2.3%	24.1%	18.9%
	> 20%	0.4%	13.6%	8.1%
	> 25%	0.1%	7.3%	2.0%
	> 30%	0.0%	3.8%	0.3%
3 Hours	> 15%	11.4%	47.2%	41.5%
	> 20%	3.4%	33.5%	28.7%
	> 25%	0.9%	22.8%	16.8%
	> 30%	0.2%	14.9%	7.4%
4 Hours	> 15%	27.0%	65.8%	58.2%
	> 20%	11.4%	53.1%	47.7%
	> 25%	4.1%	41.4%	36.2%
	> 30%	1.2%	31.2%	23.9%

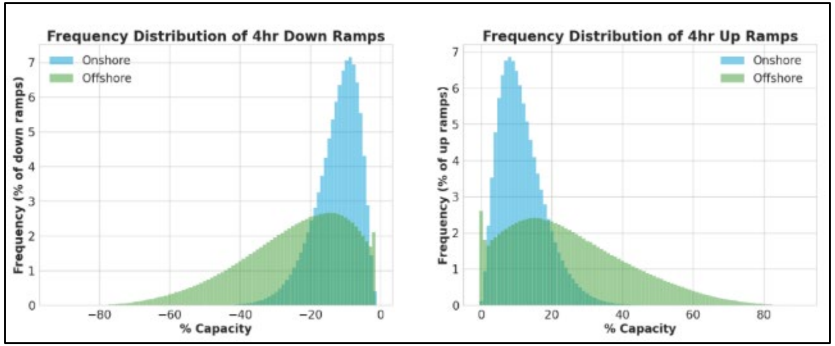
6. Intra-day Variability of Wind and Solar

- VER ramp frequency distribution plots









6. Intra-day Variability of Wind and Solar

- The following table shows the total mileage of the variable resource during a given day. Mileage is defined as the sum of the absolute value daily 24 1-hour ramps

Region Source	Average Mileage Per Day (% Capacity)	Maximum Mileage Per Day (% Capacity)
Onshore Wind	58.8%	156.0%
Offshore Wind	114.2%	444.8%
Solar	106.1%	197.2%
Wind + Solar	82.1%	172.8%

6. Intra-day Variability of Wind and Solar

- Observations
  - Offshore wind ramps are typically twice as large as onshore wind ramps, most likely due to lack of geographic diversity of offshore wind
  - Understanding the amount of ramping mileage of variable energy resources can help plan for how much regulation would be needed on the system to match the variability

2021 VER DATA SERIES

Historical 2020 Data Update and New Facility Additions

2021 VER Data Series – Historical 2020 Update

- The ISO worked with DNV GL to update the 2020 historical data set (2000-2019) and add historical weather for 2020 to augment the model to 21 years (2000-2020)
- Additional historical output from load, wind, and solar will also be reviewed to update the bias and calibration of the models

2021 VER Data Series – New Facility Additions

- In addition to the annual update, the ISO had budget to add new hypothetical wind and solar facilities to explore resource diversity in areas where the region currently doesn't have any existing facilities
  - Note: The new hypothetical wind and solar facilities are NOT included in the stochastic data set described earlier
- In an effort to balance available budget and interest in modeling new hypothetical plants, the following facilities were added to the historical model
  - Six new hypothetical 1,200 MW offshore wind plants off the coast of MA, NH, & ME
    - Located in Federal waters up the coast from southeast of Cape Cod to the Canadian border
  - Four new hypothetical onshore wind plants in previous cluster study regions
    - Two 600 MW facilities, one in Western Maine and one in Central Maine
    - Two 1,200 MW facilities in Northern Maine
  - Seven new hypothetical 100 MW utility scale solar facilities
    - One in VT, NH, MA, CT, and RI and two in ME
    - Located in vicinity of existing or proposed utility scale facilities
- Note: These facilities' locations do not indicate an ISO preference or any indication on feasibility of interconnection. They are for hypothetical purposes only to examine the diversity of wind/solar resources in regions that currently do not have an existing facility

2021 VER Data Series – New Facility Additions, cont.

Offshore Wind Plant	Latitude	Longitude	Hub Height (m)	Wind Plant Capacity (MW)	State
Cape Cod	41.46250	-69.5742	150	1,200	MA
Boston	42.27708	-70.2728	150	1,200	MA
Seabrook	42.82307	-70.2638	150	1,200	NH
Wyman	43.72208	-69.0470	150	1,200	ME
Bar Harbor	44.22864	-67.8431	150	1,200	ME
Calais	44.50961	-66.9413	150	1,200	ME

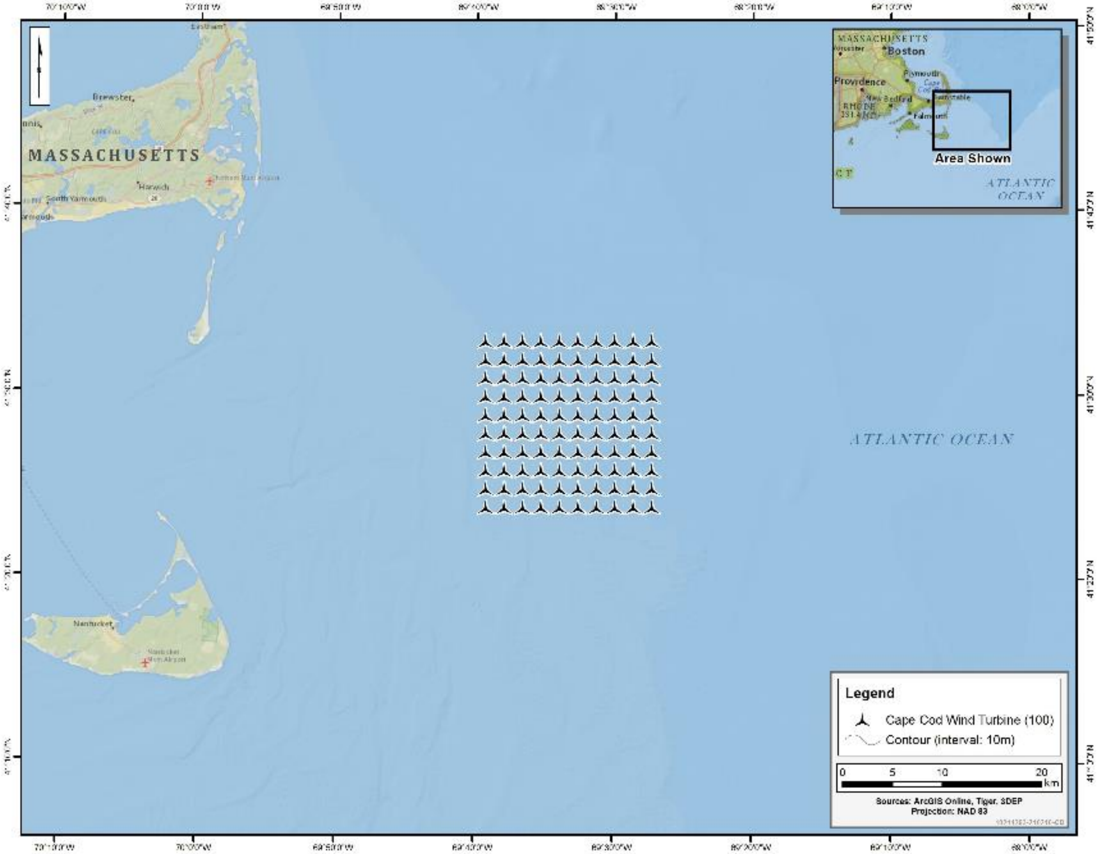
Onshore Wind Plant	Latitude	Longitude	Hub Height (m)	Wind Plant Capacity (MW)	State
Maine South	44.60497	-70.8989	120	600	ME
Maine Central	45.07148	-70.0202	120	600	ME
Maine North 1	46.12256	-68.5006	120	1,200	ME
Maine North 2	46.91812	-68.1691	120	1,200	ME

Utility Solar Plant	Latitude	Longitude	Approx. Elevation (m)	Solar Plant Capacity (MW)	State
Spencer	42.28559	-72.0101	259	100	MA
Cranston	41.73384	-71.5282	85	100	RI
Hartford	41.88470	-72.5482	50	100	CT
Carroll	44.03158	-71.0348	125	100	NH
Addison	44.17892	-73.2494	59	100	VT
Hancock	44.43843	-68.5905	90	100	ME
York	43.38082	-70.9327	119	100	ME

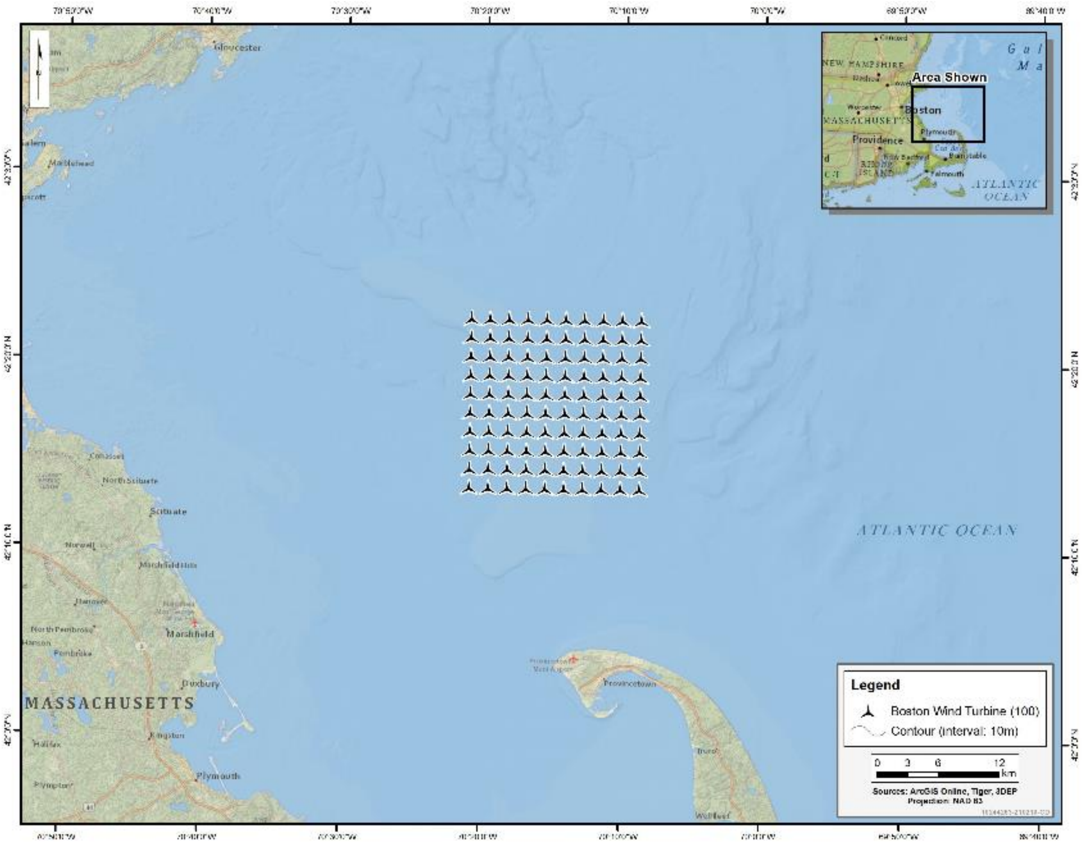
New Offshore Wind Plants

- For the 6 new offshore wind plants, DNV GL has created hypothetical turbine layouts based an assumed 1x1 nautical mile spacing similar to the current BOEM lease area proposal.
- For the offshore wind plants, DNV GL has utilized the proxy GE 12 MW turbine. The proxy 12 MW power curve was used for the GE Haliade-X turbine and is largely based on the SG 8.0-167 and Vestas/MHI V164-10 MW power curves.
- A hub height of 150 m has been assumed for the offshore wind plants.

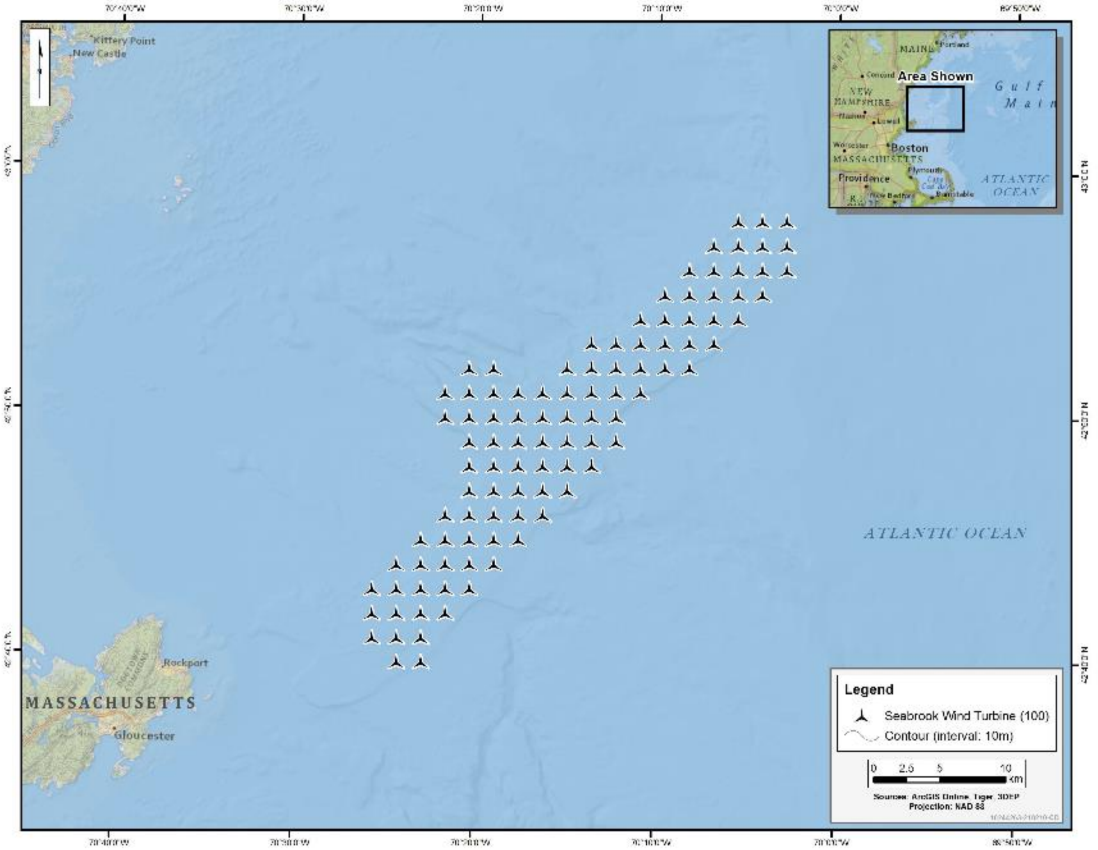
Cape Cod Offshore Wind



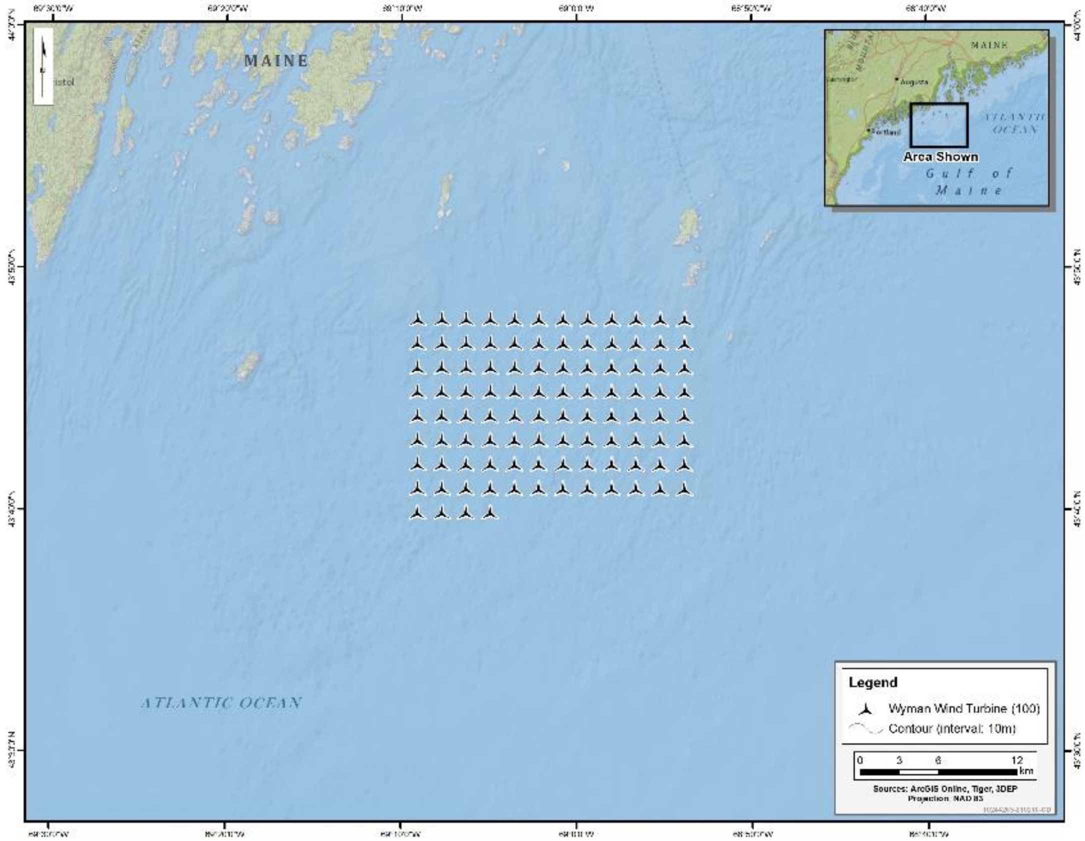
Boston Offshore Wind



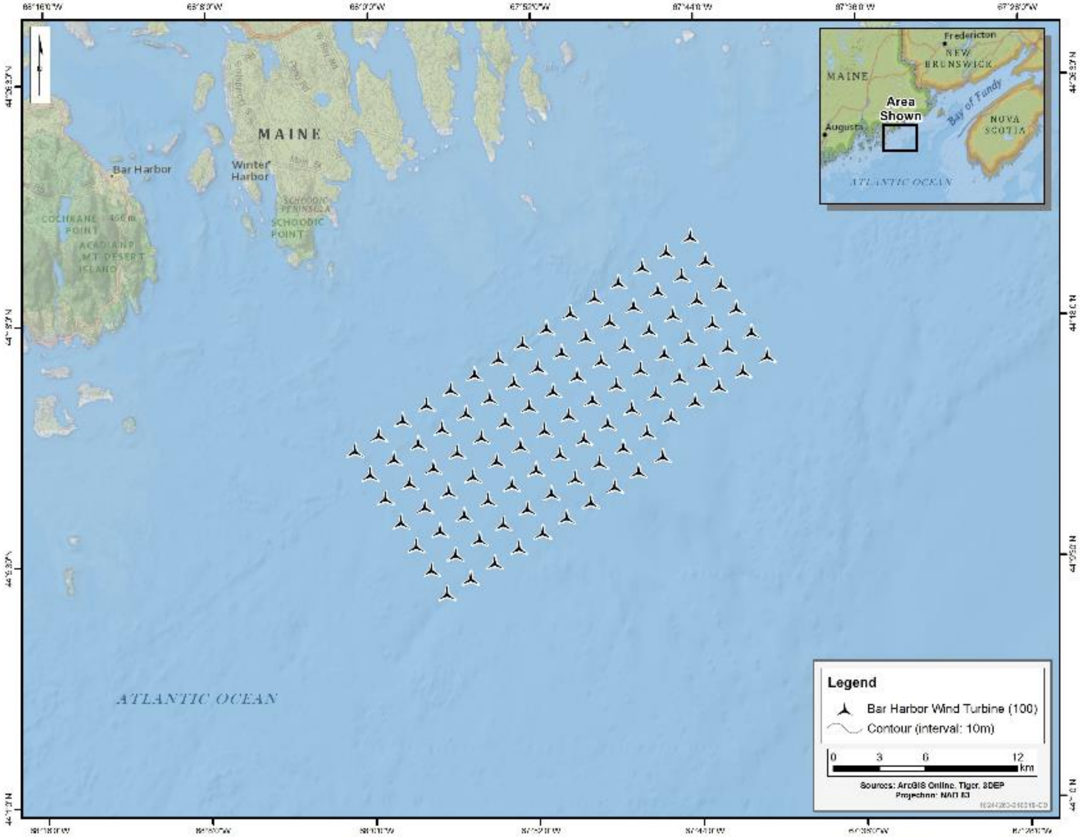
Seabrook Offshore Wind



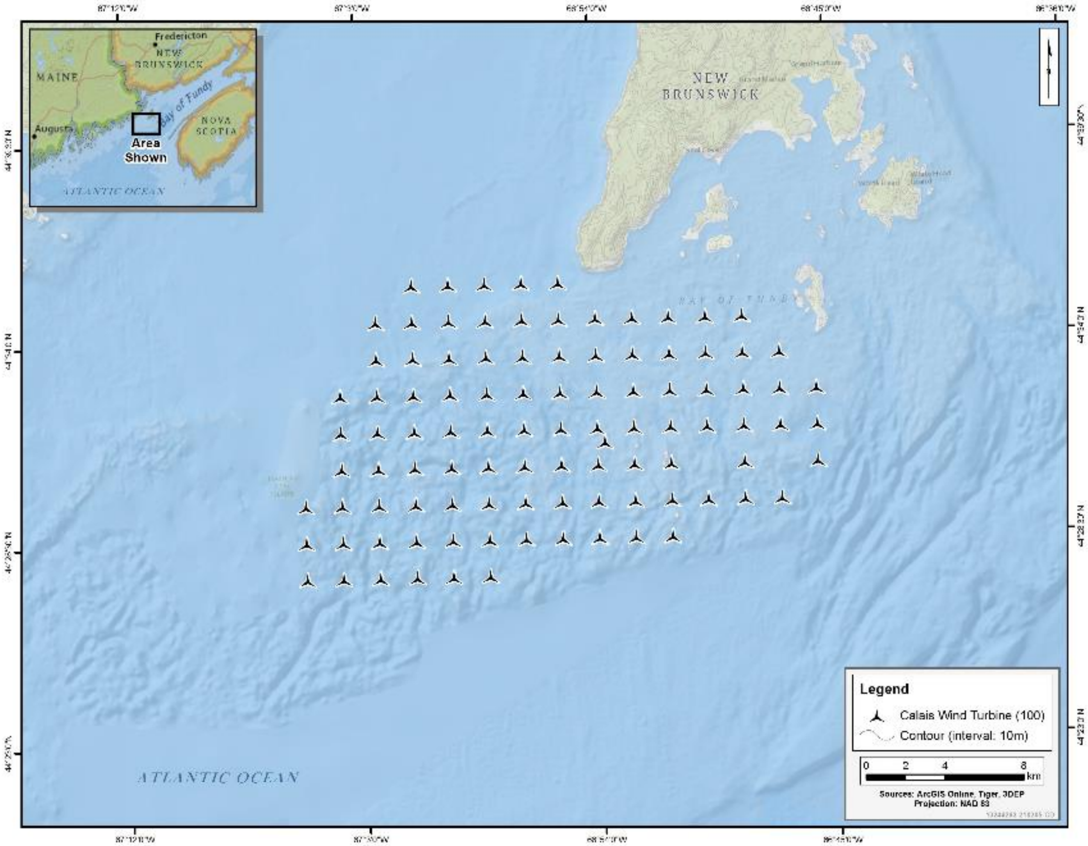
Wyman Offshore Wind



Bar Harbor Offshore Wind



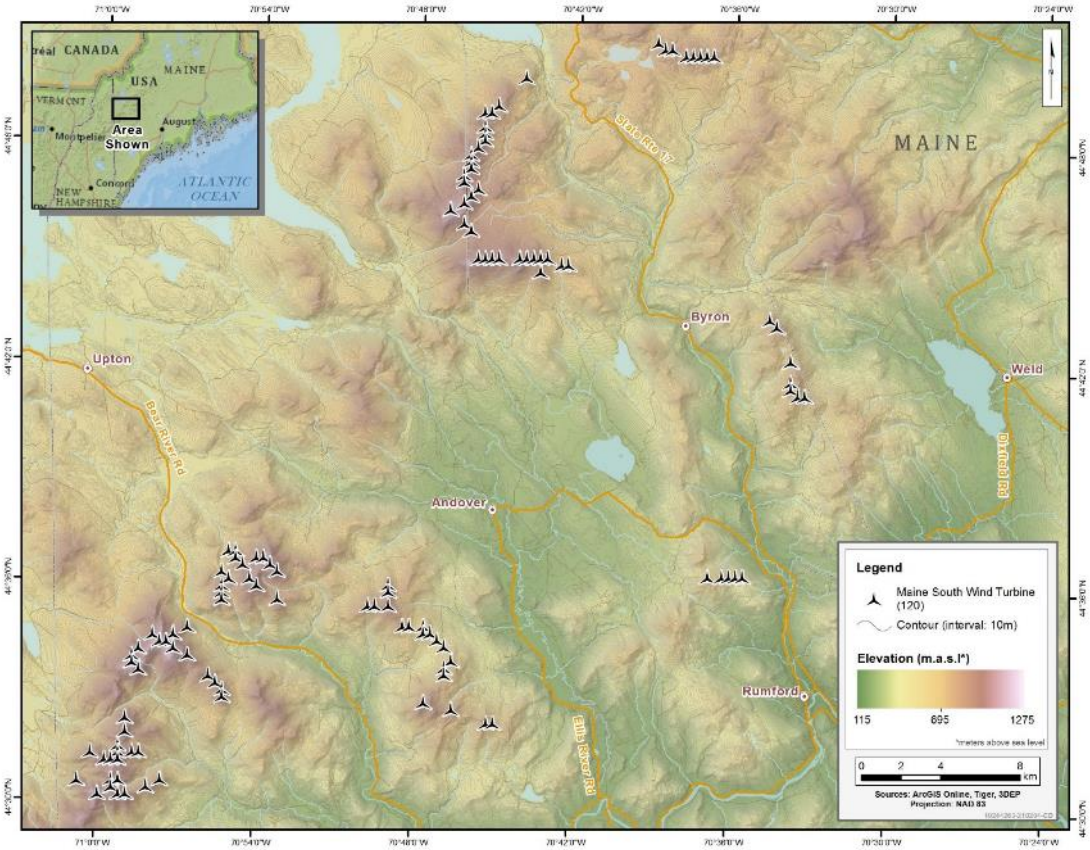
Calais Offshore Wind



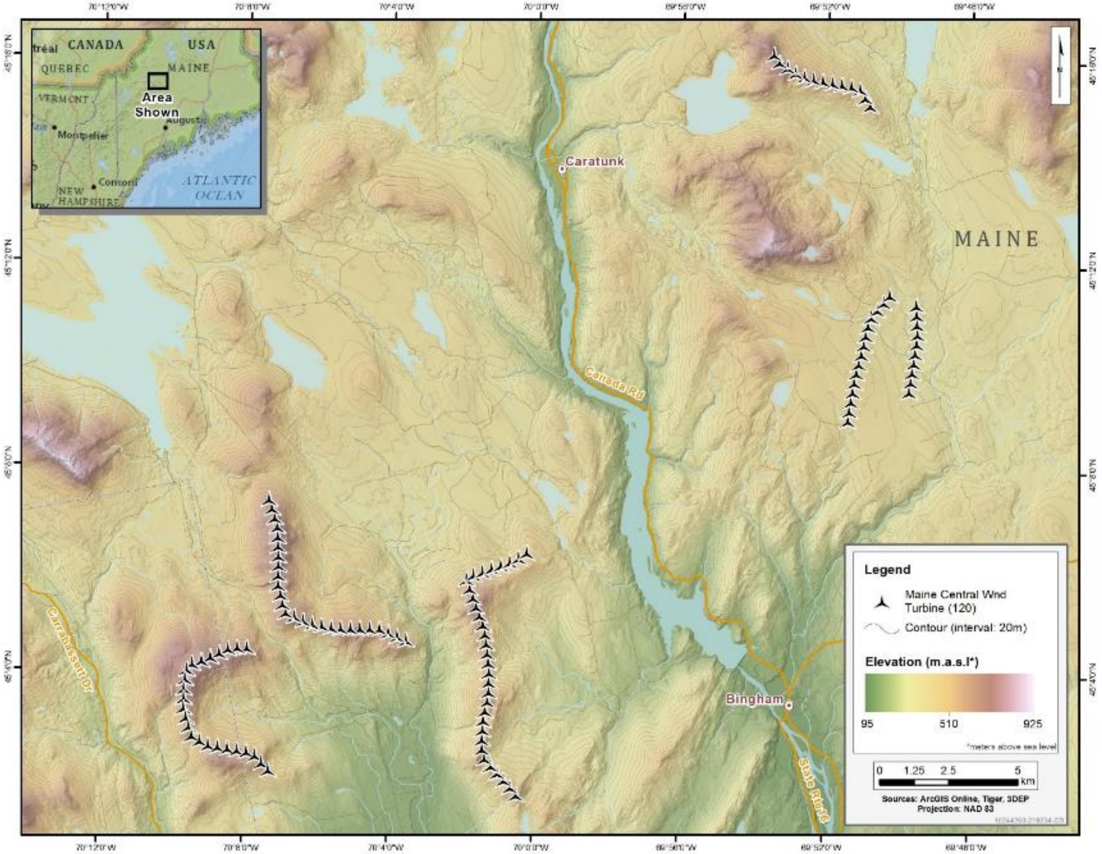
New Onshore Wind Plants

- For the 4 new onshore wind plants, DNV GL has created hypothetical turbine layouts.
- Based on publicly available information, DNV GL believes an onshore turbine similar to the Nordex N149 4.5 MW or Vestas V162-5.6 MW turbine will be available in the next several years.
- As a specific turbine model has not been defined for the onshore modeling, and there are currently few publicly available large onshore turbine power curves, DNV GL has created a proxy 5 MW turbine power curve based on their understanding of the likely performance of future large-scale turbines.
- A hub height of 120 m and rotor diameter of 160 m has been assumed for the onshore wind plants.

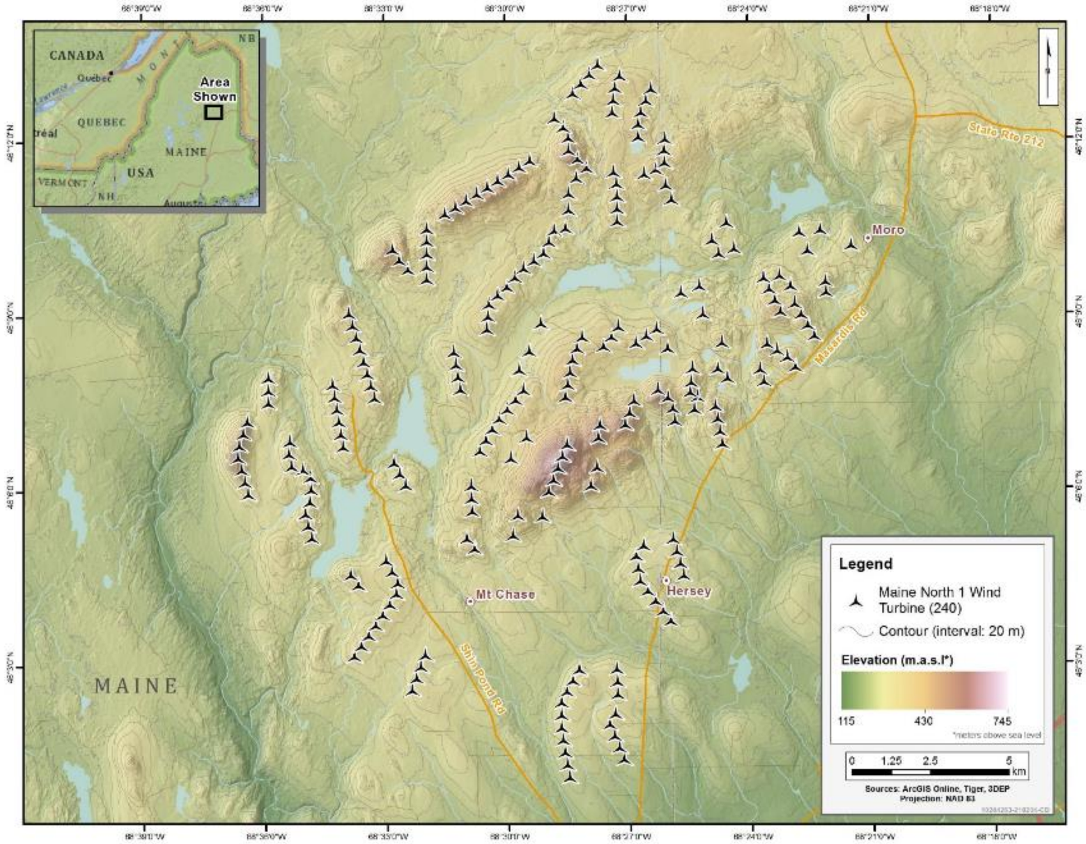
Maine South Onshore Wind



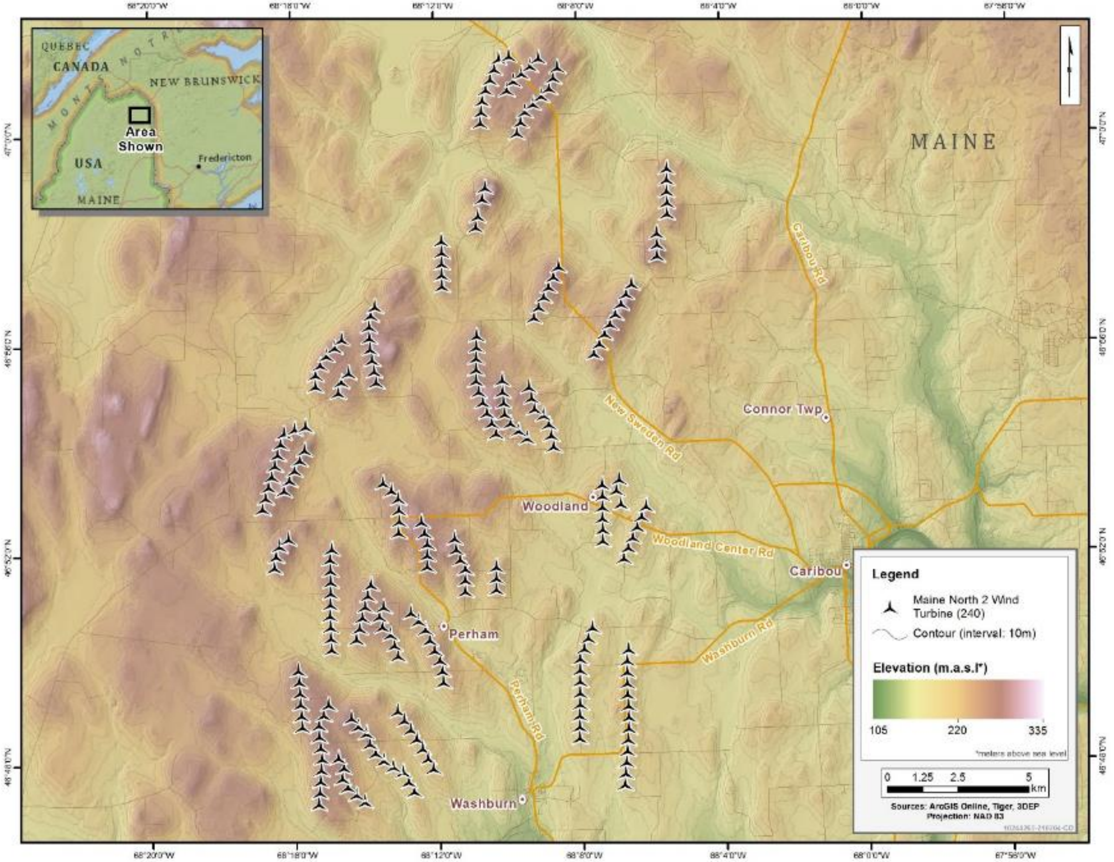
Maine Central Onshore Wind



Maine North 1 Onshore Wind



Maine North 2 Onshore Wind



New Utility Scale Solar Plants

- ISO-NE has provided approximate locations for the 7 hypothetical utility scale solar plants throughout New England in the vicinity of existing or proposed facilities
- An approximate solar array size of 1 km^2 is used
- The following assumptions were made for each solar plant

Parameter	Value
AC Capacity	100 MW
Maximum Panel Tilt	60 degrees East-West
Array Axis Tilt	0 degrees (horizontal)
Array Axis Azimuth	0 degrees
Panel Module Type	Monocrystalline Silicon
Inverter Type	Central Inverter
Mounting System	Ground Mounted Single Axis Tracker
DC/AC ratio	1.3

Timeline

- The 2021 ISO-NE VER data set (2000-2020) with the new facilities is expected to be posted on the PAC website in the March-April 2021 timeframe
  – Similar to previous releases, the wind power data will be aggregated into a single onshore and single offshore profile to avoid any market sensitive data related to wind-to-power curves

Questions