WHEN TRUST MATTERS

Probabilistic Time Series Modeling

Chris Hayes, Principal Meteorologist, DNV

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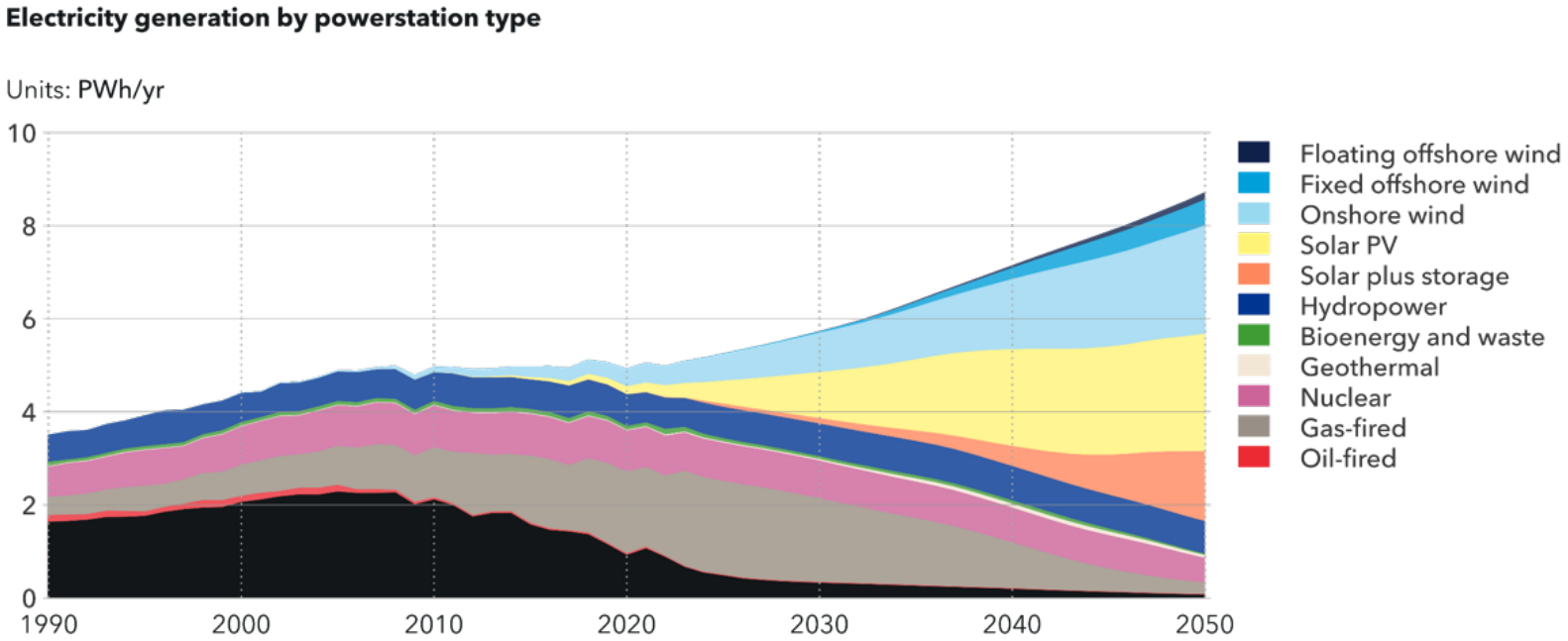
Increasing Variable Energy Resources (VER)

- Challenges:
  - Availability of wind/solar during peak demand
  - Balancing transmission and resource variability
  - Increased electrification
- Risks
  - Wind + Solar Lulls
  - Extreme Events (duration)



2023 DNV Energy Transition Outlook: North America

95+ GW of combined wind and solar planned in coastal regions

Need for time series and stochastic modeling

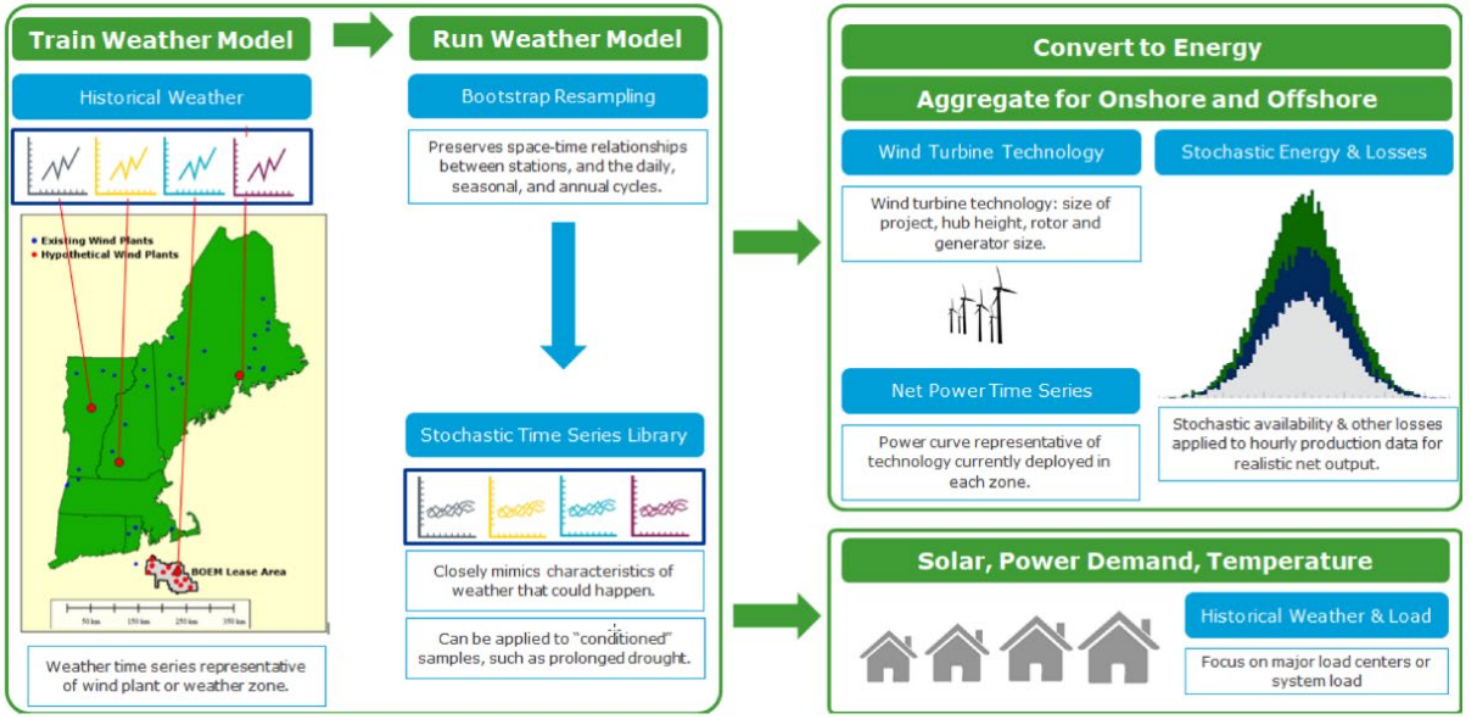
- **Historical data alone cannot capture rare events such as:**
  - Prolonged cold snaps and heat waves
  - Extended periods of low wind or solar generation
  - Misalignment between resource availability and energy demand
- **Realistic time series production modeling:**
  - Project specific
  - Mesoscale modeling, satellite-based irradiance
  - Loss modeling:
    - Turbine wakes, availability
  - Technology:
    - Wind turbine, PV tracker type

	Modeled Wind Speed Bias	Modeled Wind Speed MAE	R-Squared to Obs
Mean	-0.04 m/s	0.05 m/s	0.90
Stdev	0.06 m/s	0.05 m/s	0.01

	Modeled Energy [% Difference]	Modeled NCF Difference
Mean	-2.0%	-0.9
Stdev	8.0	3.0

Robust Energy & Co-Variability Modeling

- **DNV Stochastic Engine**
  - Bootstrap resampling approach
  - 20,000 years of plausible hourly weather [**1.75 million hours**][1]
  - Preserves daily, seasonal, and annual patterns
  - Maintains correlations with related datasets and projects
  - Coincident, physically realistic time series across all projects

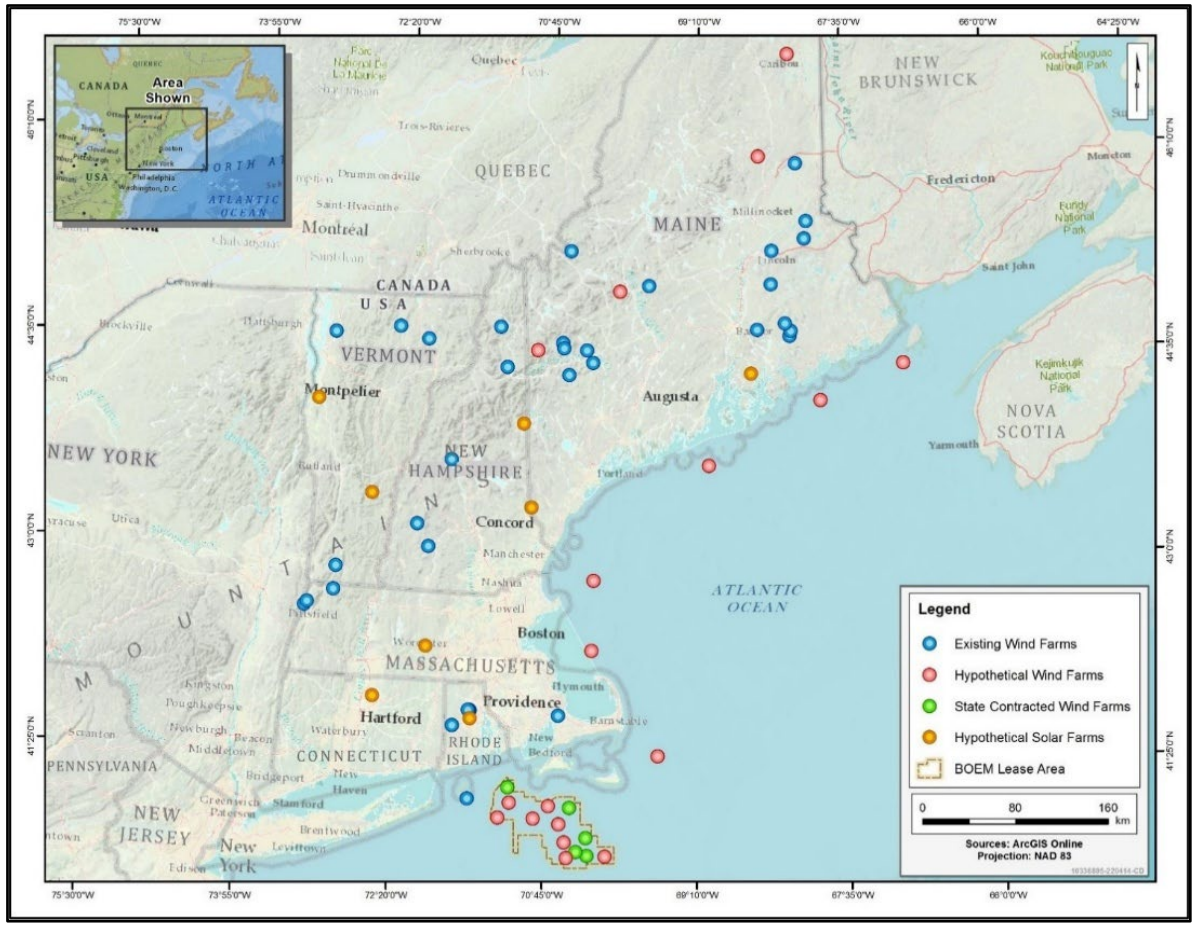


- BTM solar
- Utility solar
- Onshore / Offshore Wind
- Load
- Net Load
- Weather

1. https://www.iso-ne.com/static-assets/documents/2021/03/a9_stochastic_time_series_modeling_for_isone_rev_2.pdf

Example application: ISO-NE

- Support for:
  - Economic planning, energy security, Transmission planning, resource adequacy, capacity accreditation
- Existing datasets insufficient
  - Limited historical record
  - Non-coincident wind/solar
  - No coverage for offshore lease areas
- Offshore wind concerns
  - Voltage control challenges[1]
  - Nearly ½ system peak load (12 GW)
  - System critical hours



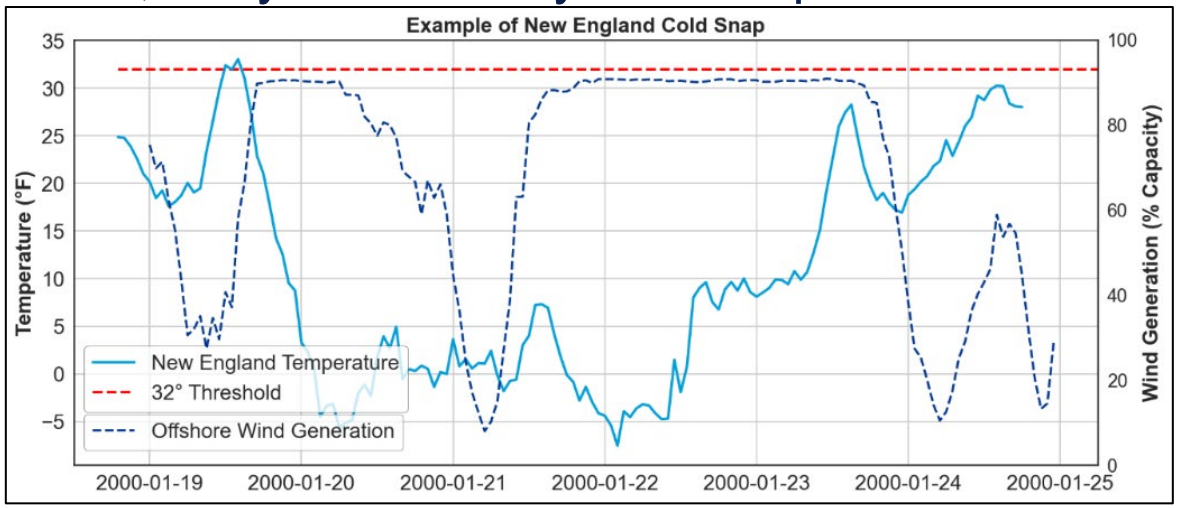
1. https://www.iso-ne.com/static-assets/documents/2020/02/a7a_wind_power_time_series_isone.pdf

Stochastic dataset enables robust analysis

- Reliability of VER during cold snaps / heat waves
- Probability of wind and solar droughts
- Correlation of load, wind and solar
- Probabilistic 8760's (P90, P10, etc)
- Distributions of wind at min load
- Intra-day variability of VER (ramping)

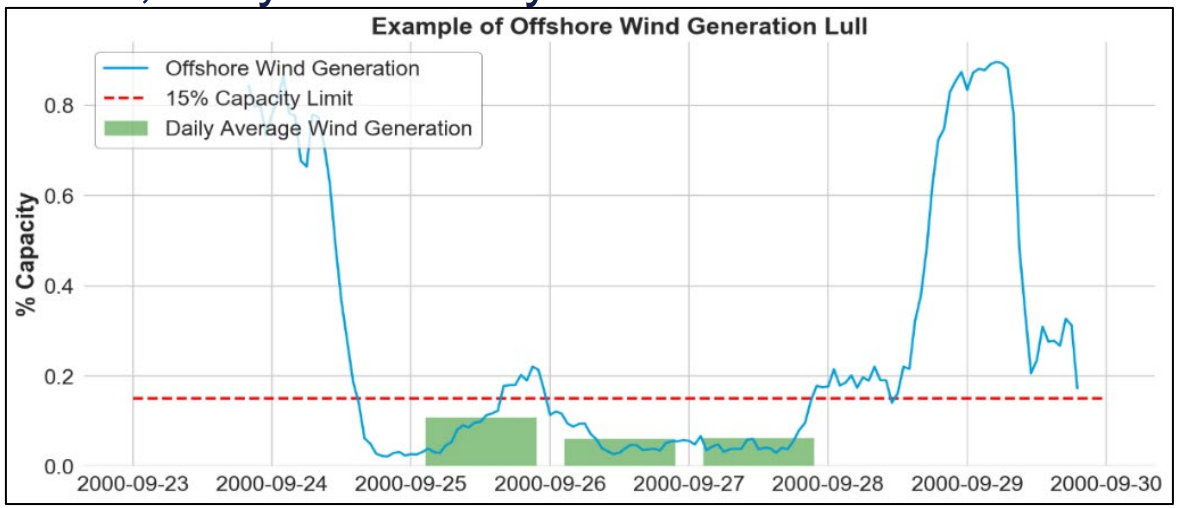
Reliability during cold snaps / heat waves[1]

- 20-years: 16-day cold snap
- 20,000 years: 24-day cold snap



Probability of wind and solar drought[1]

- 20-years: 6-day wind lull (< 15% capacity)
- 20,000 years: 9-day wind lull



1. https://www.iso-ne.com/static-assets/documents/2021/03/a9_dnv_gl_report_analysis_of_stochastic_dataset_for_iso_ne_rev1.pdf

Planning Studies

Transmission Planning for the Clean Energy Transition (TPCET)[1]

- 10th/90th percentile for offshore wind conditions.
- Increased offshore wind assumption from 60% to 90%
- Higher output for offshore wind than past assumption
- Wind generation during peak load events

Resource Adequacy Screen and Probabilistic Resource Availability Analysis[2]

- Future Grid Reliability Study (FGR)
- GE Multi-Area Reliability Simulation (MARS)
- Probabilistic Resource Availability Analysis
  - Randomly select from multiple hourly profiles during the simulation
  - Reflect the variable output under different weather conditions

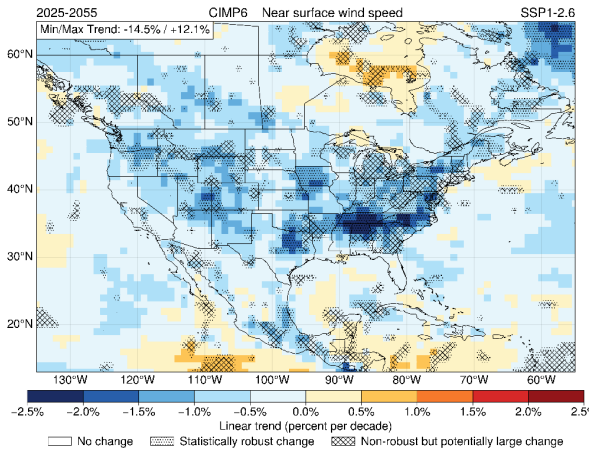
1. https://www.iso-ne.com/static-assets/documents/2021/08/a3_transmission_planning_for_the_clean_energy_transition_pilot_study_results_and_assumption_changes.pdf
2. https://www.iso-ne.com/static-assets/documents/2021/09/a6_fgrs_assumptions_for_resource_adequacy_screen_and_probabilistic_resource_availability_analysis.pdf

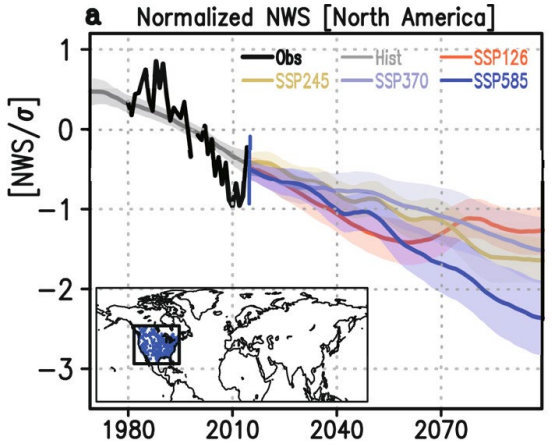
DNV

Climate Change Impacts

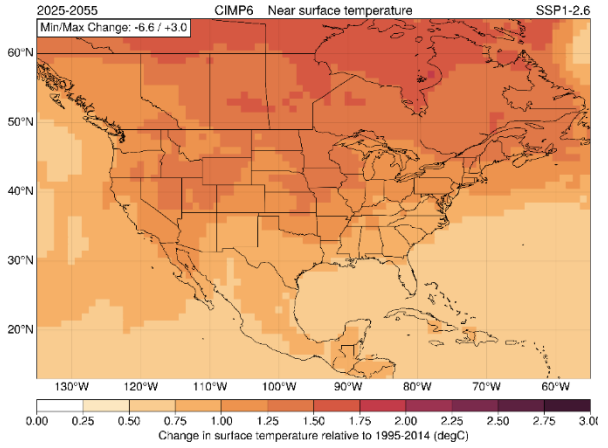
- Current dataset does include potential impacts of future climate change.
- Resource and load impacts from increasing temperature and electrification
- Recent studies indicate likely decreases in surface wind speeds and increases in solar irradiance across some regions.
- DNV is actively working to investigate and develop solutions to help address future risk.

Projected changes in near-surface wind speed

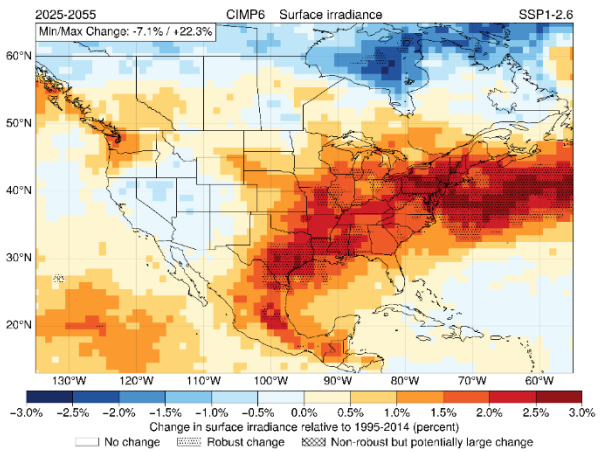




Projected changes in near-surface temperature

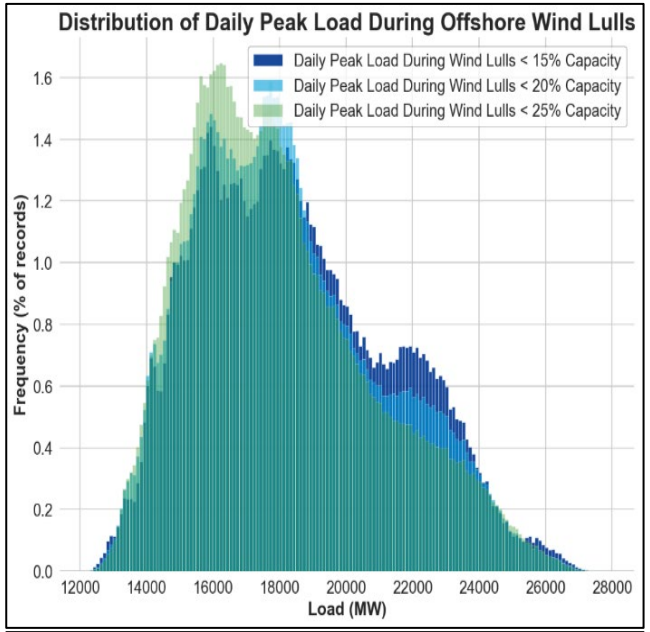


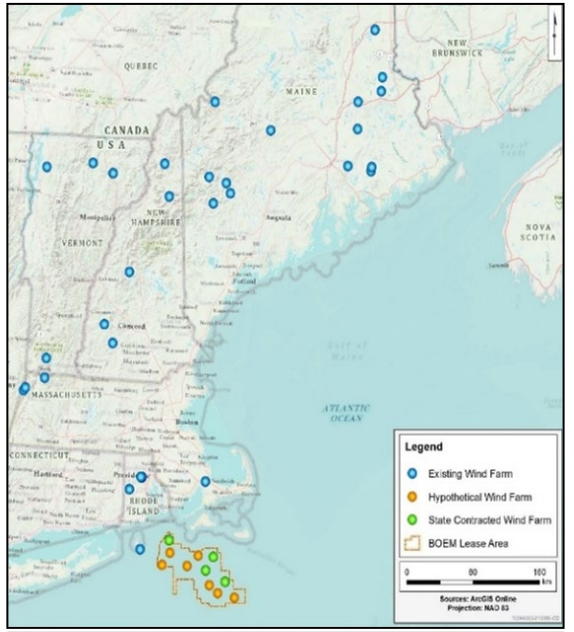
Projected changes in solar irradiance

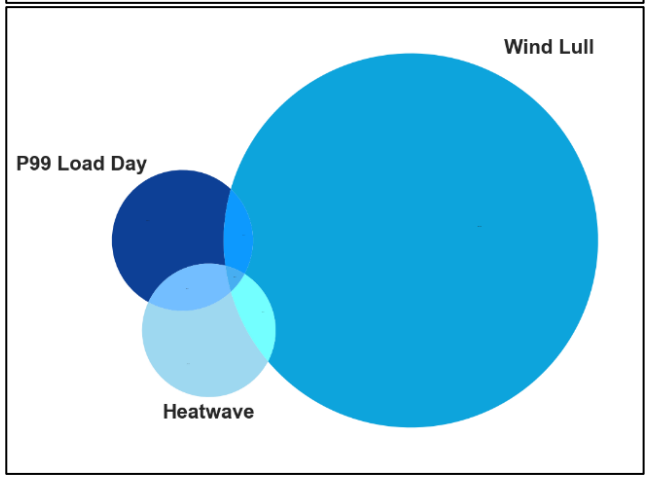


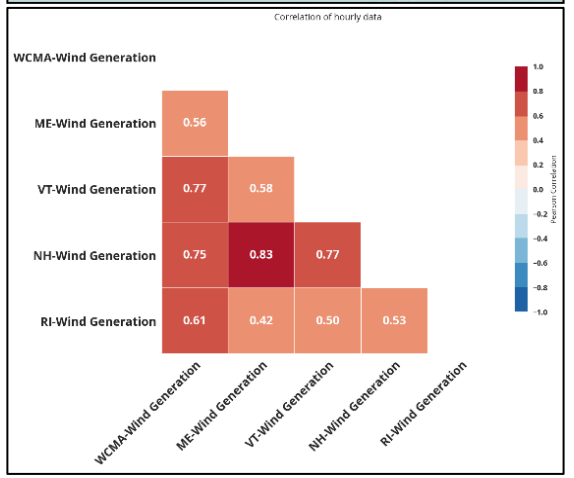
Conclusions

- Short-term datasets unable to capture rare events
  - Durations of cold snaps, heat waves and wind lulls
- Need to account for uncommon events
  - Extended duration cold snaps, heat waves
  - Overlapping weather events and periods of high demand
- TPCET assumptions of wind generation during peak load events confirmed
- Increased geographic diversity and resource mix can reduce lulls impacting grid / energy reliability
- High solar generation during wind lulls helps mitigate power demand impact.
- Coincidence is key









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