Resource Adequacy: How did we get here (and where are we going)?

Michael Milligan, Consultant

michael@milligangridsolutions.com

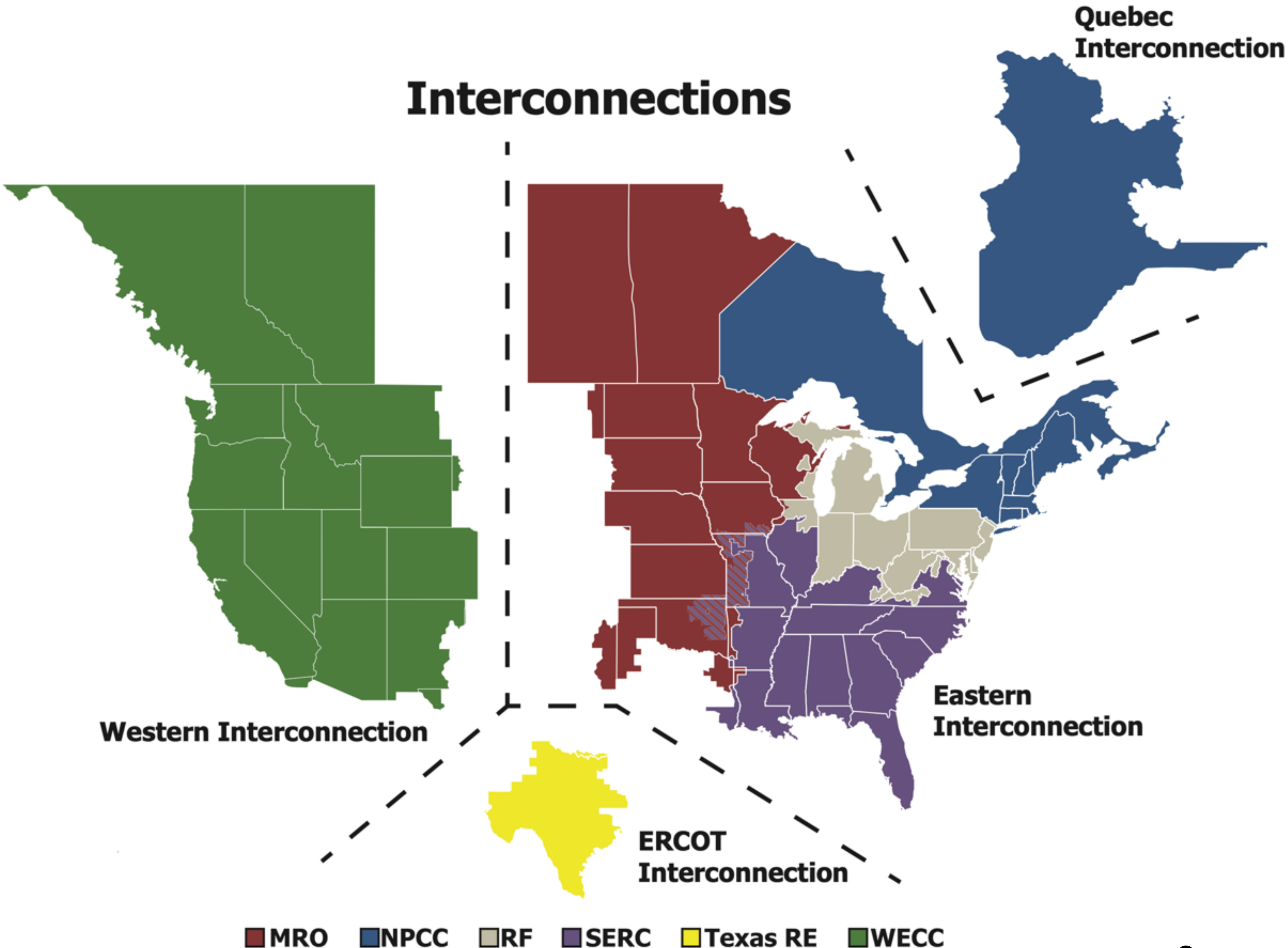
NARUC/NASEO Training, May 6, 2021

GridLAB

Outline

- Historical reliability assessments: LOLE
- Impact of renewables
- Emerging interest in portfolio effects
- What about transmission, and long-term weather?
- Gap between model capability and decision-making

Reference: The North American Grid



Source: NERC

Resource Adequacy

Resource Adequacy (RA) is a counting problem

- **Have we built enough stuff to supply demand at some future date(s)?**
  - RTO, utility IRP, region
- **“How adequate” can be turned upside down into “How often do we have a problem?”**
- **How many problems?**
- **How long did they last?**
- **How large was the energy deficit?**
- **How large was the capacity deficit?**

What should be counted?

- Do we want to count only resources (RA)?
- Do we want to include resources plus transmission (system adequacy)?
- Do we want to consider external support from power pool participation or other neighbors who might have the capacity/energy to help during an emergency?

…and what is “acceptable” RA target?

- **How many loss-of-load events per period?**
- **How long of a LOL event is too long?**
- **How much demand/energy is “ok” to not supply?**
- **Policy questions**

- **Trade-off between reliability and cost.** ***Reliability is not free***

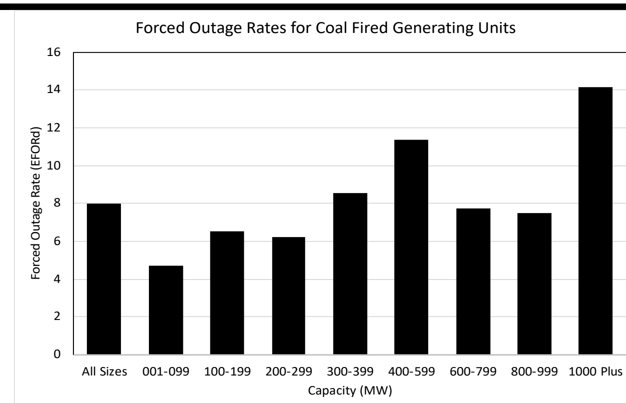
Traditional Approach to RA

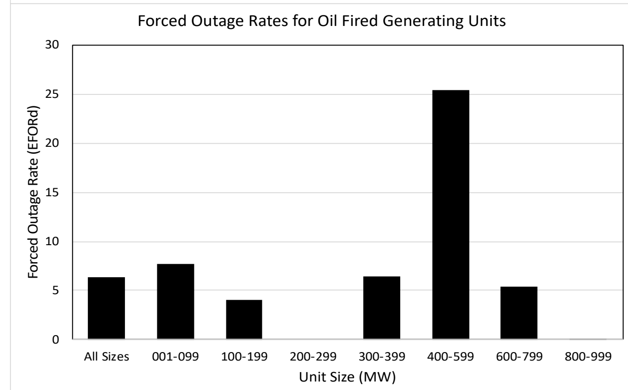
- **Often measured based on installed capacity, peak load, and a planning reserve**
- **A fixed planning reserve margin (PRM), often in a range of 12-15% above forecasted peak demand, was (and is still, unfortunately) common**
  - 10,000 MW peak, 11,500 Installed capacity is a 15% PRM.
- **However, this isn't a true reliability measure; the following questions are not answered:**
  - How often does it fail?
  - How long are failures?
  - Or…how successful are we in keeping the lights on?
- **And – it does not work with high levels of renewables**

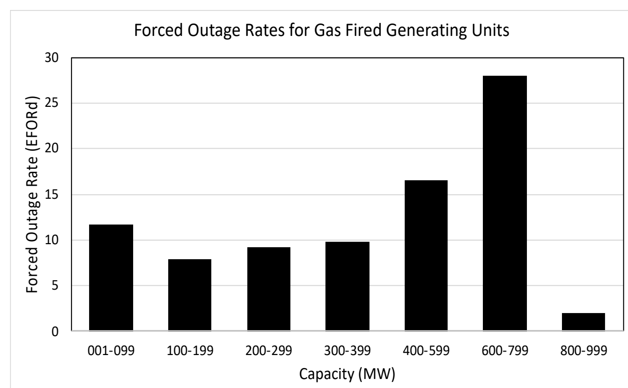


Resource Adequacy: From PRM to LOLP

- ***How adequate is adequate enough?***
- **Quantify the number of times system will be inadequate – often measured as hours/year or days/year (1d/10y ≈ 99.97%)**
- **Probability that demand will exceed supply: Loss of load probability (LOLP)**

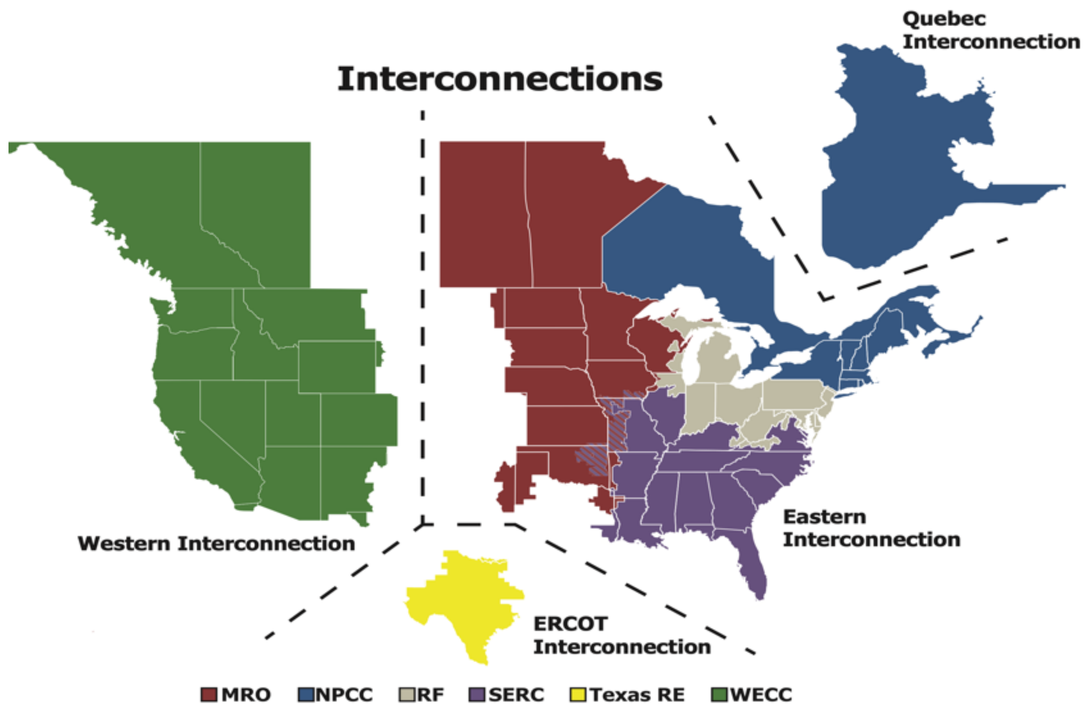




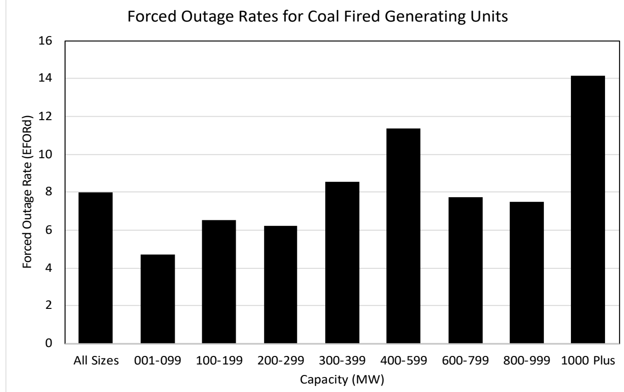


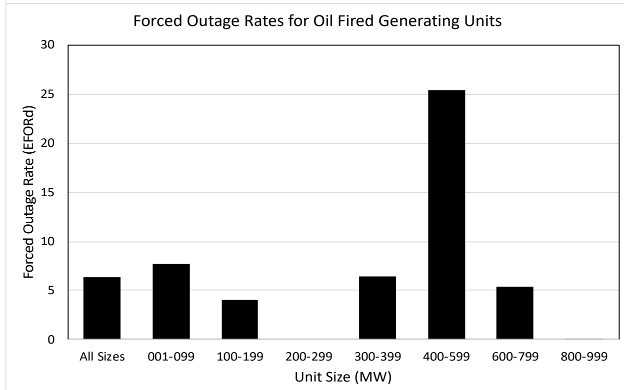
Forced outage rates source: NERC

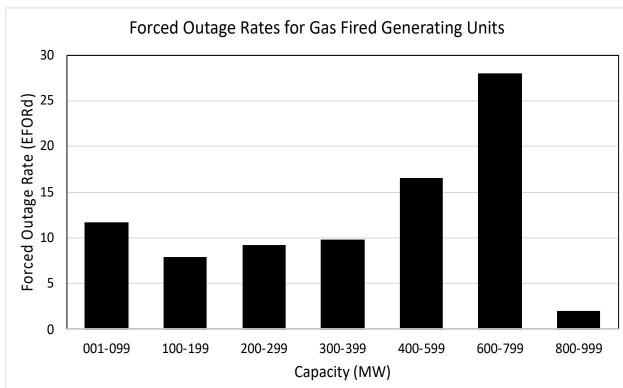
Resource Adequacy: From PRM to LOLP



- ***The "Loss of load" part of this term should be changed to "probability of emergency import" in interconnected systems***



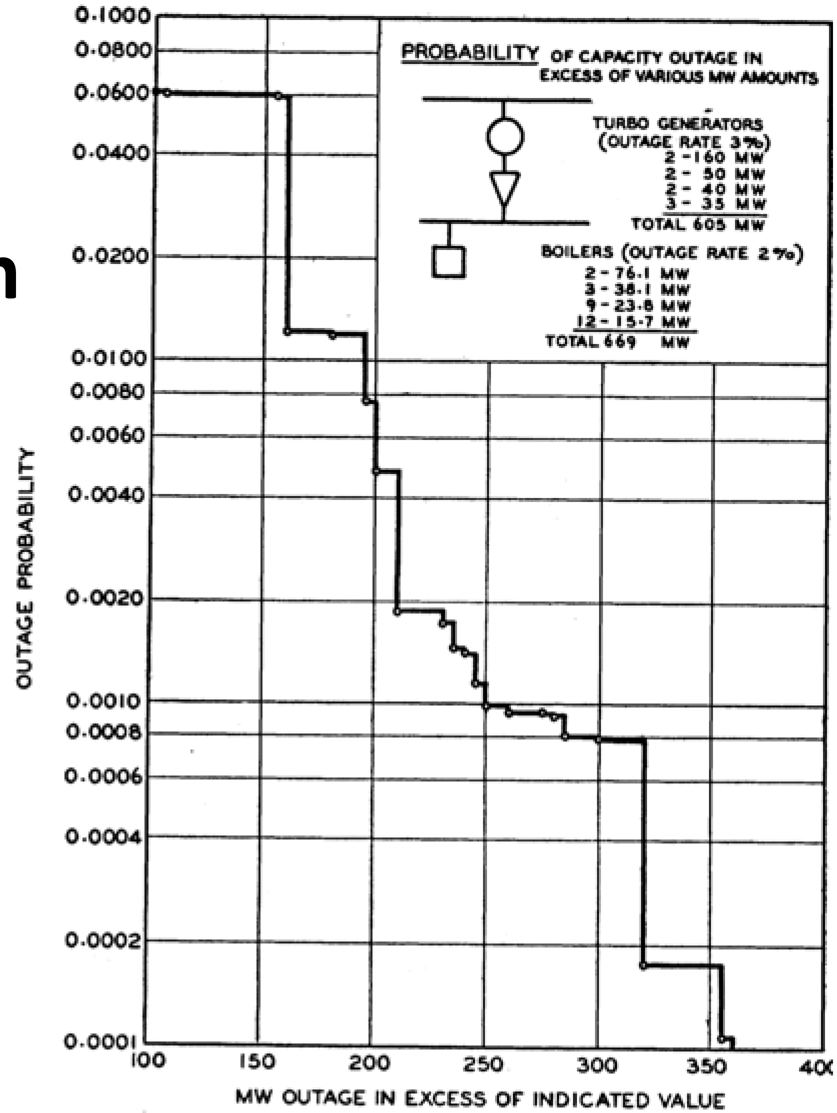




Forced outage rates source: NERC

First assessments using LOLP

- **Computation capability limited**
- **Select the peak hour from each weekday**
- **Exclude holidays (~6) falling on weekdays**
- **5 x 52 – 6 = 254 peak demand values used for an annual assessment (about 3% of the year)**



LOLP development

- **Calabrese et al introduced convolution method in 1947 that is still common**
- **Calabrese (1950): 1 day in 50 years "should be satisfactory"**
- ***Remember – one data point per non-holiday weekday!***

Determination of Reserve Capacity by the Probability Method
G. Calabrese
Transactions of the American Institute of Electrical Engineers
Year: 1950 | Volume: 69, Issue: 2 | Journal Article | Publisher: IEEE
Cited by: Papers (22)
Abstract (1917 Kb)

Determination of Reserve Capacity by the Probability Method Effect of Interconnections
G. Calabrese
Transactions of the American Institute of Electrical Engineers
Year: 1951 | Volume: 70, Issue: 1 | Journal Article | Publisher: IEEE
Cited by: Papers (7)
Abstract (479 Kb)

Generating Reserve Capacity Determined by the Probability Method
Giuseppe Calabrese
Transactions of the American Institute of Electrical Engineers
Year: 1947 | Volume: 66, Issue: 1 | Journal Article | Publisher: IEEE
Cited by: Papers (54)
Abstract (2547 Kb)

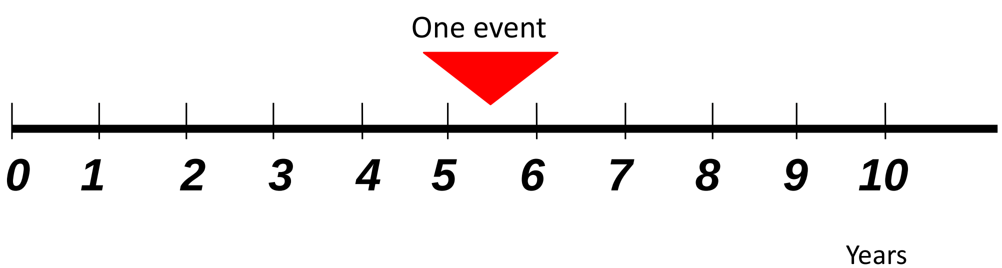
Probability method of finding reserve capacity–effect of interconnection
Giuseppe Calabrese
Electrical Engineering
Year: 1951 | Volume: 70, Issue: 10 | Journal Article | Publisher: IEEE
Abstract (874 Kb)

Terms

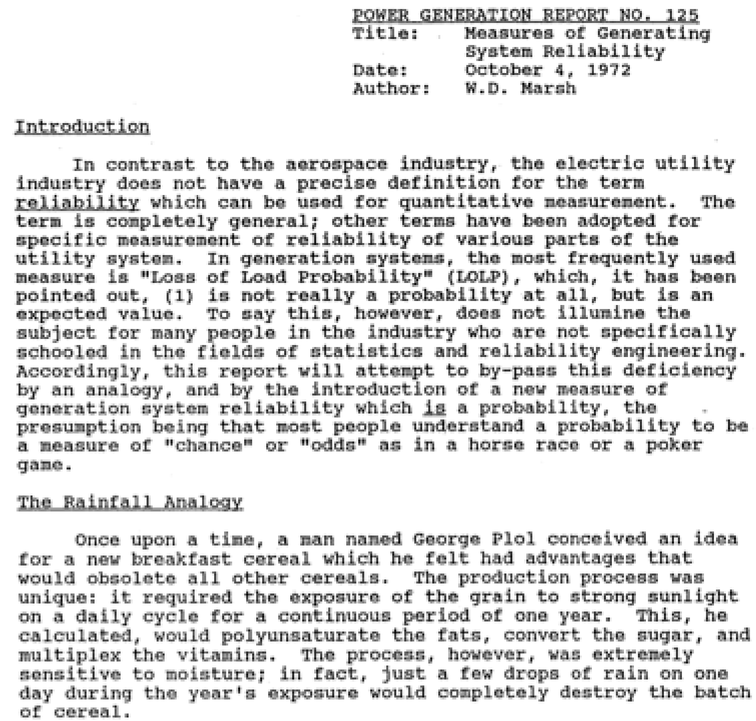
- **Probability: between 0, 1 inclusively**
- **P(heads) = 0.5**
- **Expected value = probability x number of trials (or similar)**
- **Expected number of heads after 100 coin tosses = 100 x 0.5 = 50**
- **Power system**
  - o LOLP = loss of load probability (0.0-1.0)
  - o LOLE = loss of load expectation (days/year, hours/year, etc.)

LOLE development: 1 day/10 years

- **1 day/10 years is a "nice round number" for a reliability target**
- **Is it from Marsh?**
- ***We don't know where it came from***
- **Corresponding LOLP = 1/3650 = 0.0002734**



Remember, one data point per non-holiday weekday.



POWER GENERATION REPORT NO. 125
Title: Measures of Generating System Reliability
Date: October 4, 1972
Author: W.D. Marsh

Introduction

In contrast to the aerospace industry, the electric utility industry does not have a precise definition for the term reliability which can be used for quantitative measurement. The term is completely general; other terms have been adopted for specific measurement of reliability of various parts of the utility system. In generation systems, the most frequently used measure is "Loss of Load Probability" (LOLP), which, it has been pointed out, (1) is not really a probability at all, but is an expected value. To say this, however, does not illumine the subject for many people in the industry who are not specifically schooled in the fields of statistics and reliability engineering. Accordingly, this report will attempt to by-pass this deficiency by an analogy, and by the introduction of a new measure of generation system reliability which is a probability, the presumption being that most people understand a probability to be a measure of "chance" or "odds" as in a horse race or a poker game.

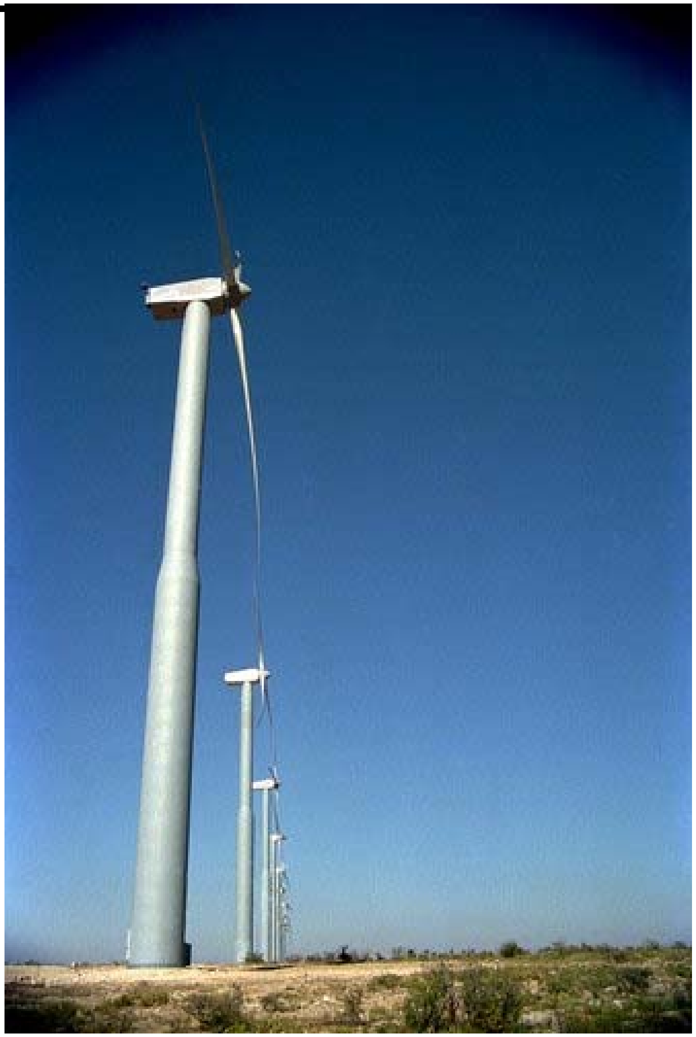
The Rainfall Analogy

Once upon a time, a man named George Plol conceived an idea for a new breakfast cereal which he felt had advantages that would obsolete all other cereals. The production process was unique: it required the exposure of the grain to strong sunlight on a daily cycle for a continuous period of one year. This, he calculated, would polyunsaturate the fats, convert the sugar, and multiplex the vitamins. The process, however, was extremely sensitive to moisture; in fact, just a few drops of rain on one day during the year's exposure would completely destroy the batch of cereal.

LOLP: probability, 0 <= LOLP <= 1
LOLE: expected value = P x Time
LOLH: hours of LOL events
LOLEv: # of events of LOLE
EUE: Expected unserved energy

Renewables are complicating risk assessment

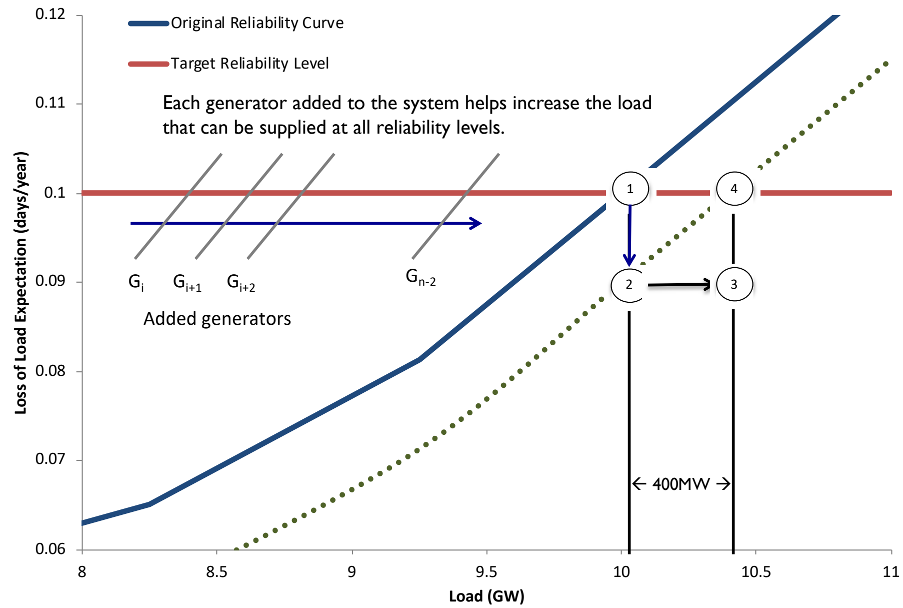
- **Traditional**
  - Most LOL risk during/near system peak
  - Focus on daily LOLP; ignore hourly data
- **With renewables**
  - Shifting risk periods
  - More interest in hourly view
  - More interest in energy metrics
- **Fortunately, methods and computational tools exist that can help**



See ESIG: Redefining Resource Adequacy: https://www.esig.energy/resources/redefining-resource-adequacy-for-modern-power-systems-derek-stenclik-december-2020/

Effective load-carrying capability (ELCC)

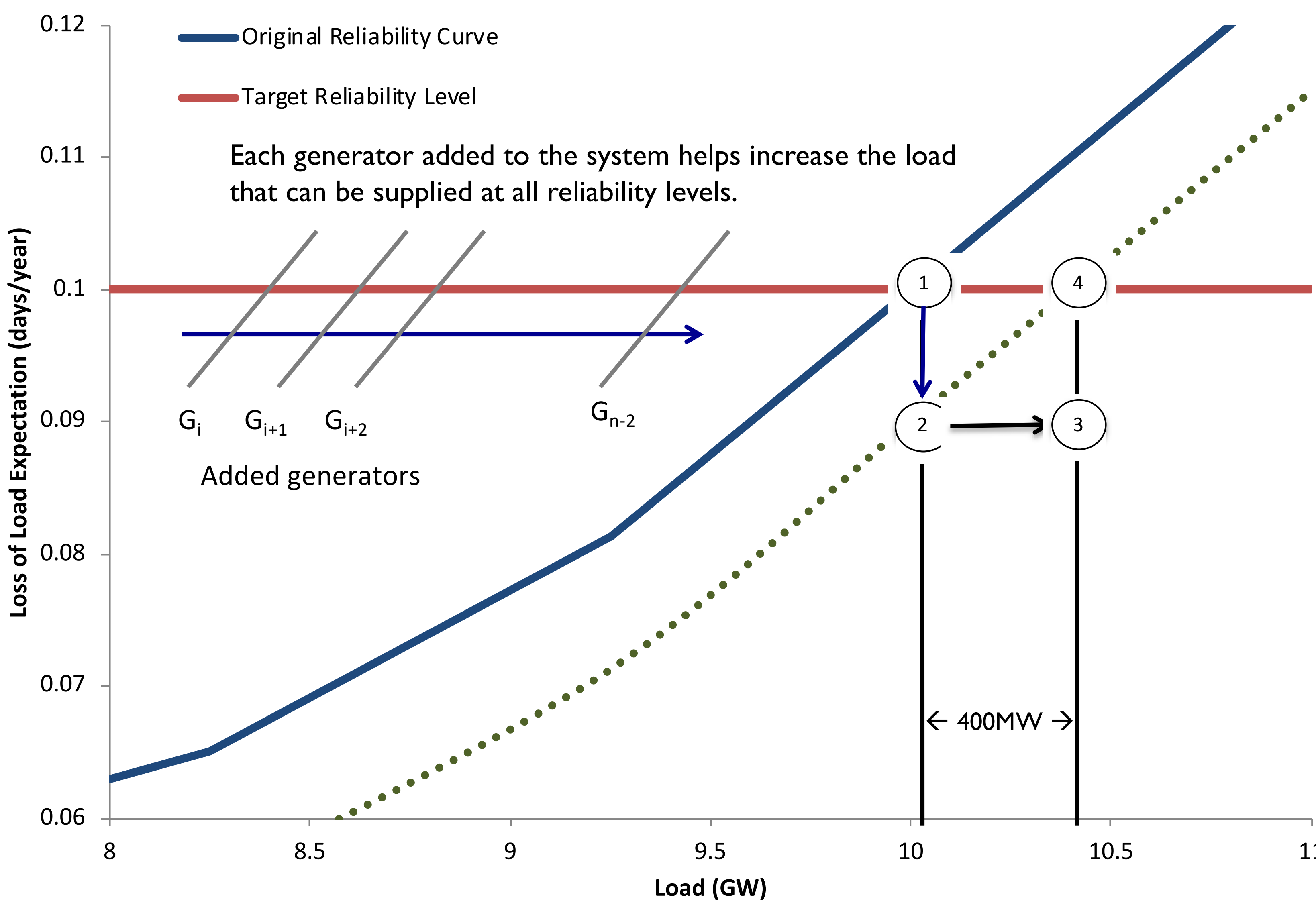
- **Rooted in base-load evaluations from the 1950's forward**
- **Easily adapted to renewables**
- **Part of a framework of reliability assessments**



Larger graph is on next slide

- ***ELCC calculation assumes no other changes to power system***

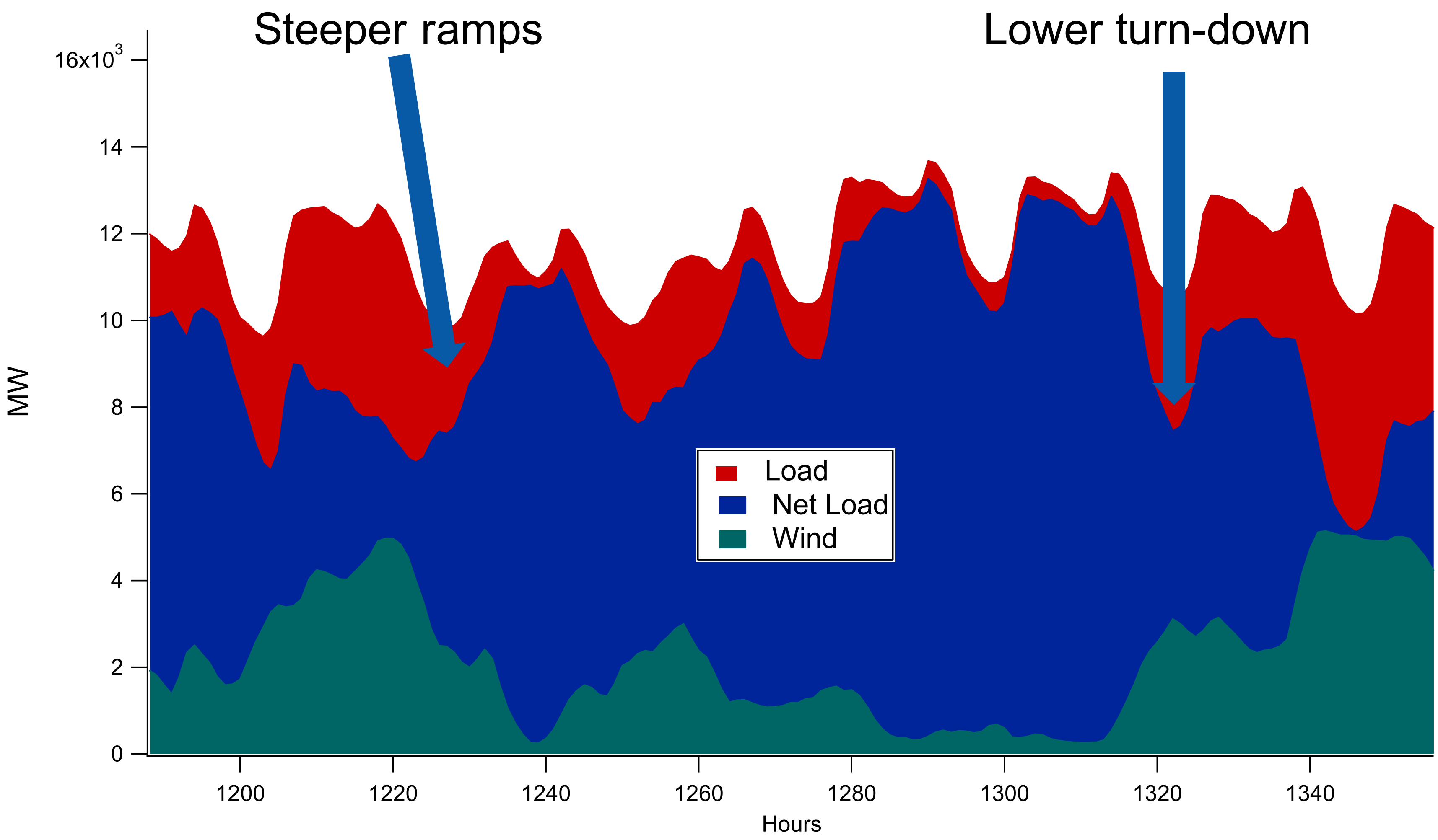
Graphical depiction of ELCC



Recipe for ELCC

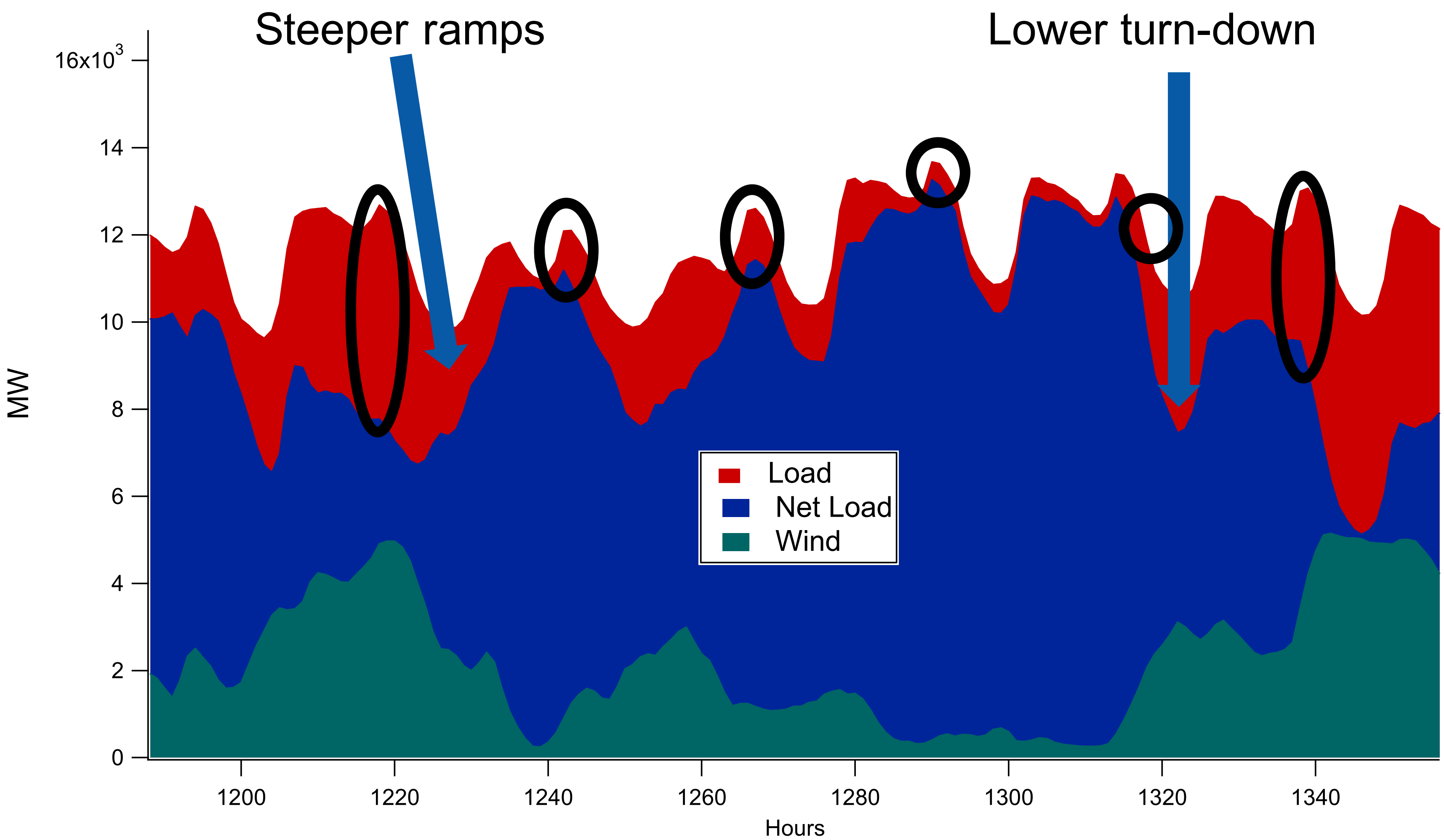
- **Reliability model, or production simulation model**
- **Inputs:**
  - Hourly demand, wind, solar, hydro data
  - Resource data including forced outage rates
  - Multiple years of time-sync'd data
- **Output**
  - Each model run provides LOLE output
  - Iteratively re-run model until LOLE target is achieved with, and without, renewable resource (multiple model runs)

Enter: Renewables (wind example)

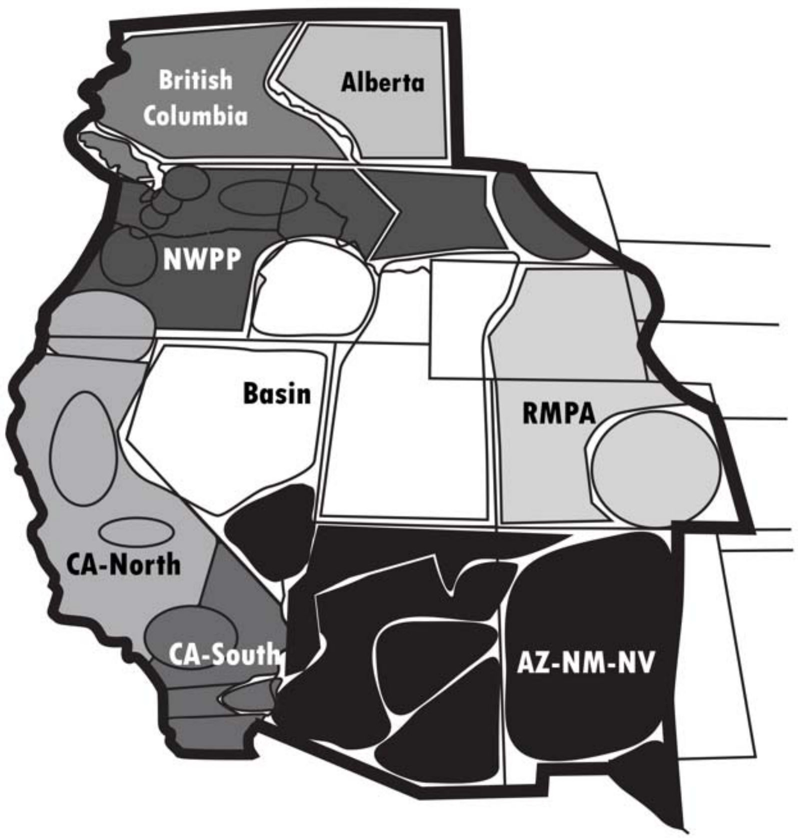


Enter: Renewables (wind example)

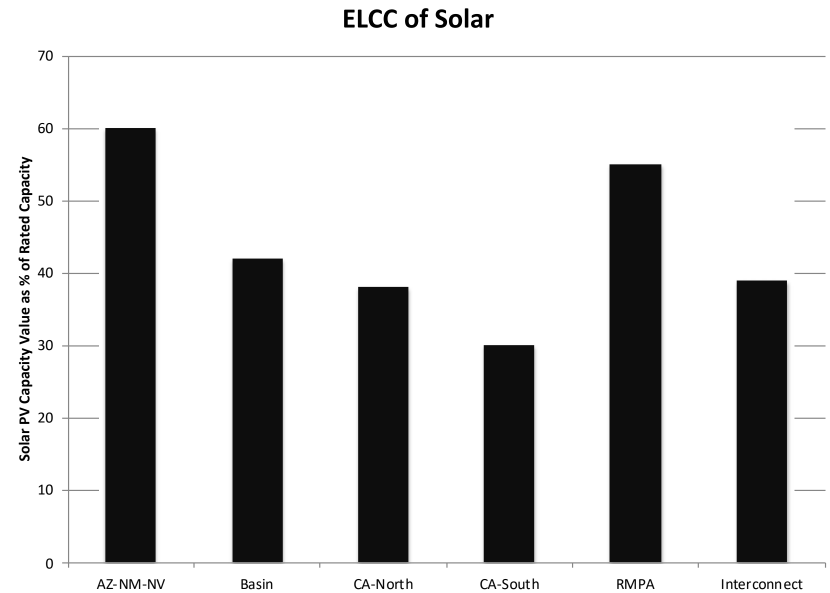
Partial capacity contribution

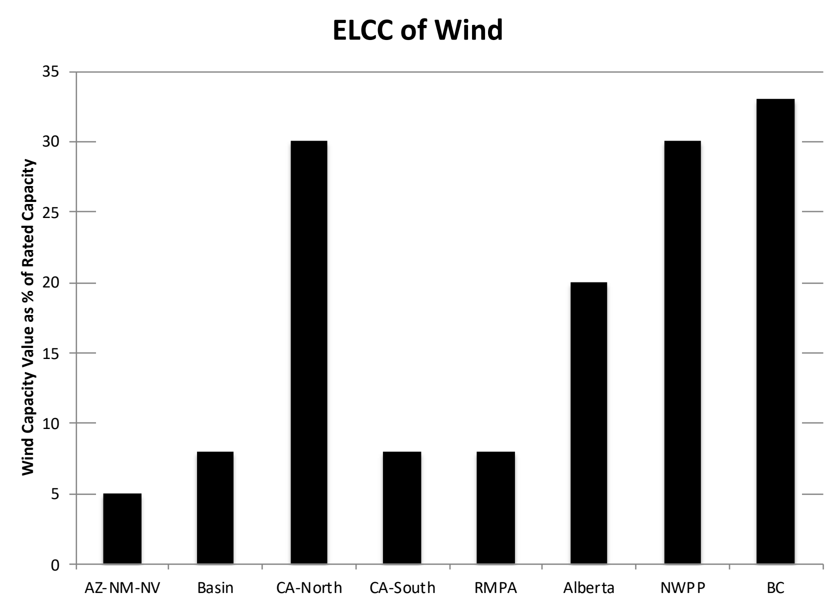


Example Wind/Solar Capacity Value



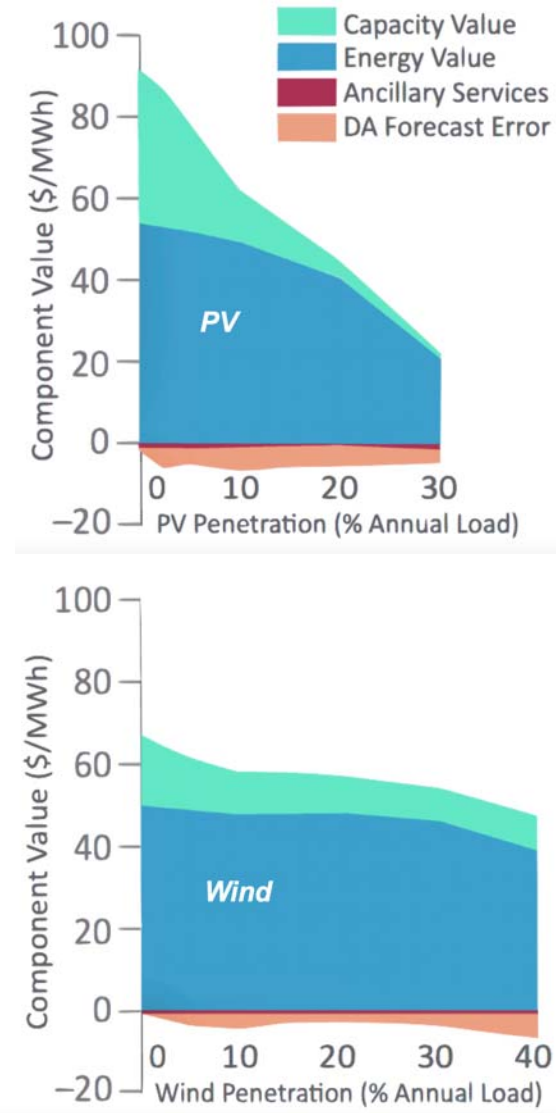
Adapted from Milligan, Michael; Bethany Frew; Ibanez, Eduardo; Kiviluoma, Juha; Holttinen, Hannele; Söder, Lennart, Capacity Value Assessments for Wind Power: An IEA Task 25 Collaboration. Wiley Wires. 2016.





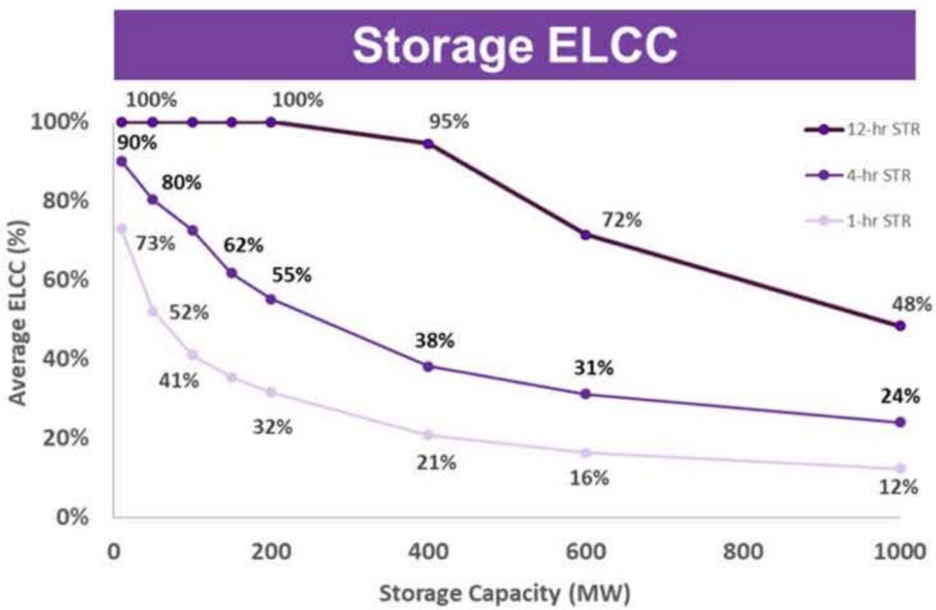
Wind/Solar Capacity Value Depends on…

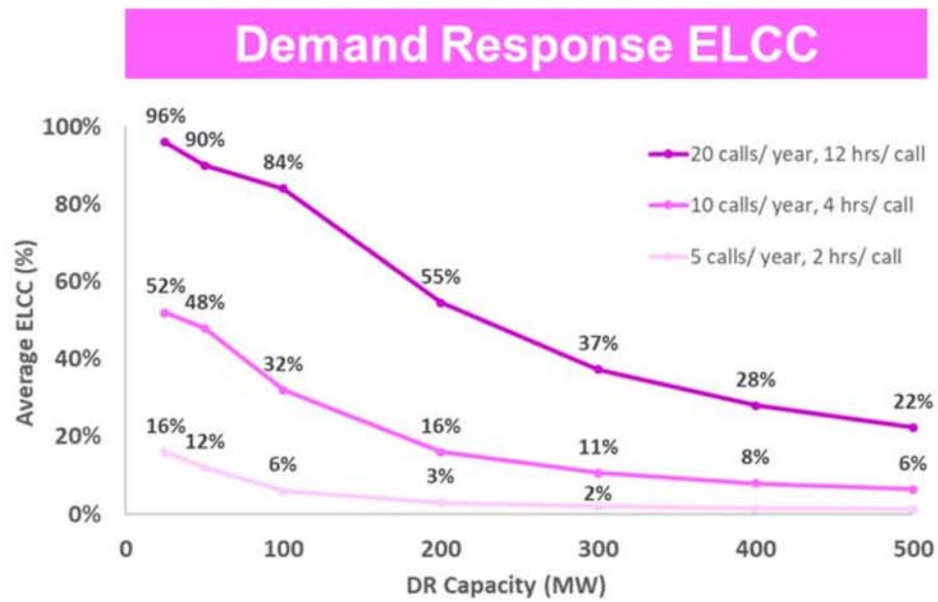
- **Penetration rates of**
  - Wind
  - Solar
- **Storage and mode of operation**
- **Maintenance schedules**
- **Demand patterns/levels**
- **Forced outage rates of other units**
- **Imports/exports**
- **Hydro generation patterns**
- **Inter-annual variation**



Andrew Mills, LBNL

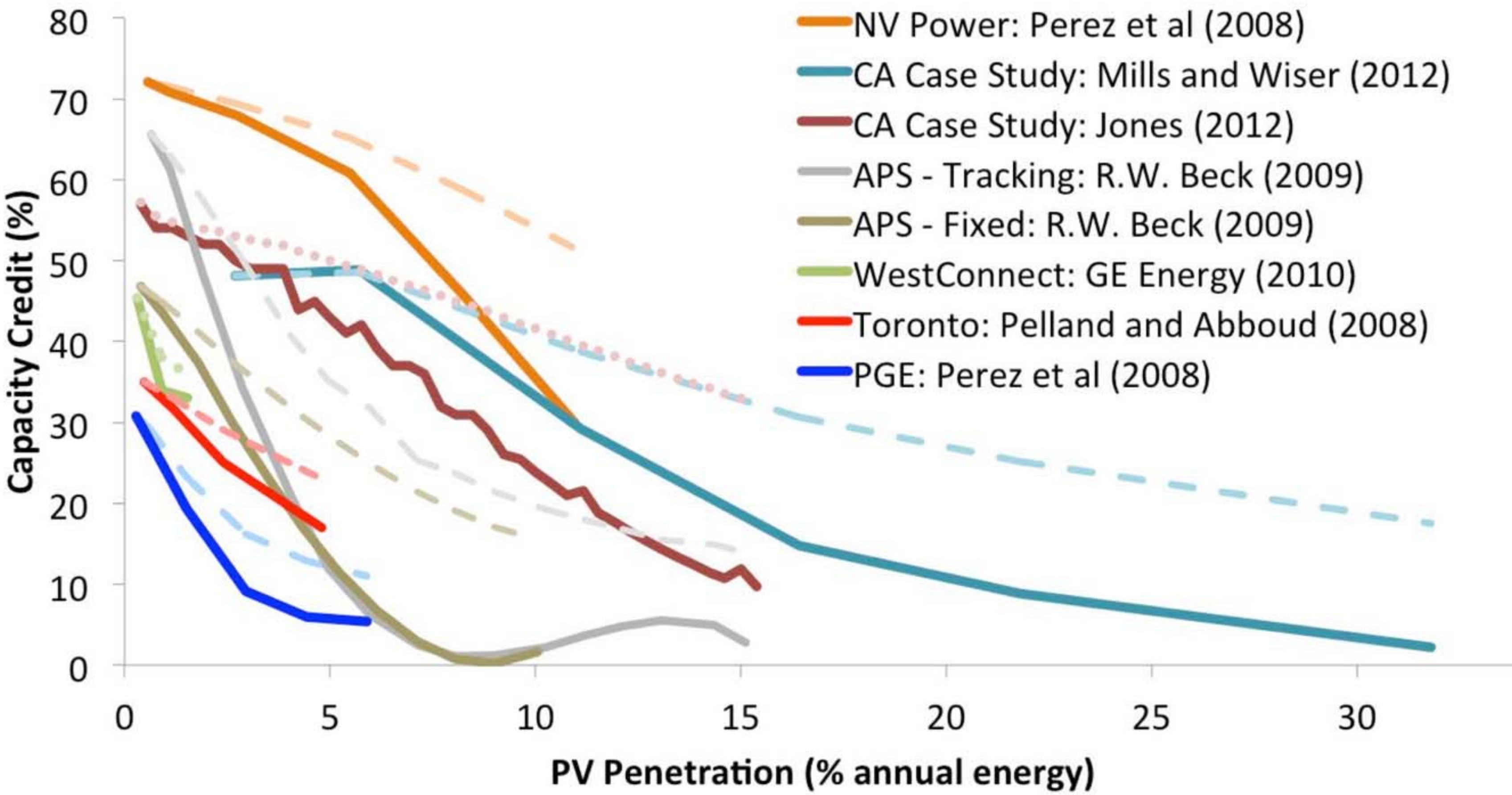
Storage and demand response examples





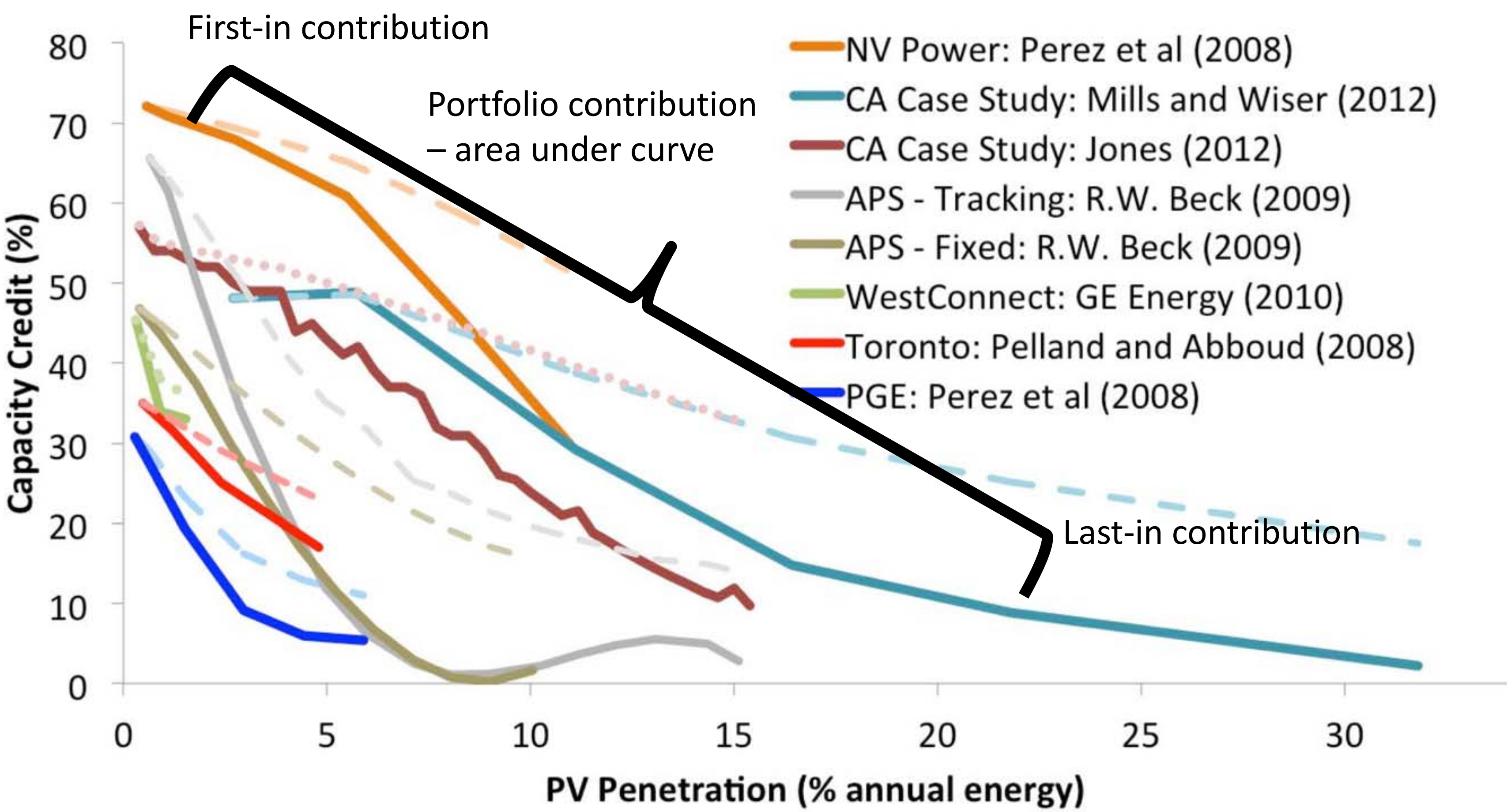
E3, https://irp.nspower.ca/files/key-documents/presentations/20190807-02_-E3-Capacity-Study-Overview.pdf

Emerging interest in portfolio effects



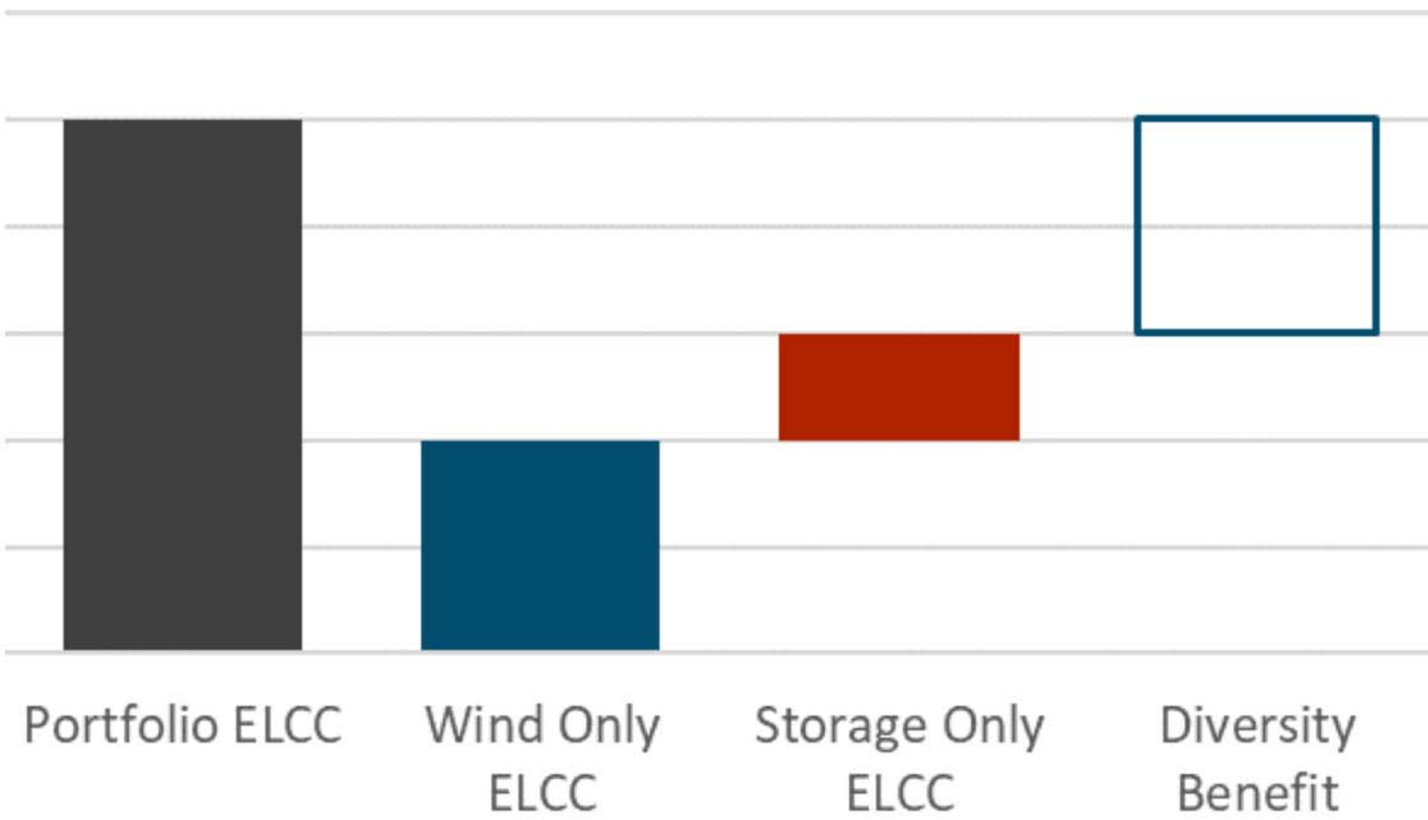
Adapted from Mills and Wiser (2012), An Evaluation of Solar Valuation Methods Used in Utility Planning and Procurement Processes. https://eta-publications.lbl.gov/sites/default/files/lbnl-5933e.pdf

Emerging interest in portfolio effects



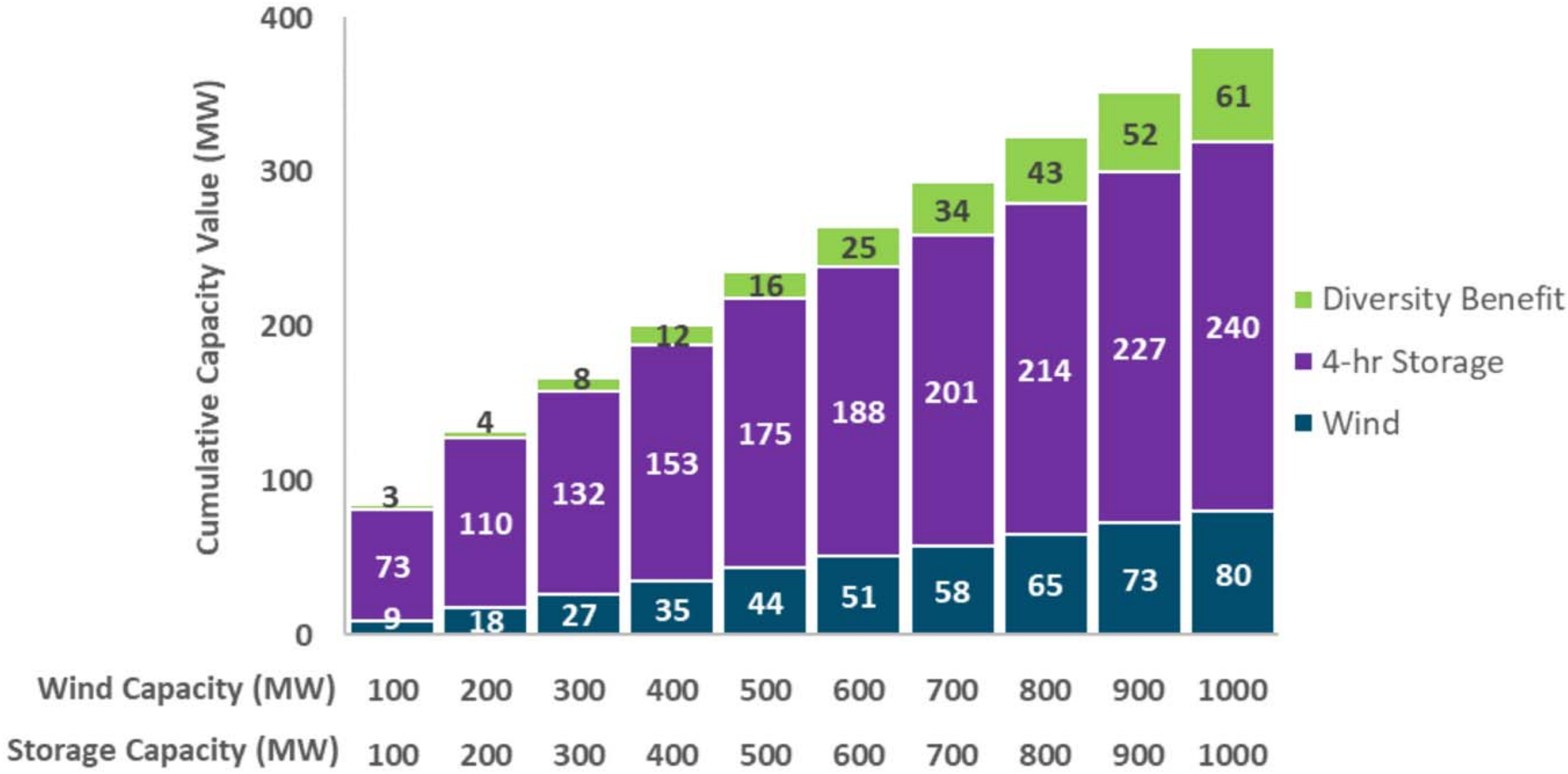
Adapted from Mills and Wiser (2012), An Evaluation of Solar Valuation Methods Used in Utility Planning and Procurement Processes. https://eta-publications.lbl.gov/sites/default/files/lbnl-5933e.pdf

Emerging interest in portfolio effects



E3, https://irp.nspower.ca/files/key-documents/presentations/20190807-02_-E3-Capacity-Study-Overview.pdf

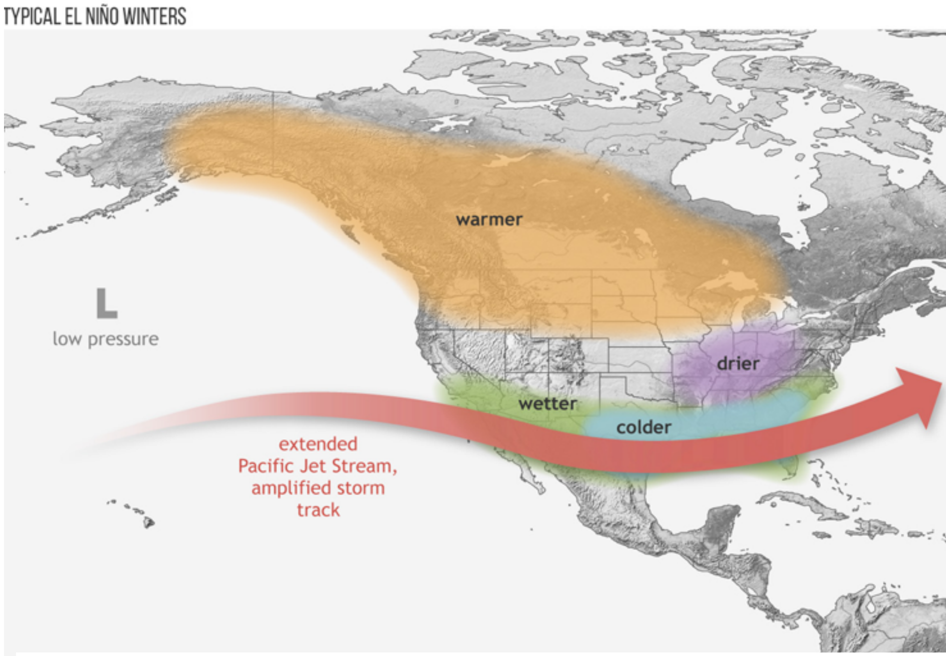
Wind and Storage Example

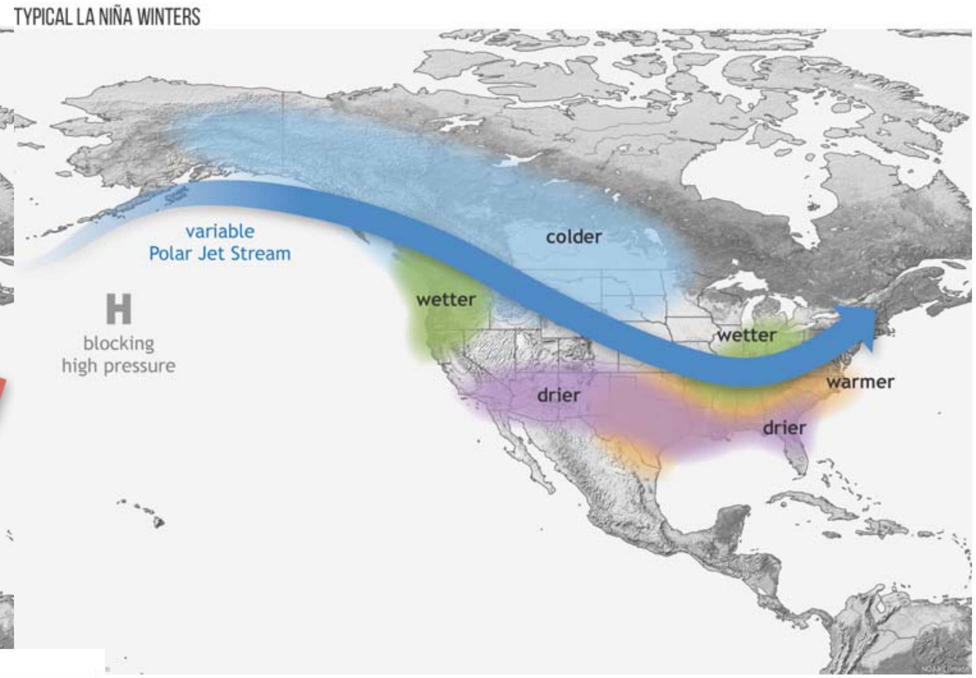


E3, https://irp.nspower.ca/files/key-documents/presentations/20190807-02_-E3-Capacity-Study-Overview.pdf

Climate.gov

How does weather affect RE?





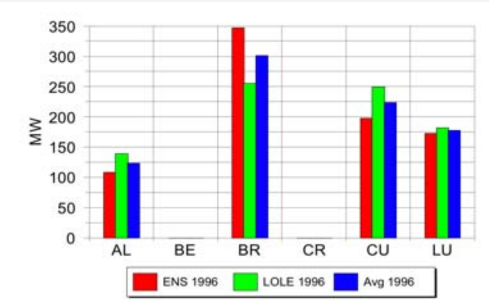


Figure 10. Optimal distribution of wind capacity using 1996 data

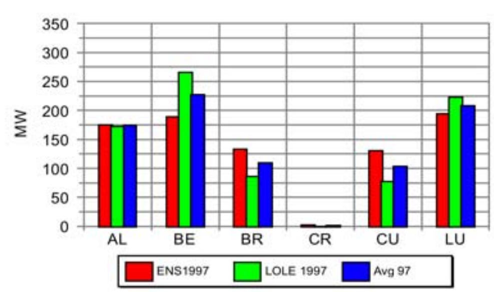
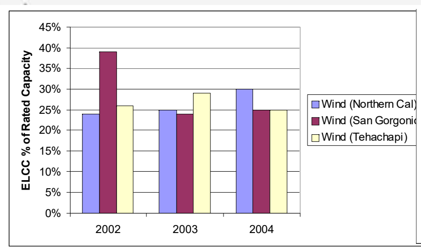


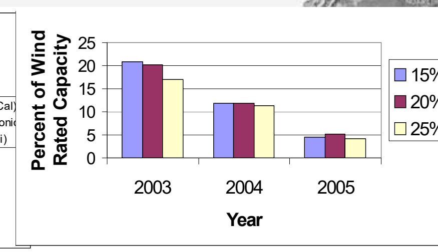
Figure 11. Optimal distribution of wind capacity using 1997 data

Milligan, M. R.; Artig, R. (1999). Choosing Wind Power Plant Locations and Sizes Based on Electric Reliability Measures Using Multiple-Year Wind Speed Measurements. Prepared for the U.S. Association for Energy Economics Annual Conference, 29 August—1 September 1999, Orlando, Florida; 11 pp.; NREL Report No. CP-500-26724. Available at http://www.nrel.gov/docs/fy99osti/26724.pdf



California RPS Integration Study

Adapted from Shiu, H.; Milligan, M. Kirby, B.; Jackson, K. (2006). California Renewables Portfolio Standard Renewable Generation Integration Cost Report. Prepared for the California Energy Commission, May.

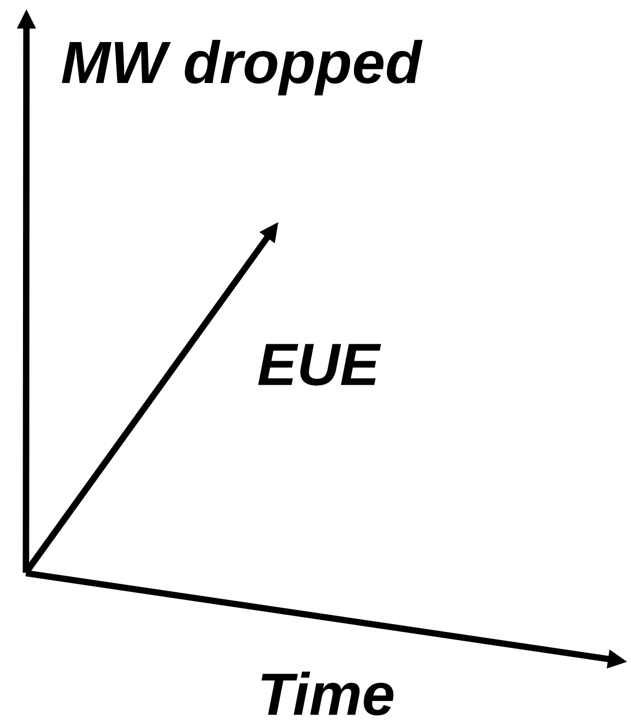


Minnesota Wind Integration Study

Zavadil, King, et al. 2006 Minnesota Wind Integration Study. https://mn.gov/puc/assets/000664_tcm14-4689.pdf

What is appropriate reliability/RA target?

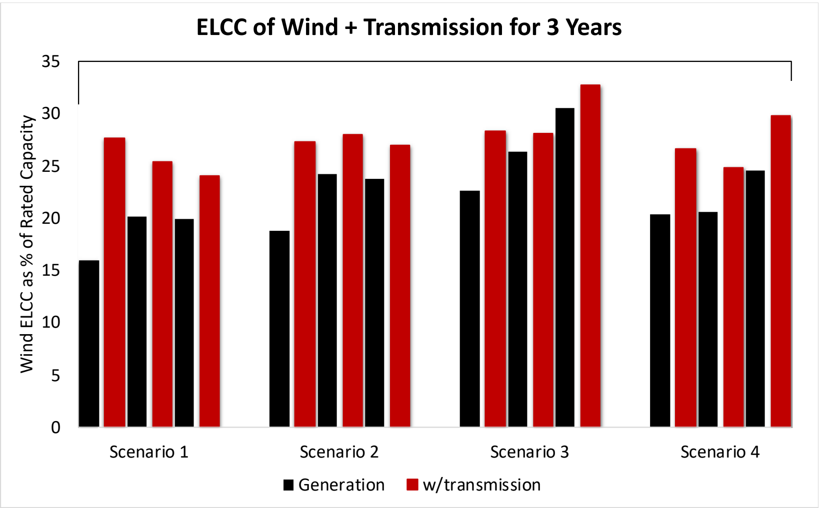
- **1 day/10 years legacy target, no real justification, focuses on daily event**
  - No information about the event length, depth, capacity
- **Are 10 "small" events the same as 1 "large" event?**
- **Should we focus on hours lost, capacity lost, energy lost?**

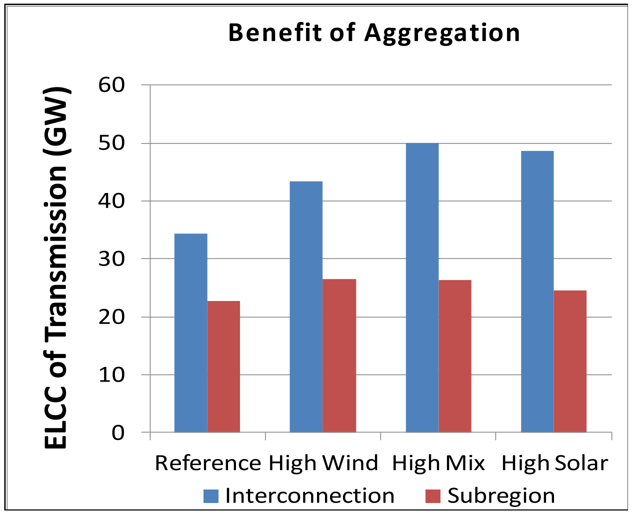


Transmission can increase reliability, enhance markets, and reduce need to build resources

Transmission can play a critical role

- **Increasing transmission links and associated operational coordination can reduce the need for installed capacity**





Adapted from Eastern Wind Integration and Transmission Study https://www.nrel.gov/docs/fy11osti/47078.pdf

Ibanez and Milligan (2012), "Impact of Transmission on Resource Adequacy in Systems with Wind and Solar Power." IEEE Power and Energy Society General Meeting, Summer 2012. San Diego, and "A Reliability-Based Assessment of Transmission Impacts in Systems with Wind Energy". Available at www.nrel.gov/publications

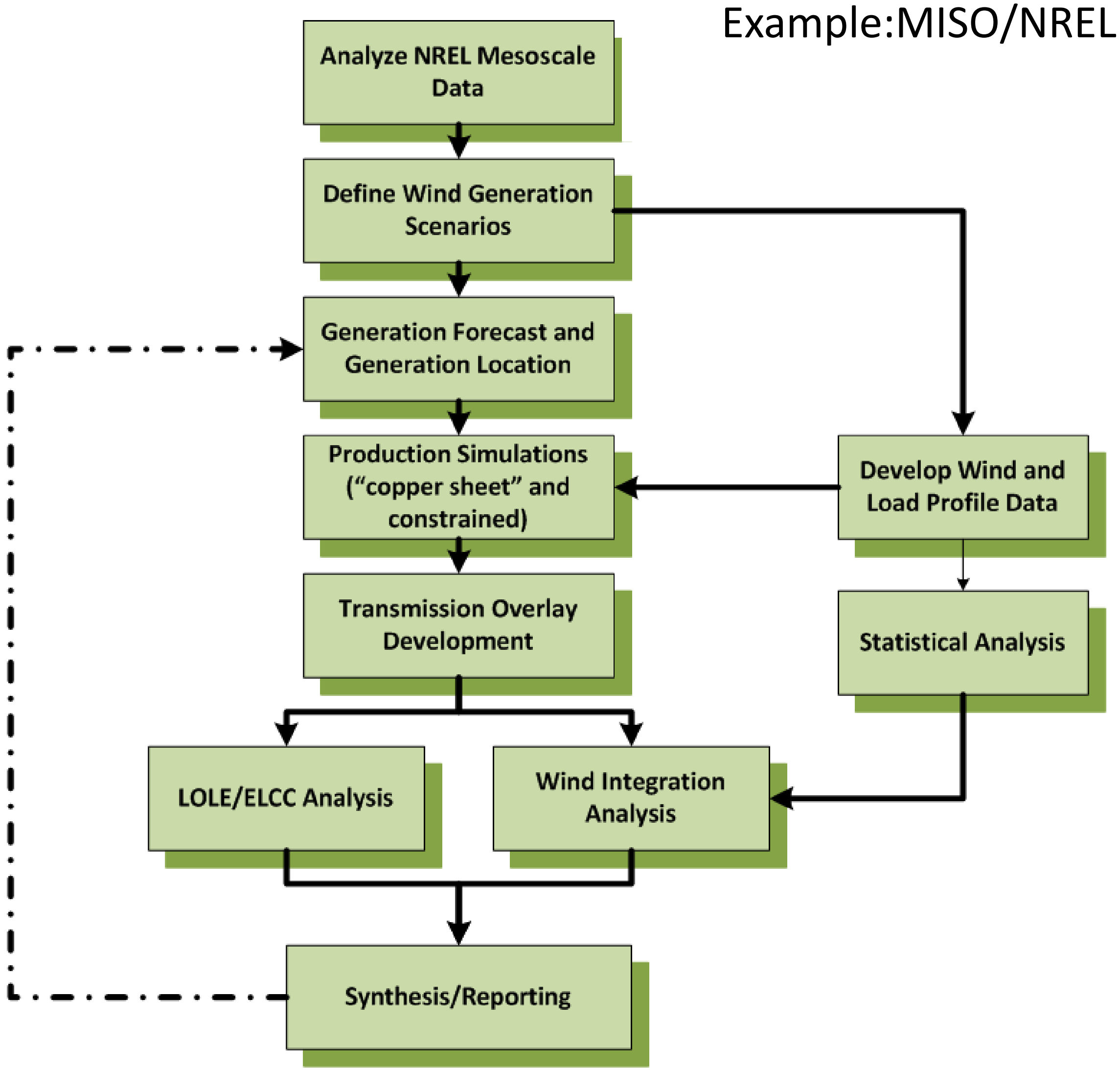
What do we need to do?

What do we need to do?

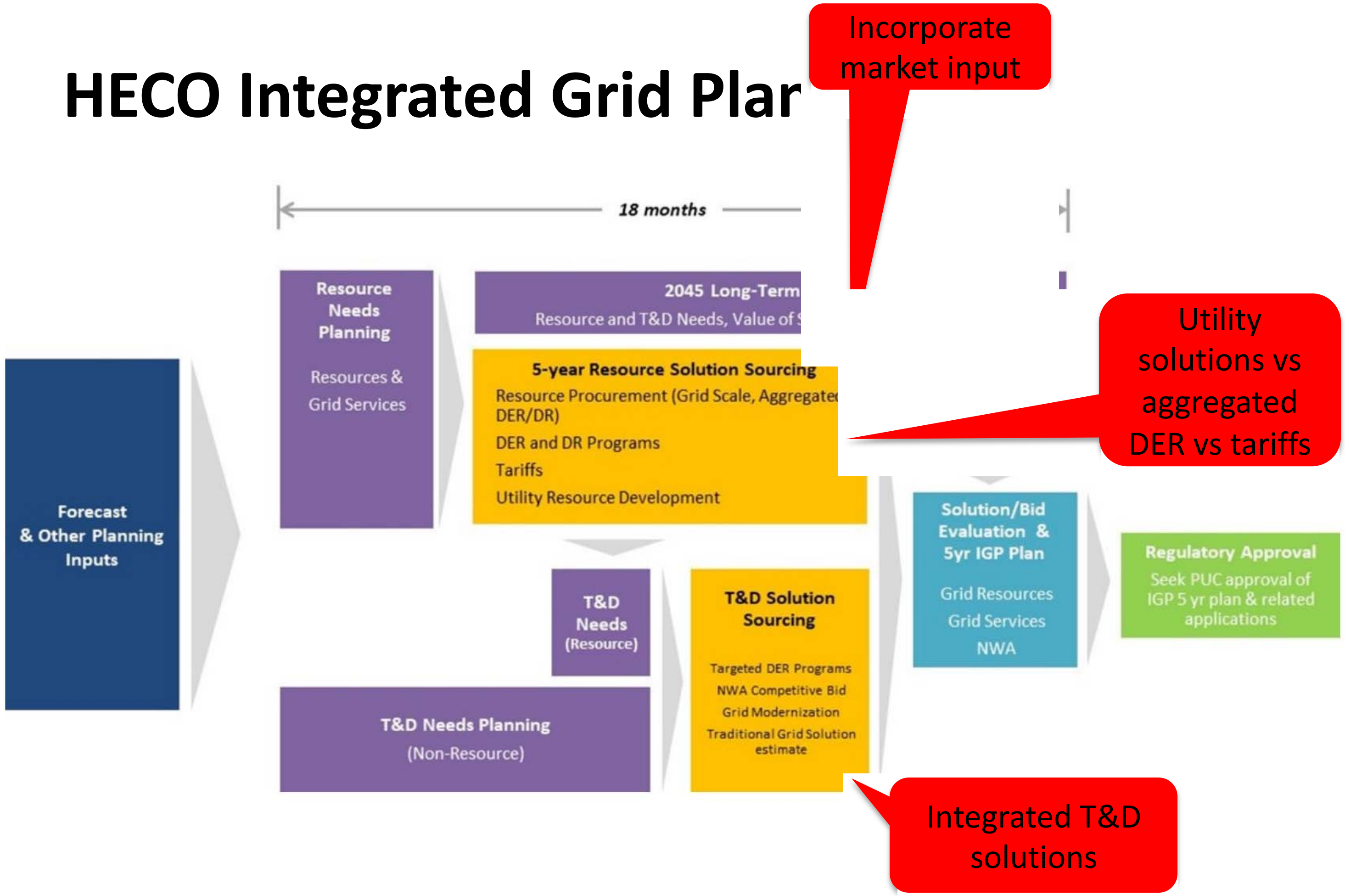
- Integrate resource, transmission, distribution planning
- Focus on “energy-first” planning
- Think more about long-term weather impacts – on demand and resources (wind, solar, hydro)
- Re-think metrics
- Incorporate DR, storage
- Close the gap between technical modeling capability and decision-making

Integrate transmission & resource planning

Example:MISO/NREL Study Process (EWITS, 2010)



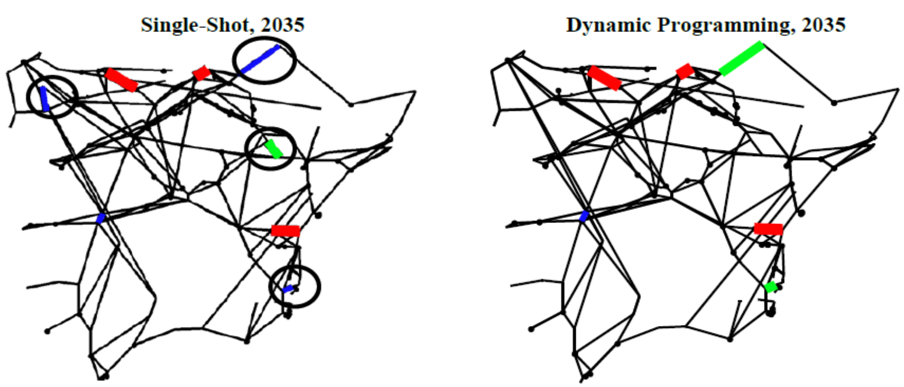
Integrate G, T, D planning (HI example)



https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/20180301_IGP_final_report.pdf

Transmission planning challenges

- **Most are well-known…**
- **Design and build for the short-term, or the long-term?**
- **Renewable energy siting in advance?**
  - Example: ERCOT's Competive Renewable Energy Zones (CREZ)

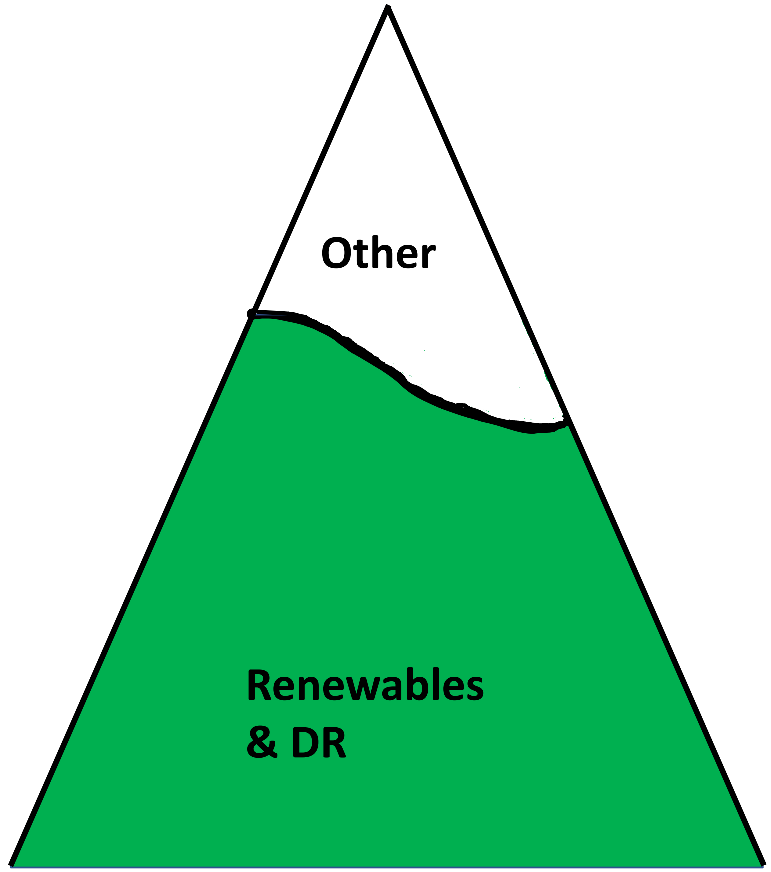


2035	Single-Shot	Dynamic Programming
400 MW	4	1
750 MW	1	2
1500 MW	3	3

Donohoo, P. 2011. *Integrating Dynamics and Generator Location Uncertainty for Robust Electric Transmission Planning*. INFORMS Annual Meeting. Charlotte, North Carolina, USA.

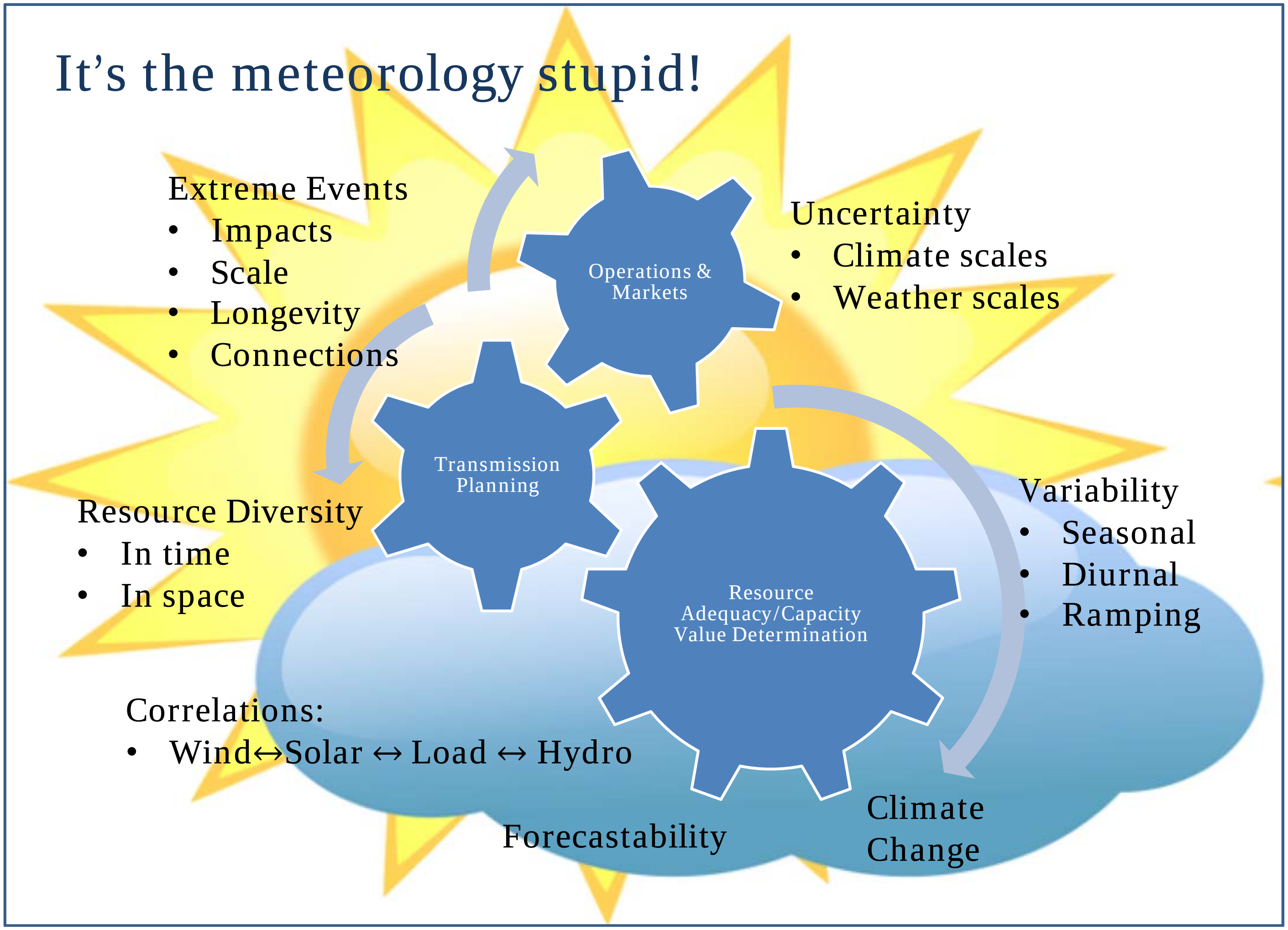
Energy-first planning

- **Who is in charge?**
- **”energy-first”* planning**
  - Focus on clean energy first
  - Then “fill in” to achieve RA (energy adequacy?)
- **Fill in with**
  - Storage
  - DR/dispatchable demand
  - Quick-start thermal
  - Other
- **Move away from “peak only” and focus on energy adequacy**



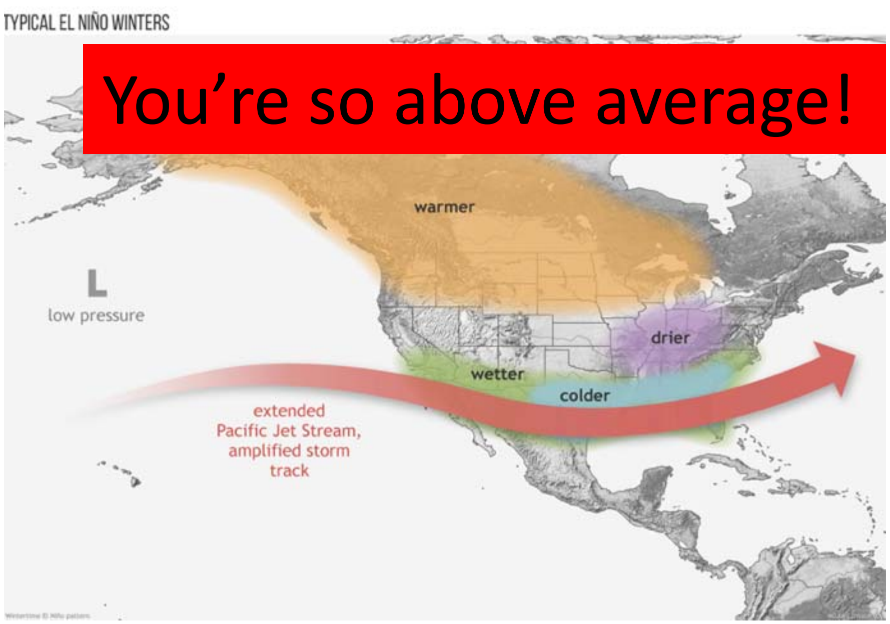
*First coined by Dave Olsen, CAISO

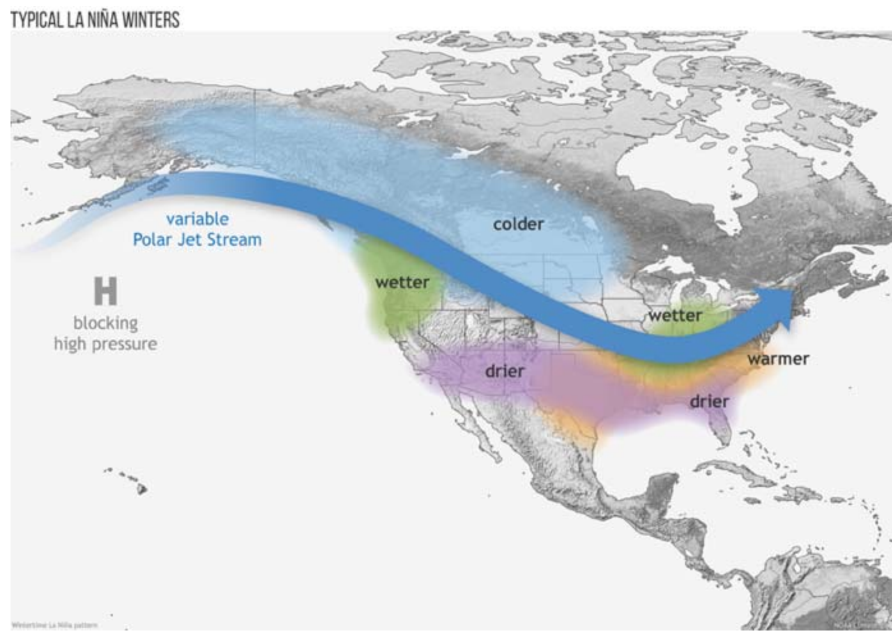
Weather, weather, weather



Long-term weather; need more robust planning

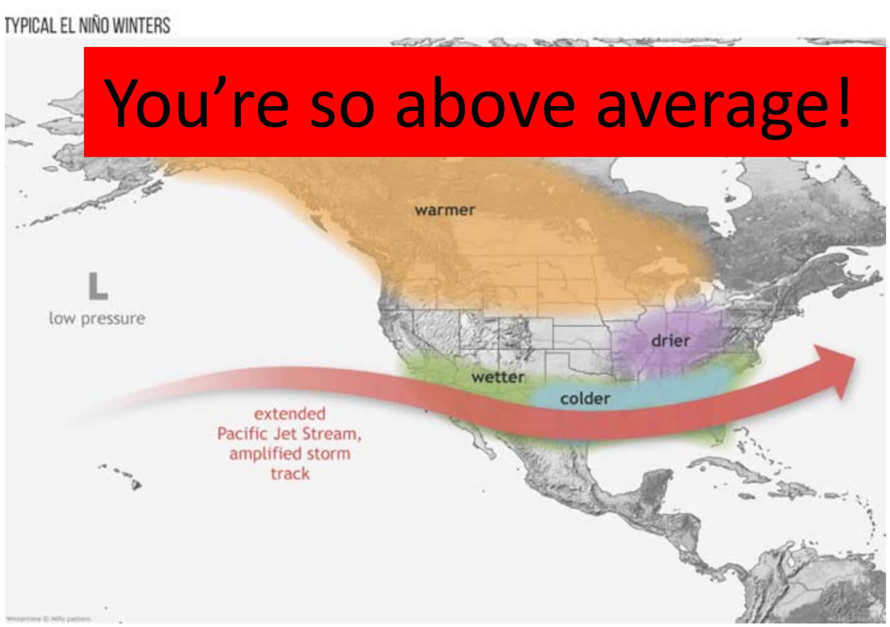
- As a species, humans often don’t have the capability to incorporate uncertainty and volatility into planning
- Planning is usually done based on “average” or “representative” weather

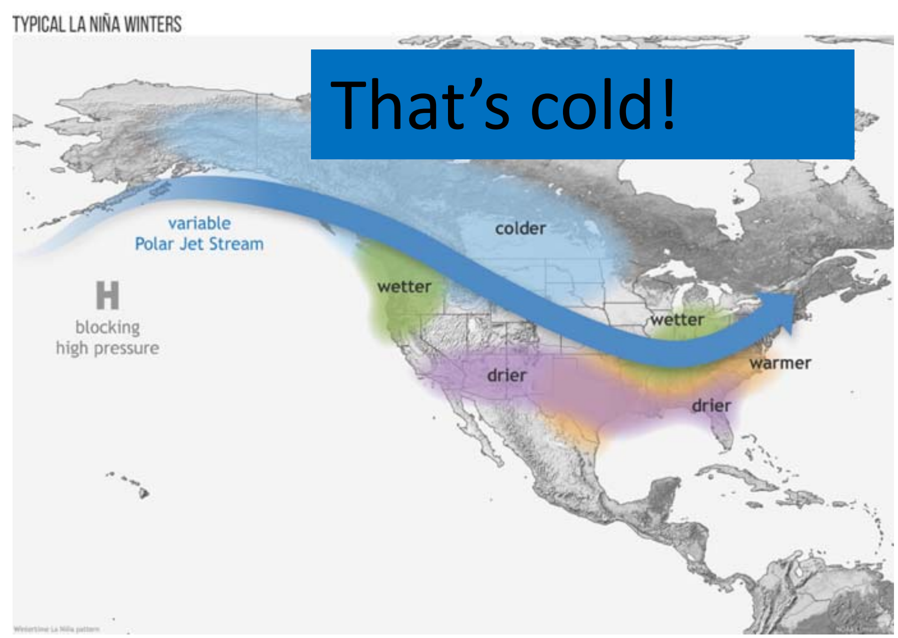




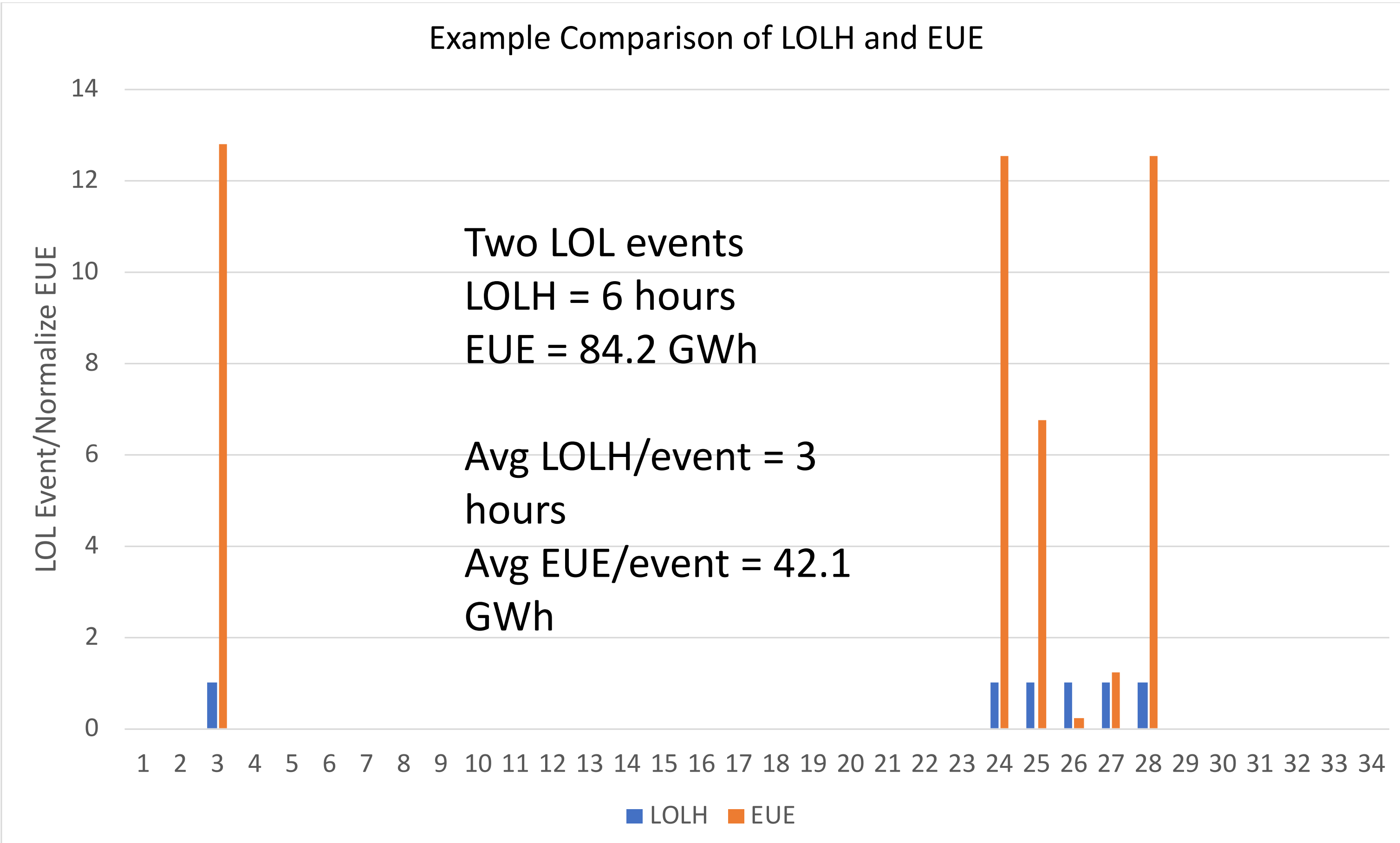
Long-term weather; need more robust planning

- As a species, humans often don't have the capability to incorporate uncertainty and volatility into planning
- Planning is usually done based on "average" or "representative" weather





We need more work on metric comparison



LOLH = loss of load hours (hours of emergency import), number of hours of shortage
EUE = expected unserved energy (emergency import energy)

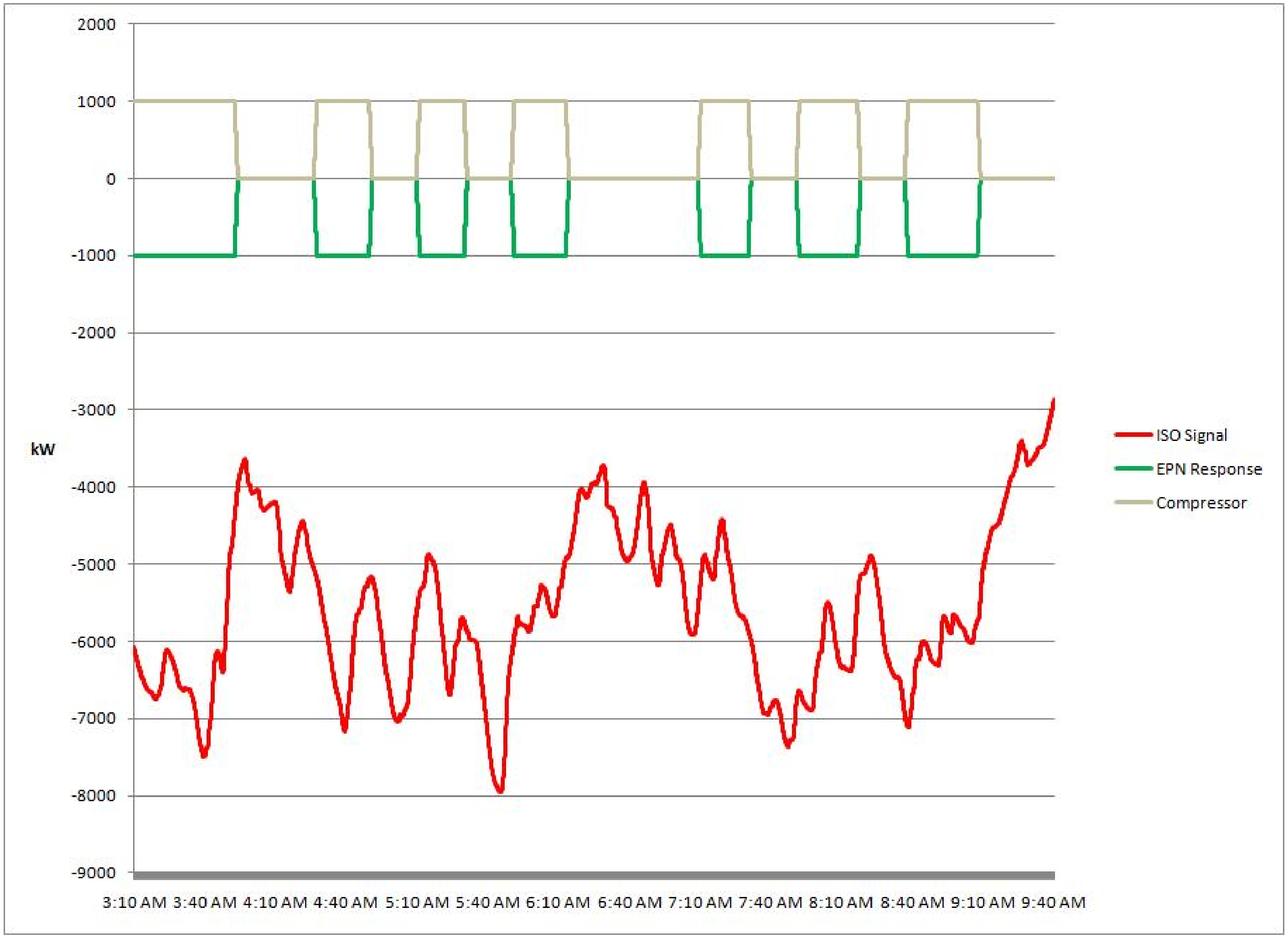
Some potentially useful metrics

Break down the wall between modeling capabilities and policy-making – and ***re-work target reliability***

- **Models (generally):**
  - LOLH – counts hours with LOL events
  - LOLE – loss of load expectation (i.e. expected value). Can be measured in days, hours, or …
  - LOLEv – counts events
  - LOLH/LOLEv – average length of LOL events
  - EUE – expected unserved energy (MWh, GWh)
  - EUE/LOLEv – average energy lost in LOL event

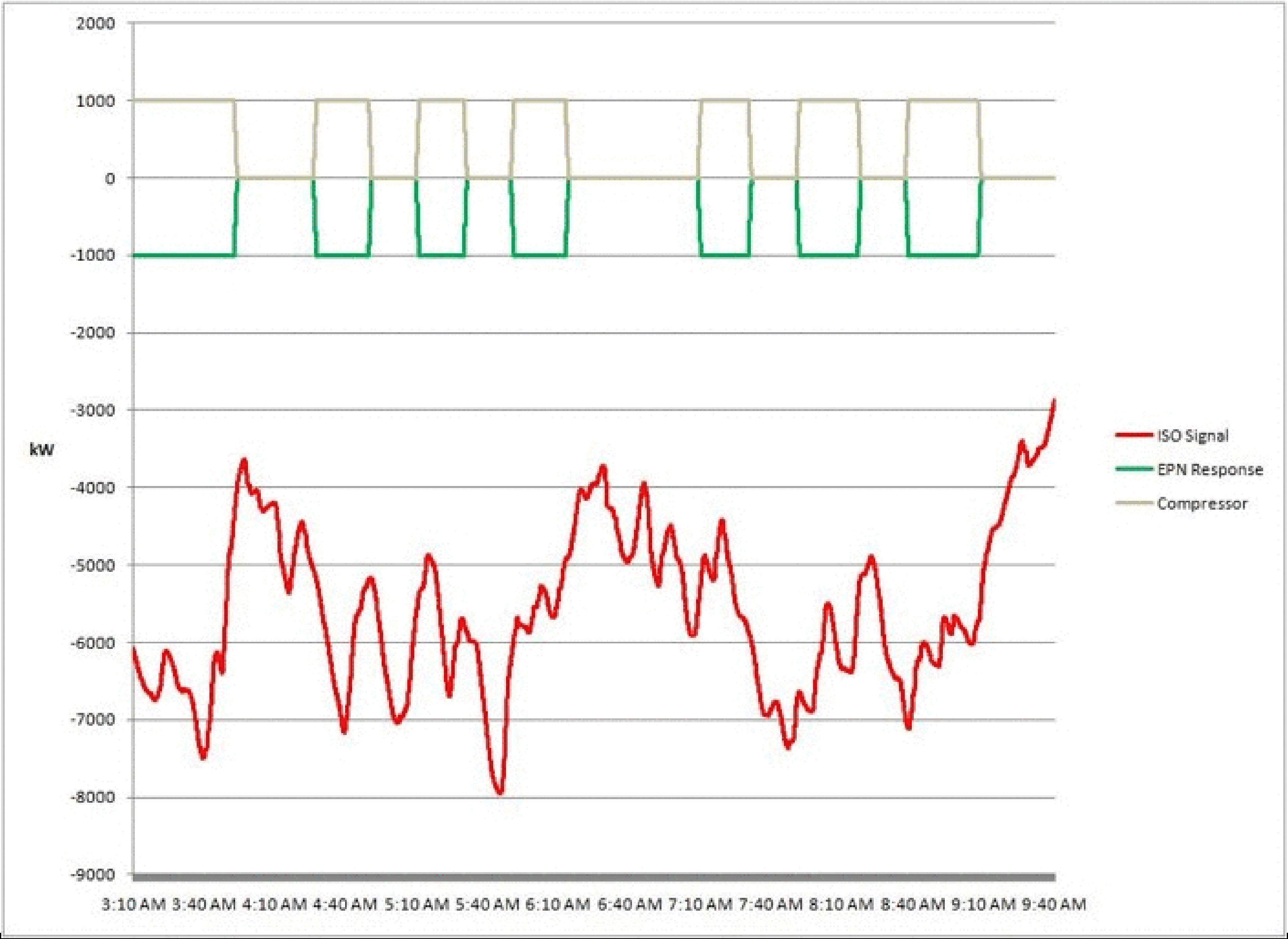
- **Policy (generally):**
  - Planning reserve margin (% by which installed capacity exceeds peak demand)
  - 0.1 d/year (sometimes)
  - Single year of modeling

Example demand response for regulation



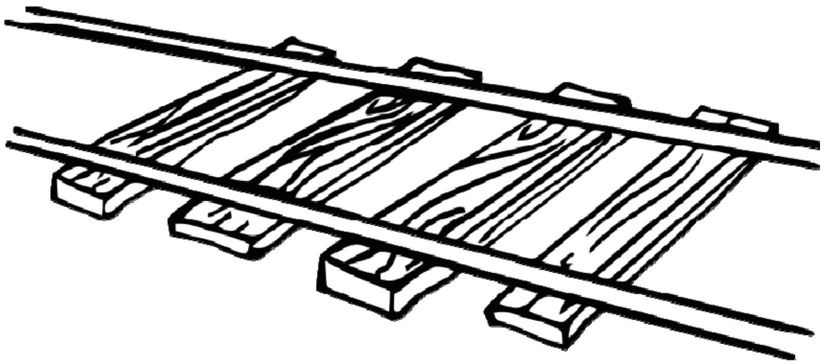
http://enbala.com/solutions.html

Animation


2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
kW
3:10 AM 3:40 AM 4:10 AM 4:40 AM 5:10 AM 5:40 AM 6:10 AM 6:40 AM 7:10 AM 7:40 AM 8:10 AM 8:40 AM 9:10 AM 9:40 AM
ISO Signal
EPN Response
Compressor

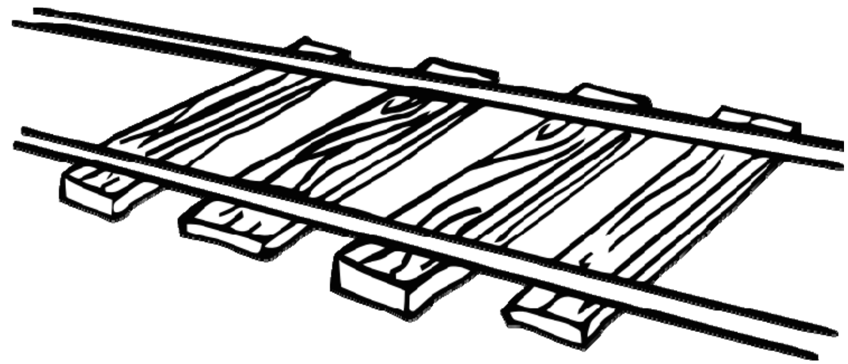
Close the gap between modeling and decision-making

Models



Multiple potential metrics that models can produce today.

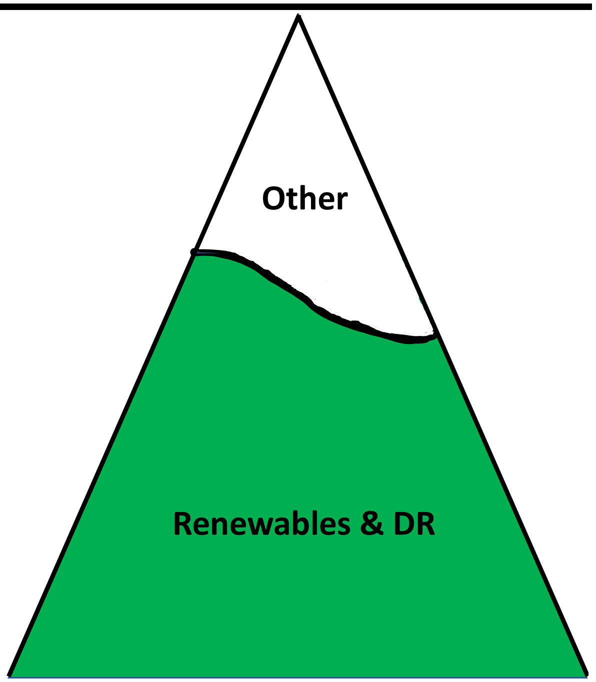
Decision-makers

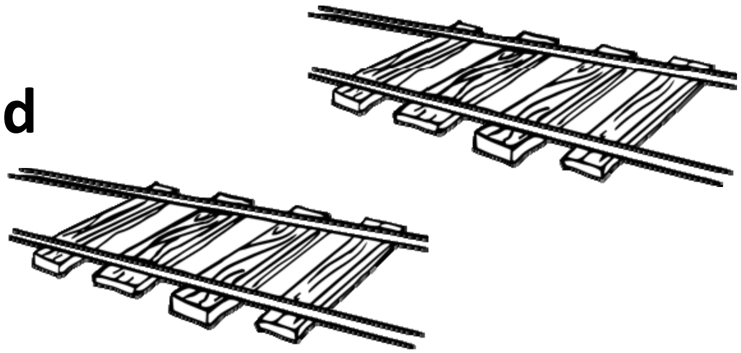


PRM or 1d/10y – often not even calculated properly

Conclude

- We already have much of what we need…in our collective heads/models, but not in practice
- Best practices must evolve – and we need to re-think reliability targets
- Need *common framework* for all resources
- We need to focus more on inter-annual variability inherent in wind/solar/hydro and demand
- We need to pay more attention to dispatchable demand and storage, and continually improve on algorithms
- Integrate transmission and resource planning
- Connect the tracks!



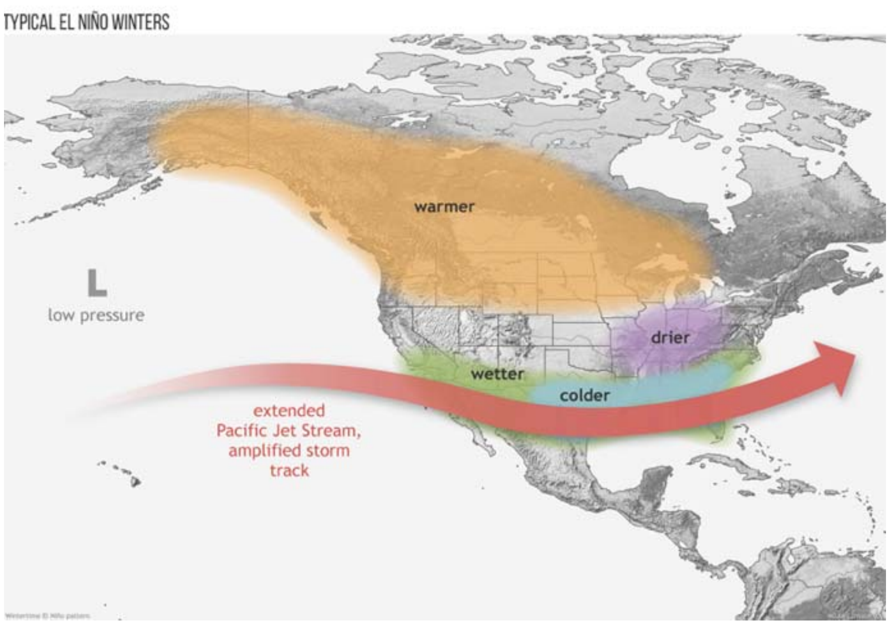


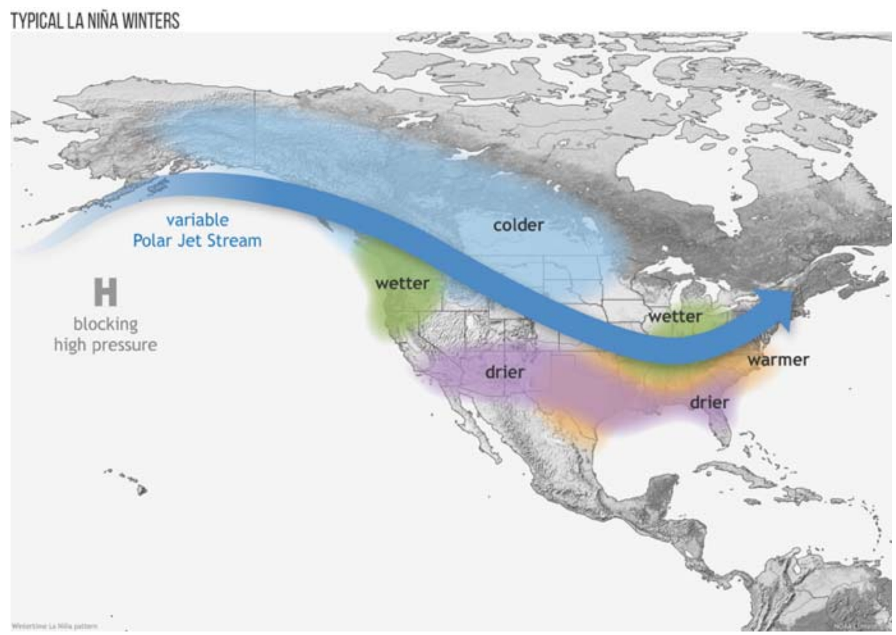

Questions?

Appendix: Long-term adequacy and resilience

Our planning processes are not robust

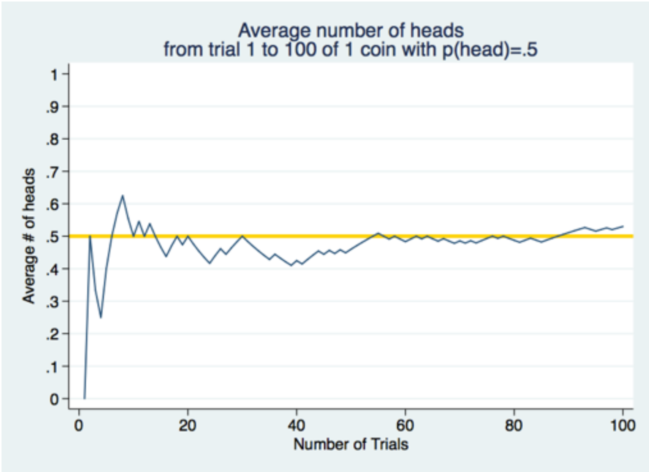
- **As a species, humans don't have the capability to incorporate uncertainty and volatility into planning**
- **Planning is usually done based on "average" or "representative" weather**





Single-mode failure and resilience

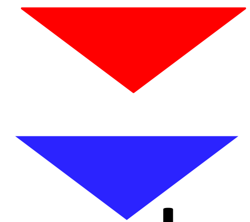
- Less convolution; more Monte Carlo*
- Get the fundamental probability distributions correct (a hard problem)
- Summer vs. winter forced outage rates should be a dependent variable, not an independent variable
- Lack of fuel supply for multiple gas plants
- Create plausible load-weather-RE years (NREL's forthcoming study on extreme weather)
- Explore the corners



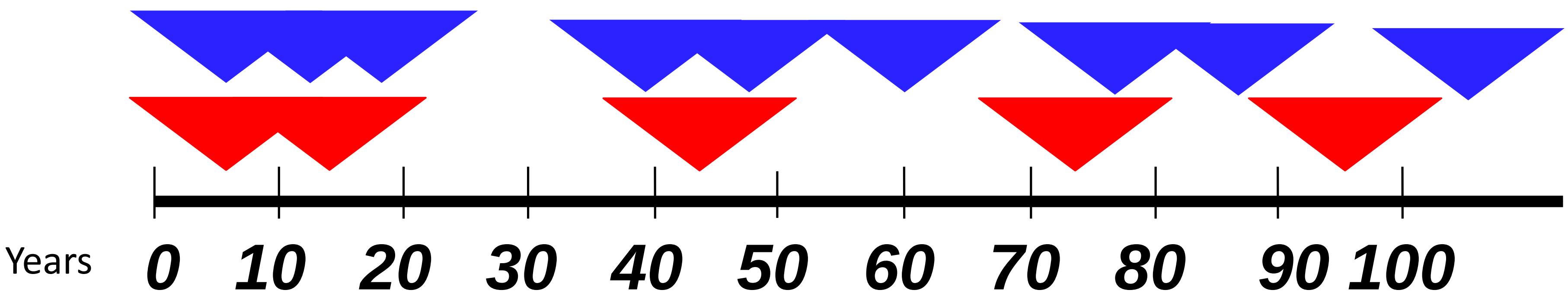
* Convolution example: 100 coin tosses. P(head) = 0.5. Expected heads = 50.
Monte Carlo: Computer "tosses" the coin 100 times. Actual number of heads will be "close" to 50. Also results in 100 "scenarios" of coin toss

Infrequent events

- **What is the risk of**
  - o "major" heat storm every 20 years
  - o "major" polar vortex every 13 years

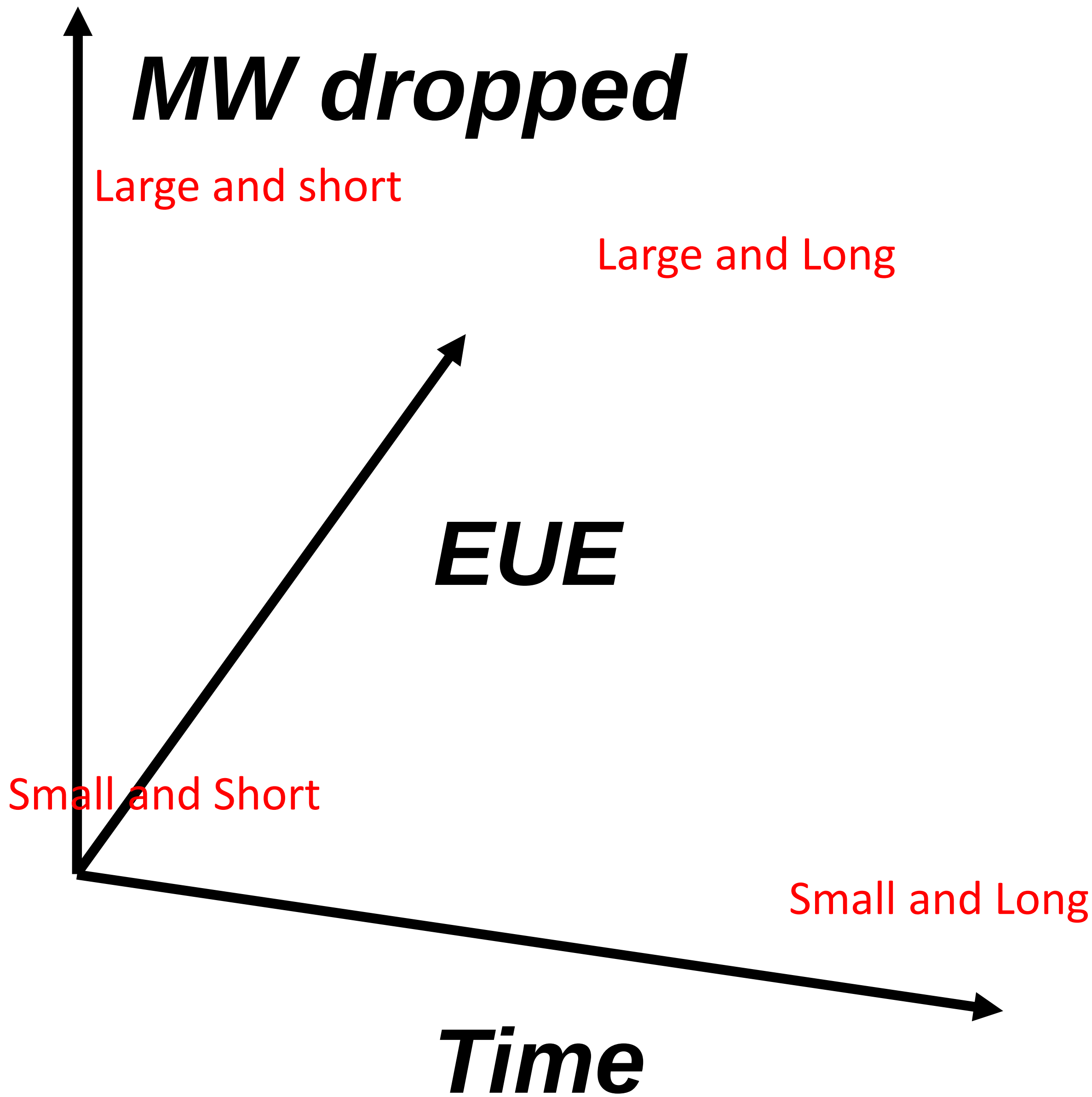


- **And how do collect good data sets and assess resilience?**



- **How to account for impact of climate change on these variables?**

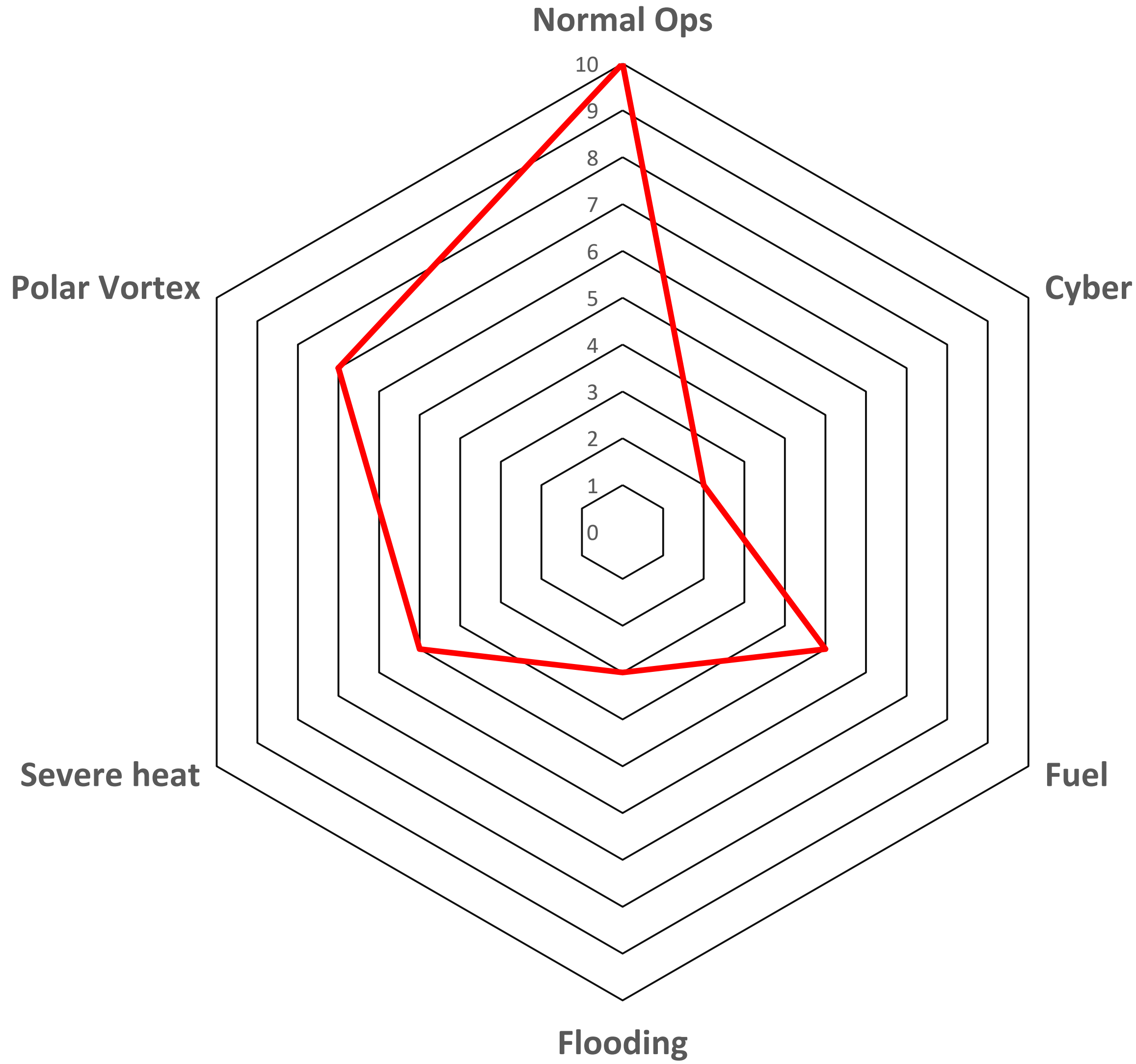
Multiple dimensions



Issues in assessment

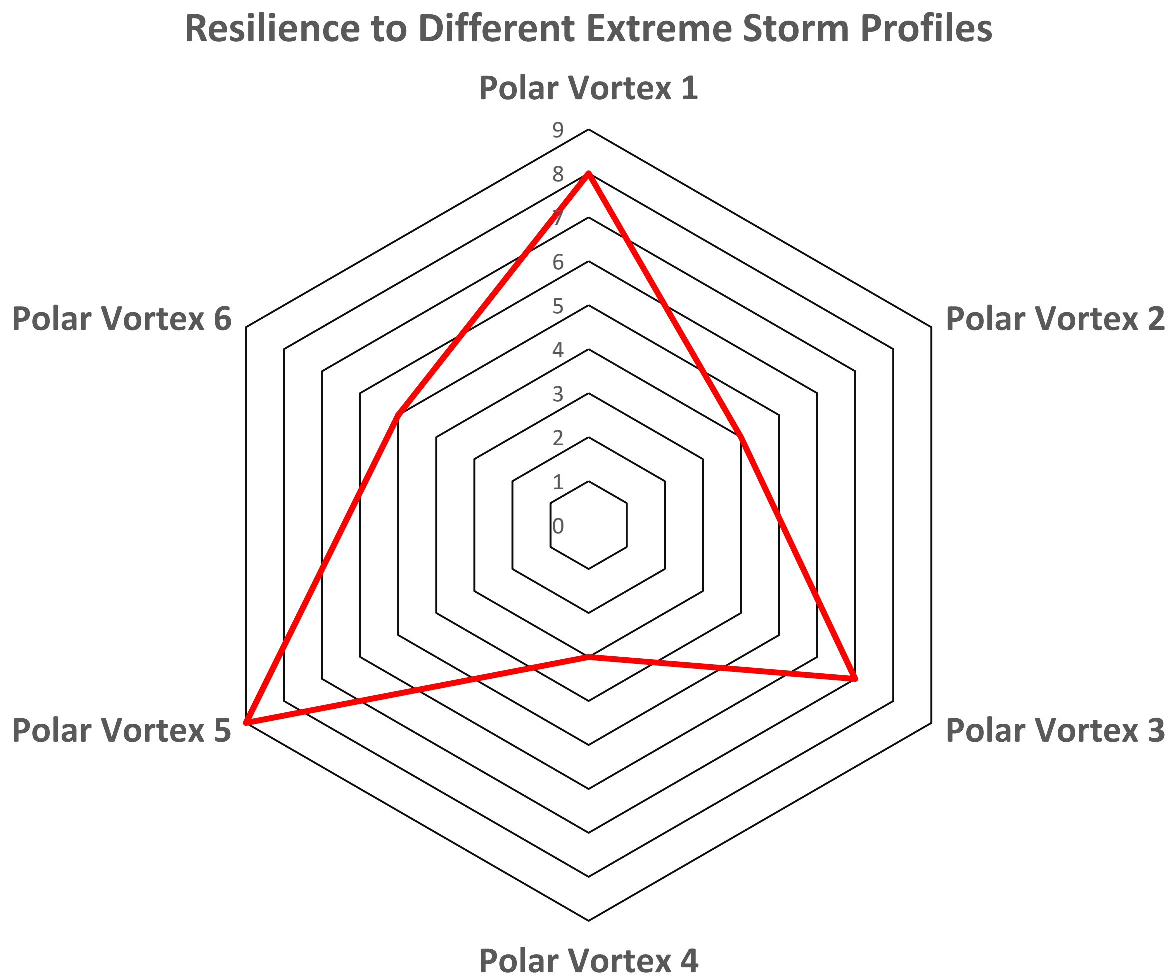
- **See NREL's forthcoming report on extreme weather**
- **Is event outside "normal" data sets?**
- **How to define large-scale threats; i.e. what happens and where? What damage/outages?**
    - Use extreme weather scenarios as inputs
    - NERC/National Labs archive for power sector use
- **Each region will have different risk profile, for example:**
    - SERC: hurricanes
    - SPP/MISO: tornados
    - ISO-NE/MISO: cold weather, gas supply disruption
    - CAISO: forest fires
- **Normalize reliability score to scale 0-10 based on metric of choice (LOLH, EUE, ??). 10= resilient, 0=failure**

Example Resilience Diagram



Scoring: 10=reliability target met; 0 = severe outages

Resilience to different storm profiles



Scoring: 10=reliability target met; 0 = severe outages

Questions?