Electric Grid Reliability Implications for a Near-Zero Emissions Energy System

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Abstract

Wind and solar energy technologies are, by their nature, variable. Variations in resource availability, based on weather patterns, occur on intra-day to inter-annual time scales. Many energy system models optimize over a single year of input weather and electricity demand data. Energy system planners need increased understanding of the variability in generation potential across multiple years and how this could impact model results. A system achieving 100% reliability modeled using Year A data will not necessarily achieve 100% reliability when applied to Year B data unless an overbuild safety margin is added. We demonstrate: 1) model results can vary significantly based on the year of data used, 2) adding wind and solar does not necessarily reduce the predictability of meeting reliability targets year-to-year and can improve predictability in many cases, and 3) we illustrate a method to derive safety margins to predictably meet 100% reliability year after year and find the least-cost option.

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Introduction

Wind and solar energy technologies are, by their nature, variable. Variations in resource availability, based on weather patterns, occur on intra-day to inter-annual time scales. Many energy system models optimize over a single year of input weather and electricity demand data. Energy system planners need increased understanding of the variability in generation potential across multiple years and how this could impact model results. A system achieving 100% reliability modeled using Year A data will not necessarily achieve 100% reliability when applied to Year B data unless an overbuild safety margin is added.

The Model

- We model **a zero-carbon** energy system including wind, solar, nuclear, and storage technologies
- Use least-cost optimization
- Quantify performance based on
  - **Reliability,**

$$\text{reliability} = \frac{\text{total annual supplied electricity}}{\text{total annual demanded electricity}}$$

- **Unmet demand** = 1 - reliability

Model Inputs

- Four full years of hourly wind, solar, and demand data for **continental US**
- Levelized costs of electricity (LCOE) of fixed and variable costs for wind, solar, nuclear

Input	Description	Source
Wind data	Mean availability 0.42	Derived from MERRA-2
Solar data	Mean availability 0.27	Derived from MERRA-2
Demand data	**Normalized to mean of 1 kW**	EIA, July 2015 – Aug. 2019

Tech	Fixed Cost	Variable Cost	Source
Wind	0.021 ($/h)/kW	0.0 $/kWh	EIA (2019)
Solar	0.022 ($/h)/kW	0.0 $/kWh	EIA (2019)
Nuclear	0.065 ($/h)/kW	0.023 $/kWh	EIA (2019)
Storage	0.0042 ($/h)/kWh	0.0 ($/h)/kWh	EIA (2019)

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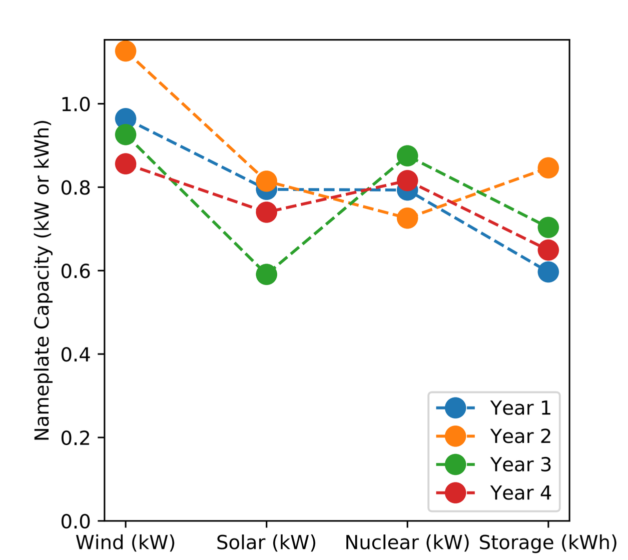
We demonstrate:

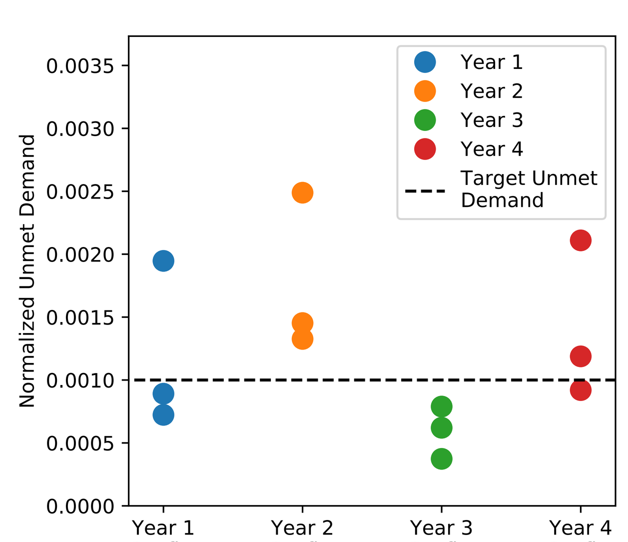
1. **Model results can vary significantly** based on the year of data used
2. **Adding wind and solar** does not necessarily reduce the predictability of meeting reliability targets year-to-year **and can improve predictability** in many cases
3. We illustrated a method to derive **safety margins** to predictably meet **100% reliability** year after year and find the **least-cost** option

Quantifying Variations in Model Results

We optimize 4 independent system configurations using the 4 years of data

- Generate least-cost installed capacities for system meeting 99.9% reliability
- The coefficient of variation, σ/μ, for installed capacities ranges from 0.067 to 0.13
- **Results scaled per kWh demand**





- Resulting configuration from Year 1 is applied to years 2, 3, and 4 for a **reliability test**
- Same for other configurations, 12 reliability tests in total

Optimizing the model on Year 2 leads to a less reliable system in alternate years, while optimizing on Year 3 yields better performance in alternate years.

We use σ/μ of the unmet demand to quantify predictability

- σ/μ = 0.51 in this case

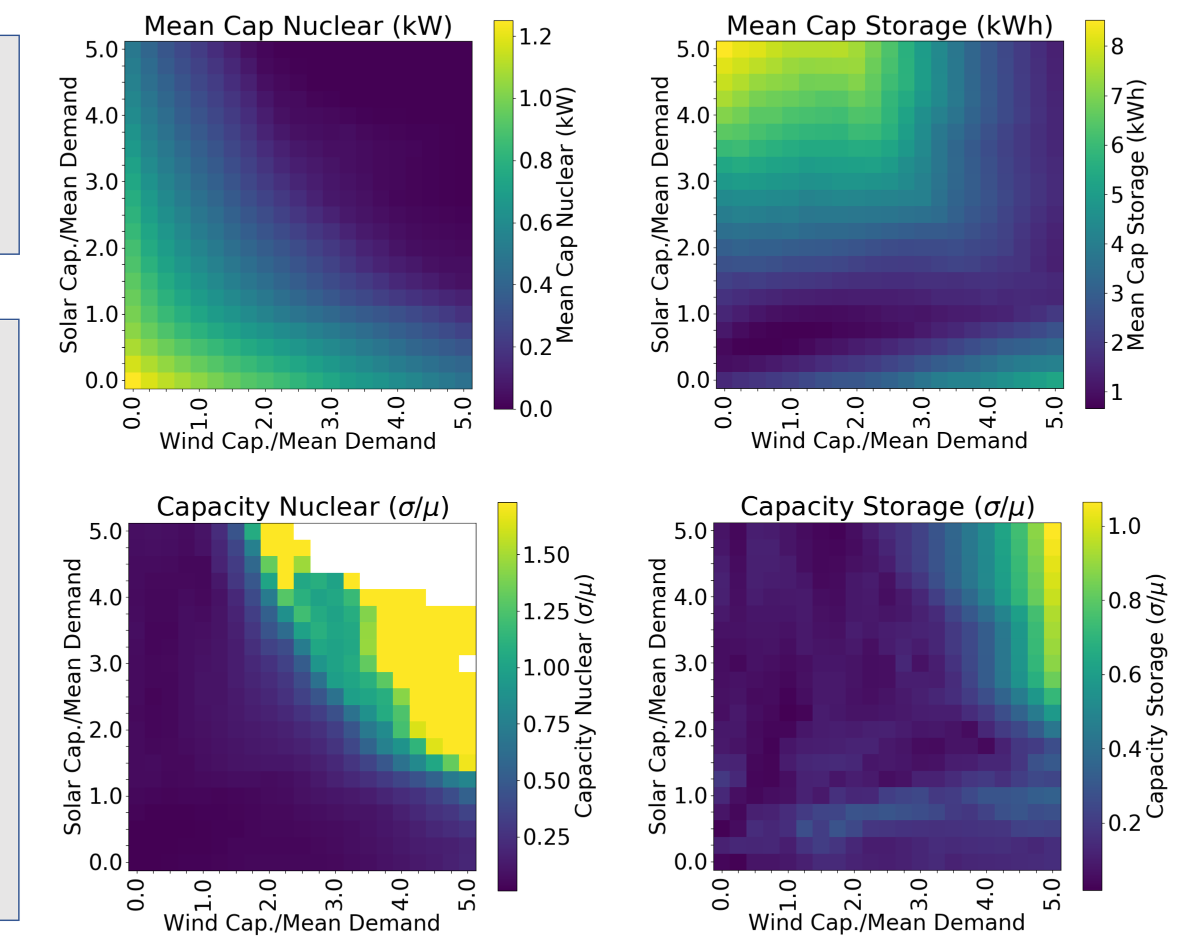
Renewables and Model Differences

- Scan across fixed solar and wind installed capacities
- Optimizes nuclear and storage capacity to deliver 99.9% reliability

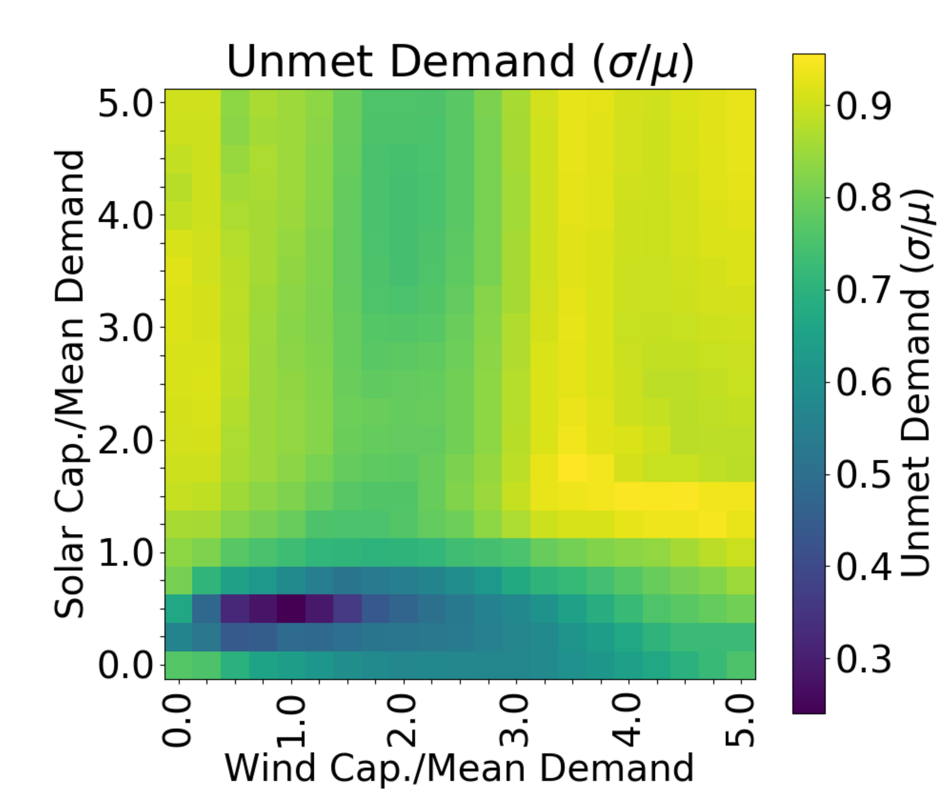
- Nuclear phases out with increasing wind and solar (top left)
- Storage, in general, increases with increasing wind and solar (top right)

The σ/μ of the capacities (bottom row) show:

1. **The models never yield identical configurations**
2. The spread in capacity values in general increases with more wind and solar



Predictability of Performance



The reliability of a model generated with Year 1 data applied to years 2, 3, and 4 is quantified using σ/μ of the unmet demand

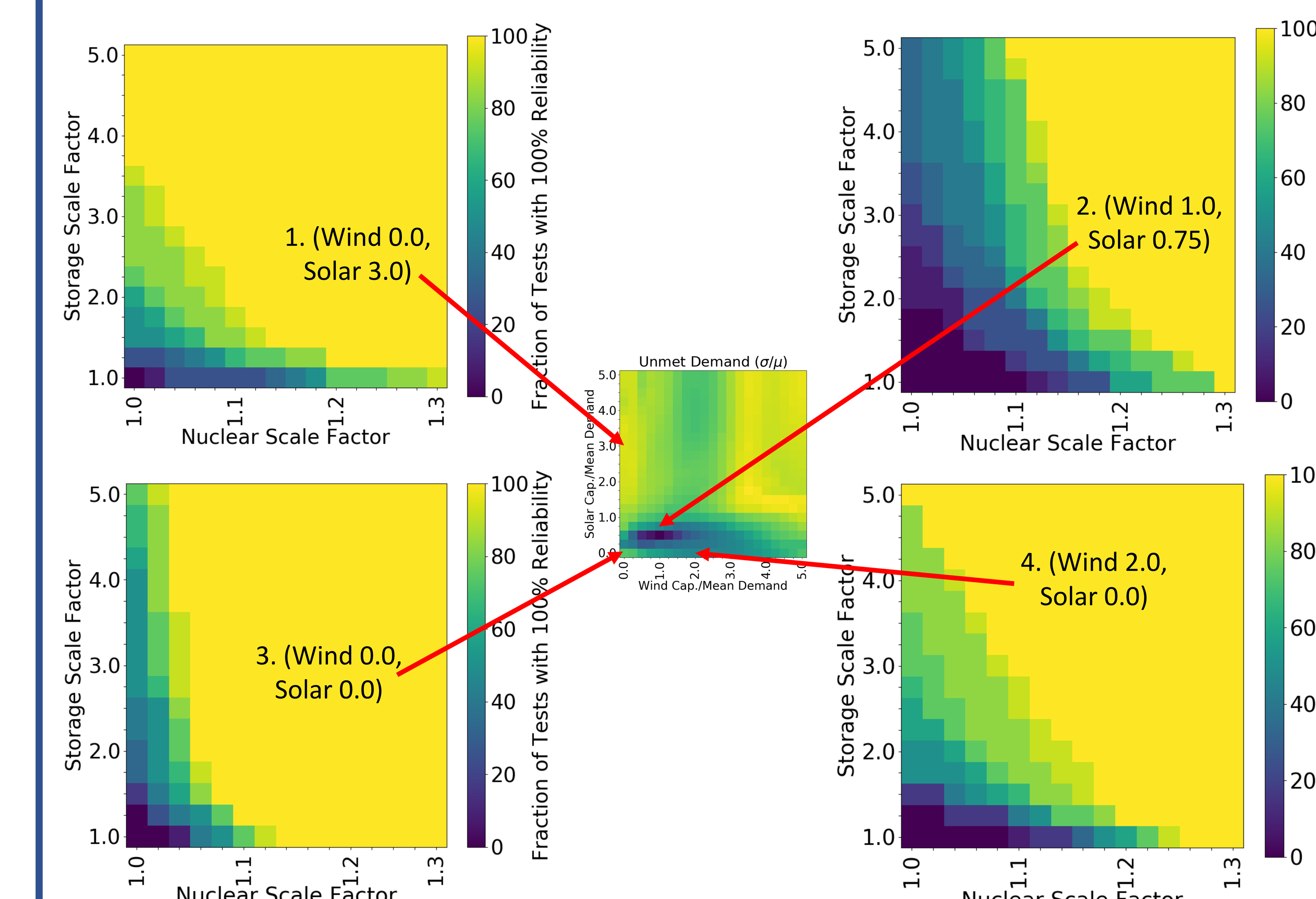
- Initial reliability = 99.9%
- Additions of wind and solar, away from the origin, lead to more stable performance year-to-year
- **There is a "trough" of stability (wind ~1.0, solar 0.5) where model performance is most similar and predictable**
- Increasing wind and solar beyond the "trough" leads to more divergent performance indicated by rising values

Predictability Safety Margins

Wind and solar, and the storage technologies to enable them, complicate the process of planning for a highly predictable, very reliability grid. We explore a method to estimate **safety margins** that achieve **100% reliability over 100% of our data**.

- Begin with the lease-cost configuration for each of the 4 years achieving 99.9% reliability
- For nuclear and storage, multiplying initial capacity by safety factor and test reliability
- Explore 4 scenarios:
  1. Considerable solar, no wind
  2. Least-cost case
  3. Zero wind, zero solar
  4. Considerable wind, zero solar

A variety of overbuild options are always available to achieving 100% reliability in 100% of our tests



Least-Cost Predictable Reliability

The levelized cost of electricity (LCOE) shows the least-cost overbuild option.

- **Black** text values are mapped to the 100% reliability in 100% of tests threshold (see above panel)
- **Red** values highlight the original 99.9% system and least-cost 100%/100% option
- **White** values are all that remain

Consider two examples with similar initial conditions:

- Scenario A) – (same as 2 from above) wind 1.0, solar 0.75, the original least-cost cfg.
- Scenario B) from the most predictable "trough" region, wind 1.0, solar 0.5

The least-cost 100%/100% option is not derived from the least-cost 99.9% system