The Urgent Need for Comprehensive, Curated, Fit-For-Use, Weather and Climate Intelligence to Support the Energy Transition

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Power Systems Use Cases

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Sharply Focused
Understanding Renewable Resources

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

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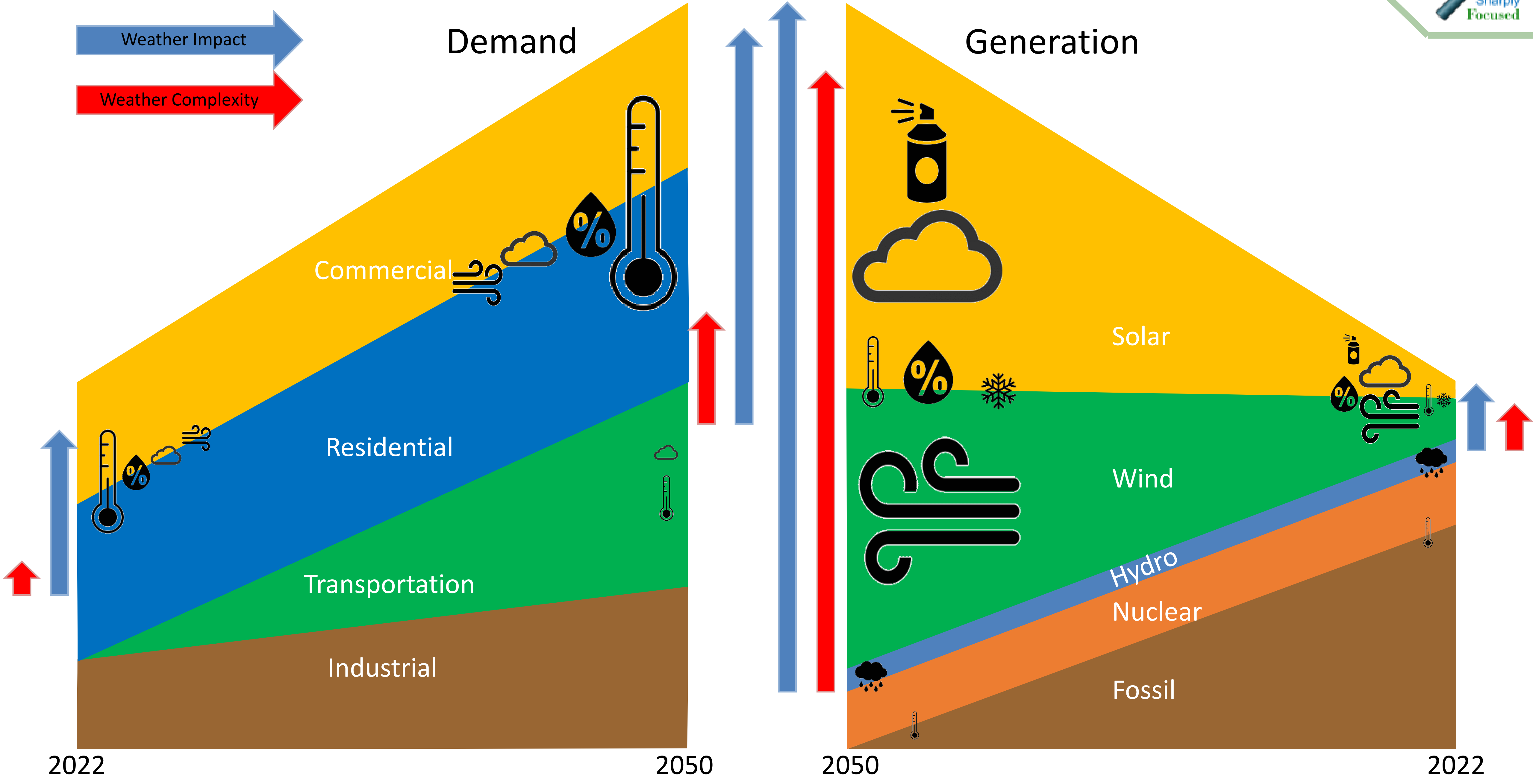
The Imperative for Weather Intelligence Dedicated to Supporting the Energy Transition

ESIG

- Current data are inadequate to assess increasing weather dependence
- A transdisciplinary approach is needed
- This is an ongoing operational need, not a research project
- Validation are uncertainty quantification are critical weaknesses
- Risk $$$’s are orders of magnitude high than investment $’s needed

The Evolving Weather - Energy Nexus



• Our Weather “Intelligence” is Inadequate

<u>Producer(s)</u>

Create initial and ongoing gridded archives

Bias correction

Ongoing generic R&D

Gridded Weather Data

- Physically consistent weather variables
- Multi-decadal, with ongoing consistent extension and uncertainty quantified
- Periodically refreshed
- **Insufficient resolution for general power systems use**

<u>Users</u>

End-use application of data

• We Need Vision, Investment & Leadership

SF Vision For A Holistic Weather Data Support Framework For The Electric System

Producer(s)

Create initial and ongoing gridded archives
Bias correction
Coordinate with curators on access

Curator

Facilitate data access
Provide uncertainty information
Document, guide, and educate

Gridded Weather Data

- Physically consistent weather variables
- Multi-decadal, with ongoing consistent extension and uncertainty quantified
- Periodically refreshed
- At a fidelity that can represent actual grid conditions (supply, demand, T&D)

Ground Truth Data

- Weather and power data from RE fleet
- Dedicated power system field environmental data

Ongoing Oversight:

- Requirements gathering/update
- Trans-disciplinary coordination
- Feedback facilitation
- R2O Coordination

Validator(s)

QA/QC of validation data
Validation and uncertainty quantification of gridded data
Coordinate with producers/curators

Users

End-use application of data
Provision of fleet data as appropriate

Ongoing Sector Specific R&D

Methodological improvements
Refresh Recommendations

Weather Dependence and Complexity are Increasing Rapidly

Weather/Climate Are Becoming Central

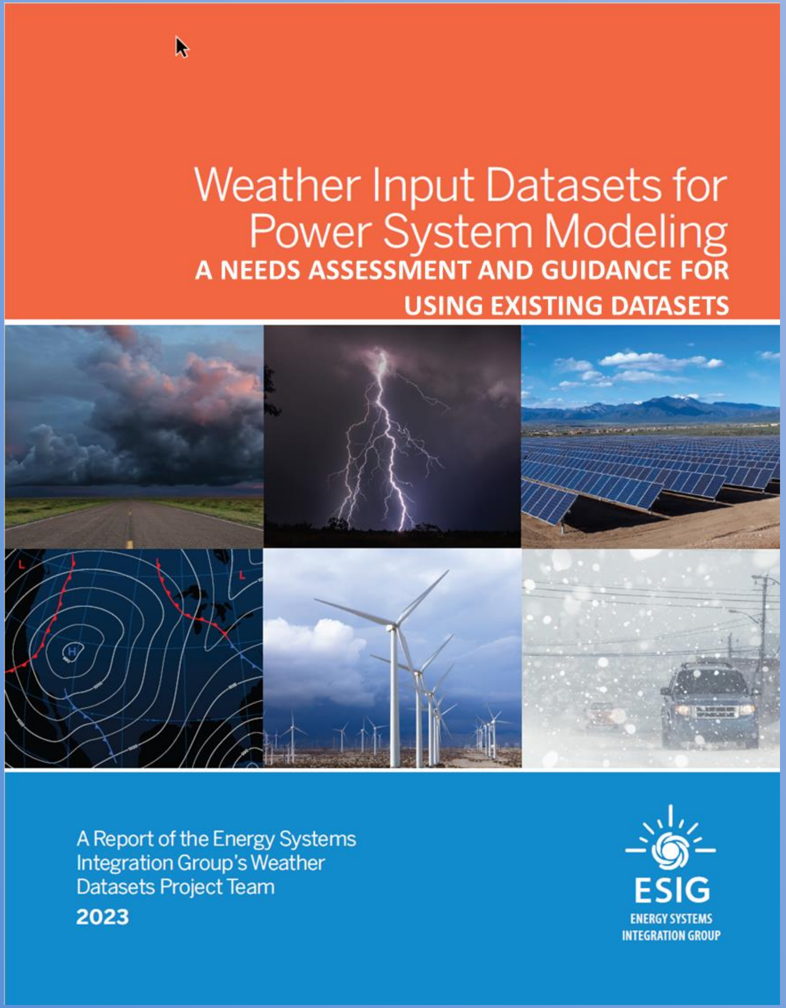
Yet We Are Largely Flying Blind

There is an Imperative for Dedicated, Accurate, and Expertly Curated Weather Information to Support the Energy Transition!

The risks resulting from inaction:

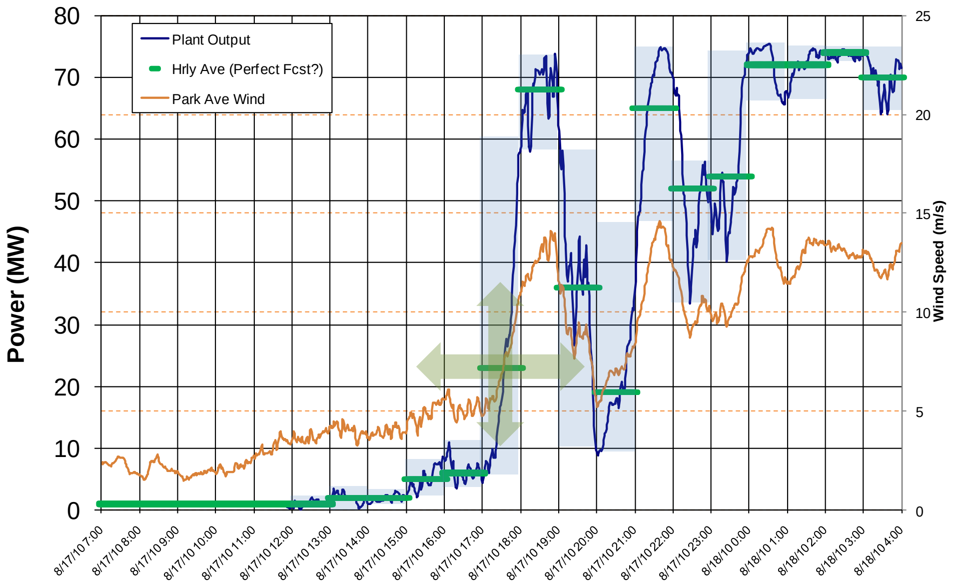
- Reliability issues tied to renewables
- Slowed/halted decarbonization
- Inefficient system design and planning

Risk $$$'s are orders of magnitude higher than task investment $'s



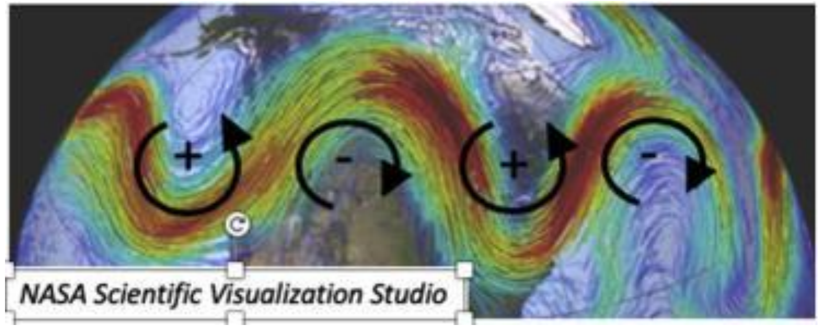
Scan for report landing page

Weather Dependence Must Be Managed/Mitigated



Variability and Uncertainty

- Mostly due to weather at high RE penetration
- Operational forecasts reduce uncertainty
- Forecasts cannot reduce variability. Planning success depends characterizing and addressing variability ahead of operations.



Ad-hoc Mitigation

- Energy Storage/P2G
- Overbuilding/fossil backup
- Not efficient or cost effective.
- May not meet policy goals.

Informed Mitigation

- Recognizes continental scale
- Builds T&G accordingly
- Requires high-quality, high-resolution, meteorological data
  - Current data is inadequate (pun intended) for the job.

Power System Models Have Always Incorporated Weather but Treatment was Relatively Simple and Mostly Concerned Load

Each dataset is regarded as being independent, so simple Monte Carlo techniques can be used

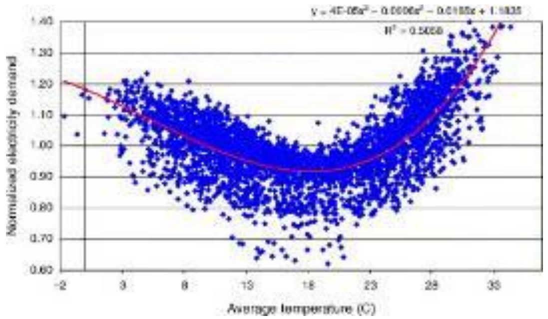
Often no connection between outages and weather

The connection between weather and load is usually manifest in relatively simple temperature relationships.

Hydro Years
Typically based on historical data
(Illustrative example. Can iterate through addition and/or other constraints)

Outage Probability Data
Historical average time to failure

Load Timeseries
Usually synthesized based on historical usage, how usage varies with temperature, and projected load growth.
Long temperature records => long load records



Hydro Year Draw

Outage Draw

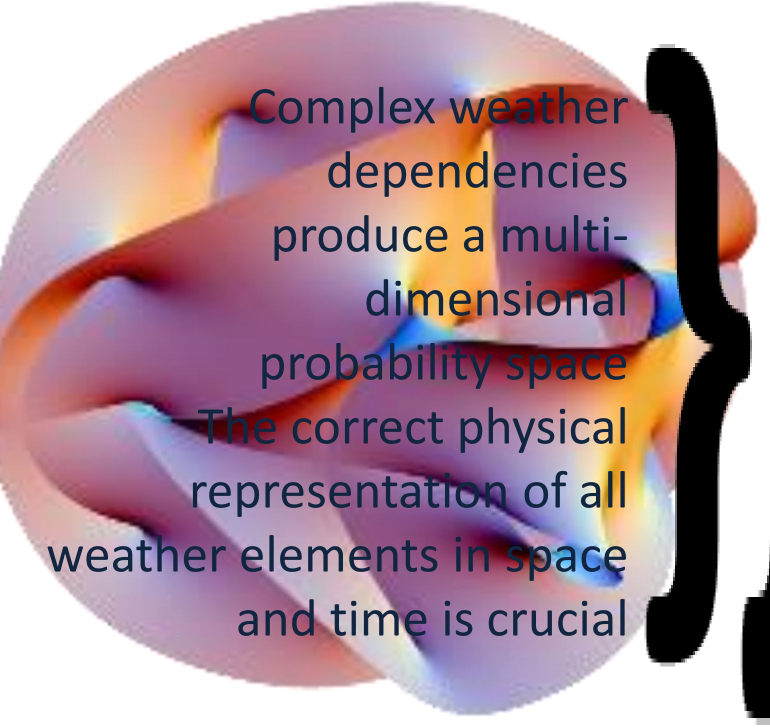
Iterate Through Load Timeseries Multiple Times With Different Random Draws

Nesting method can vary

Results

The Addition of Wind, Solar, and Storage VASTLY Complicates the Problem Space => Need better models fed with better data!

Weather in all datasets is correlated. Capturing correlations between outages and weather driving load, and wind/solar/storgage is important.



Complex weather dependencies produce a multi-dimensional probability space The correct physical representation of all weather elements in space and time is crucial

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Typically based on historical data
(Illustrative example. Can iterate through addition and/or other constraints)

Outage Probability Data
Historical average time to failure

Load Timeseries
Usually synthesized based on historical usage, how usage varies with temperature, and projected load growth.
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Wind Generation Timeseries
Typically uses synthetic wind and other weather data
Wind speed is very location specific and hard to estimate
Cubic power curve amplifies errors

Solar Generation Timeseries
Typically uses satellite derived or synthetic irradiance data
Temperature and wind speed dependent (also synthetic)
Dynamical consistency often disregarded

Hydro Year Draw

Outage Draw

Iterate Through Load Timeseries Multiple Times With Different Random Draws

Nesting method can vary

Results

Ongoing Trans-Disciplinary Bridges Are Needed To Ensure User Needs Are Met

Meteorology and power systems are complex domains.

Cross-Pollination and cooperation are needed

Handing NWP data (including reanalysis) off as black box data is a recipe for disaster!

Data Users

- What is available? What is its source? How is it produced?
- What is the accuracy possible
- What is the uncertainty?
  - In time? In space? By situatio
- What are the limitations?
- How do options compare with one another?

Data Collectors/Producers/Curators

- What do you need?
- How long? How frequent?
- For what use?
- How will you use it?
- Where? When?
- What accuracy is expected/needed?
- What conditions are important?

The Main Attributes of Time Series Data Necessary to Meet General Power System Modeling Needs

Provided for Offline Use

Including the necessary variables	Include the necessary variables at sufficient spatio-temporal resolution and accuracy to reflect actual conditions that define the generation potential at current and future wind/solar sites and temperature at load centers
Covering multiple decades with ongoing extension	Cover multiple decades with consistent methodology and be extended on an ongoing basis to capture the most recent conditions and allow climate trends to be identified
Coincident and physically consistent	Are coincident and physically consistent, in space and time, across weather variables
Validated	Are validated against real conditions with uncertainty quantified
Documented	Are documented transparently and in detail, including limitations and a guide for usage
Periodically refreshed	Are periodically refreshed to account for scientific and technological advancements
Available and accessible	Publicly available, expertly curated, and easily accessible

Source: Energy Systems Integration Group.

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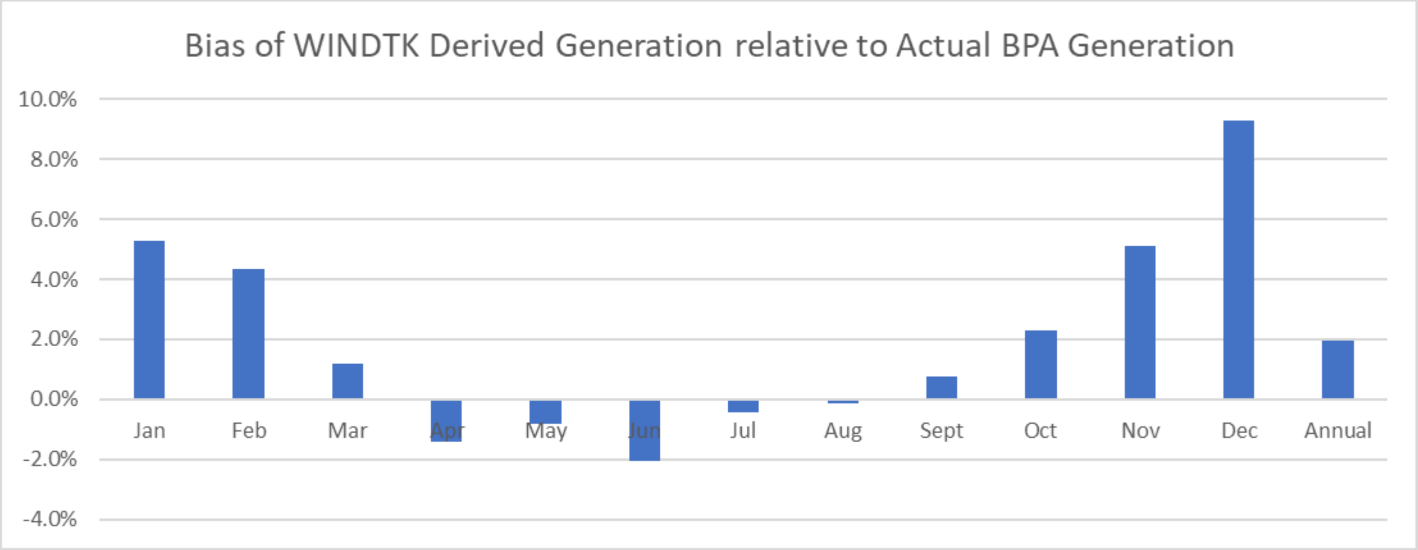
General Issues with Today's Approaches

- <u>Mostly provided for offline reference reading!</u>
- Model data (even reanalysis data) are NOT the same as observations
  - Ability to represent features is limited by resolution.
  - LARGE deviations can exist between model data and reality
  - Models have limitations and weaknesses. These are understood by NWP experts but not by general data users
- Lack of validation and uncertainty quantification:
  - Model data contains many (often millions) of data points.
  - There is very little validation at any of these points
  - Mostly because there are few observations available (but see below)
  - Validations are not targeted to specific use cases (e.g. low resource periods for RA)
- Lack of observations for validation, bias correction and generation estimation
  - Model data MUST be validated, and uncertainty quantified
  - Models will always be imperfect. Ground truth allows sophisticated bias correction to be applied
  - Generation data allows sophisticated models to be used to estimate generation time series from past met. data
  - **The rapid build out of wind and solar means this data <u>is</u> available. But it is currently proprietary. This <u>must</u> change.**
- Lack of transdisciplinary coordination and data curation. Silos everywhere.
  - Gridded (mostly synthetic) data is readily accessible and easy to use; it is very attractive to data hungry users
  - BUT most of it was <u>not</u> developed specifically for power systems use; yet it is used as if it has observational quality
  - Users must understand the limitations of the data they use and the impacts on downstream results

Validation and Uncertainty Quantification: A Critical Gap

- Validation must reflect use case requirements



- Validation and UQ requires a comprehensive Ground Truth Network
  - More on this in my next talk

- In the deep machine learning world of the future quality observations are also key to accuracy improvement

A Quick Word About Climate Change If I Have Time!

- It isn’t the focus here, but it is important
- Getting our house in order to address climate ***variability*** is the #1 priority
- By doing that in an ongoing fashion we implicitly begin to address climate trends
- We also begin to validate and quantify the uncertainty of climate change models
- While large, I believe the impact of climate change is second order compared to the massive impact of increased weather dependency and the need to properly quantify climate variability in this context

What Does The Cost-Benefit Look Like?

Total for 1990-2035: $40-80M

Resolution and methodology dependent

OR

Investment to decarbonize the grid by 2035: $330-740B[1]

About than 0.01% of expected investment

The potential cost of **flying blind** is…

- Reliability issues tied to renewables
- Slowed/halted decarbonization
- Inefficient system design and planning
- BIG $$$'s

[1] NREL 2022: https://www.energy.gov/eere/articles/nrel-study-identifies-opportunities-and-challenges-achieving-us-transformational-goal

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