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Capacity Value of Wind Plants and Overview of U.S. Experience



Composite photo created by NREL

PSCC

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Aug 22, 2011

NREL/PR-5000-52856

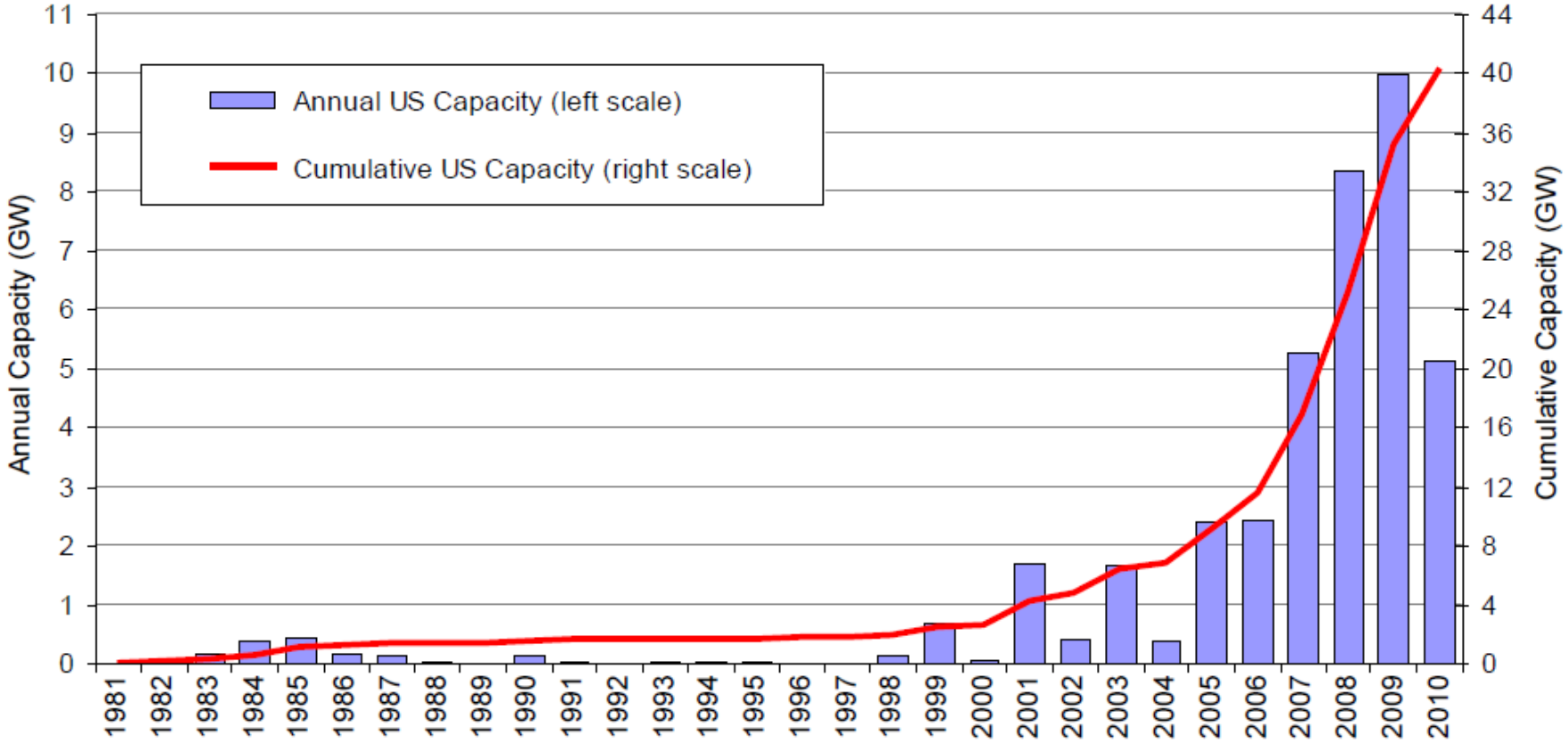
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Integration Issues in the U.S.

U.S. Experience Overview

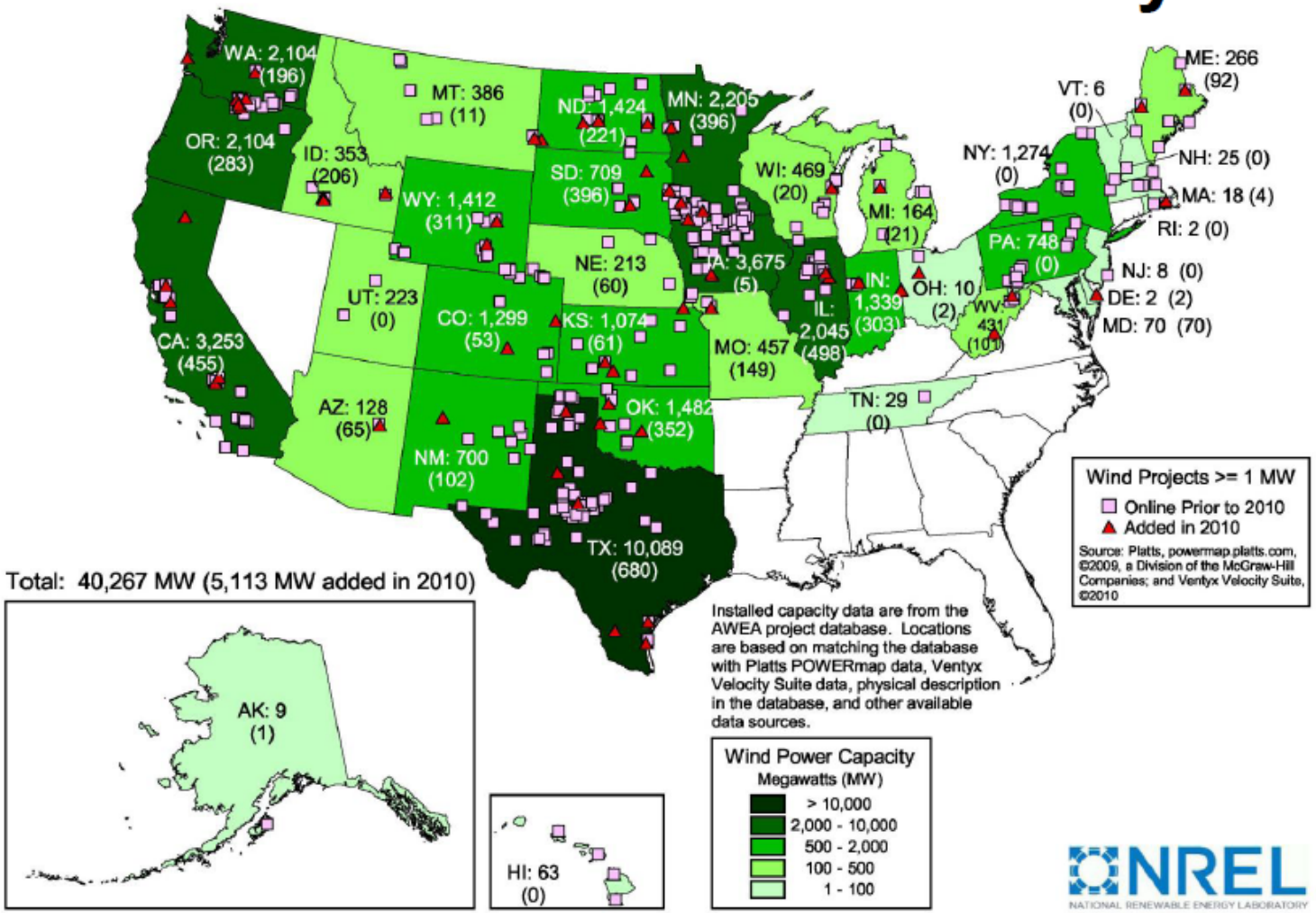
- Overview of U.S. Wind status and the interconnected system;
- Integration studies and key results;
- Selected interesting wind events;
- Selected future directions.

U.S. Wind Power Additions Slowed in 2010

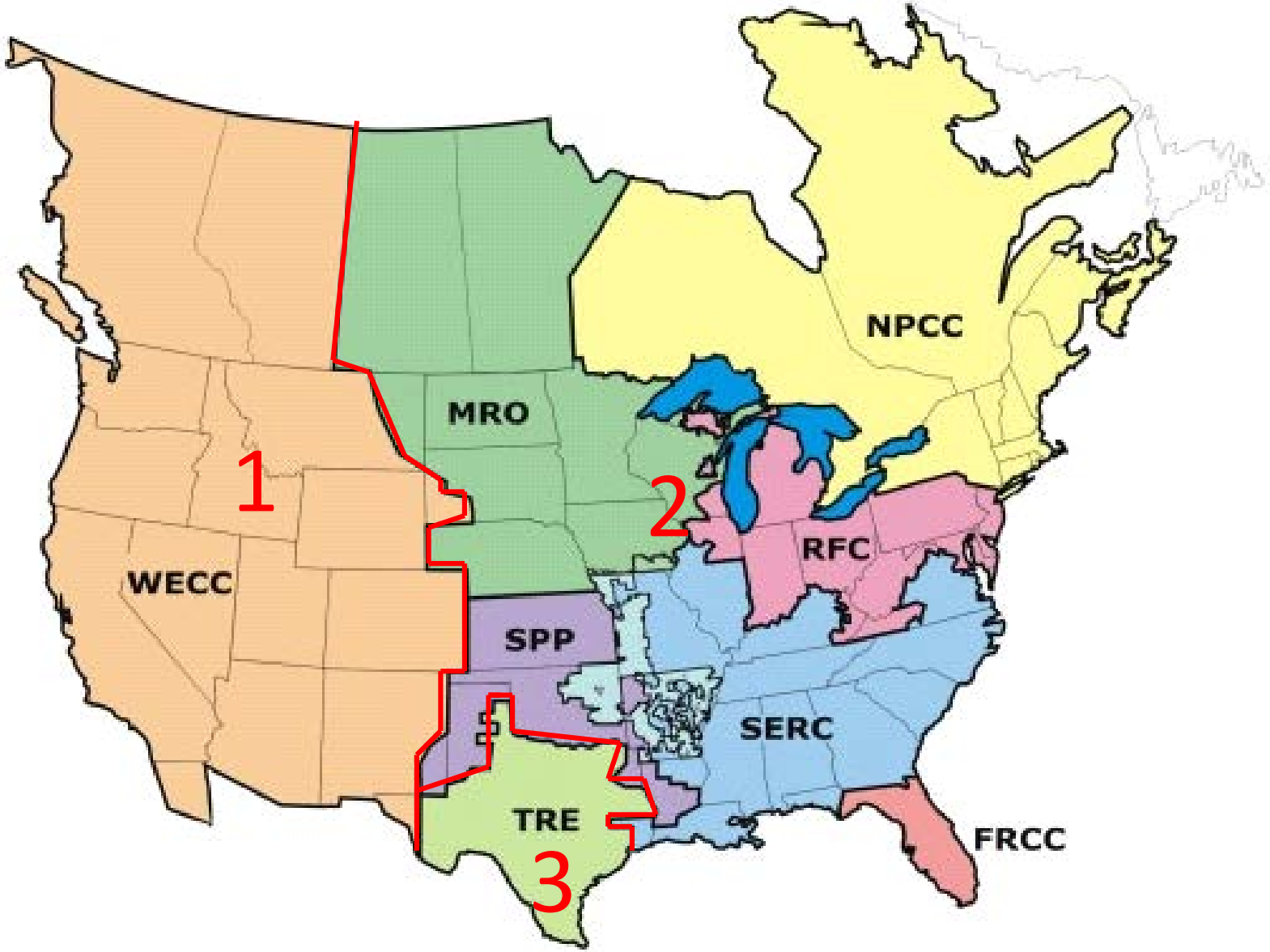


- 5.1 GW of wind power added in 2010 in US, $11 billion in project investment
- Cumulative wind power capacity up by 15%, bringing total to >40 GW
- Factors slowing growth: (1) delayed impact of financial crisis; (2) low natural gas / wholesale electricity prices; (3) slumping overall demand for energy

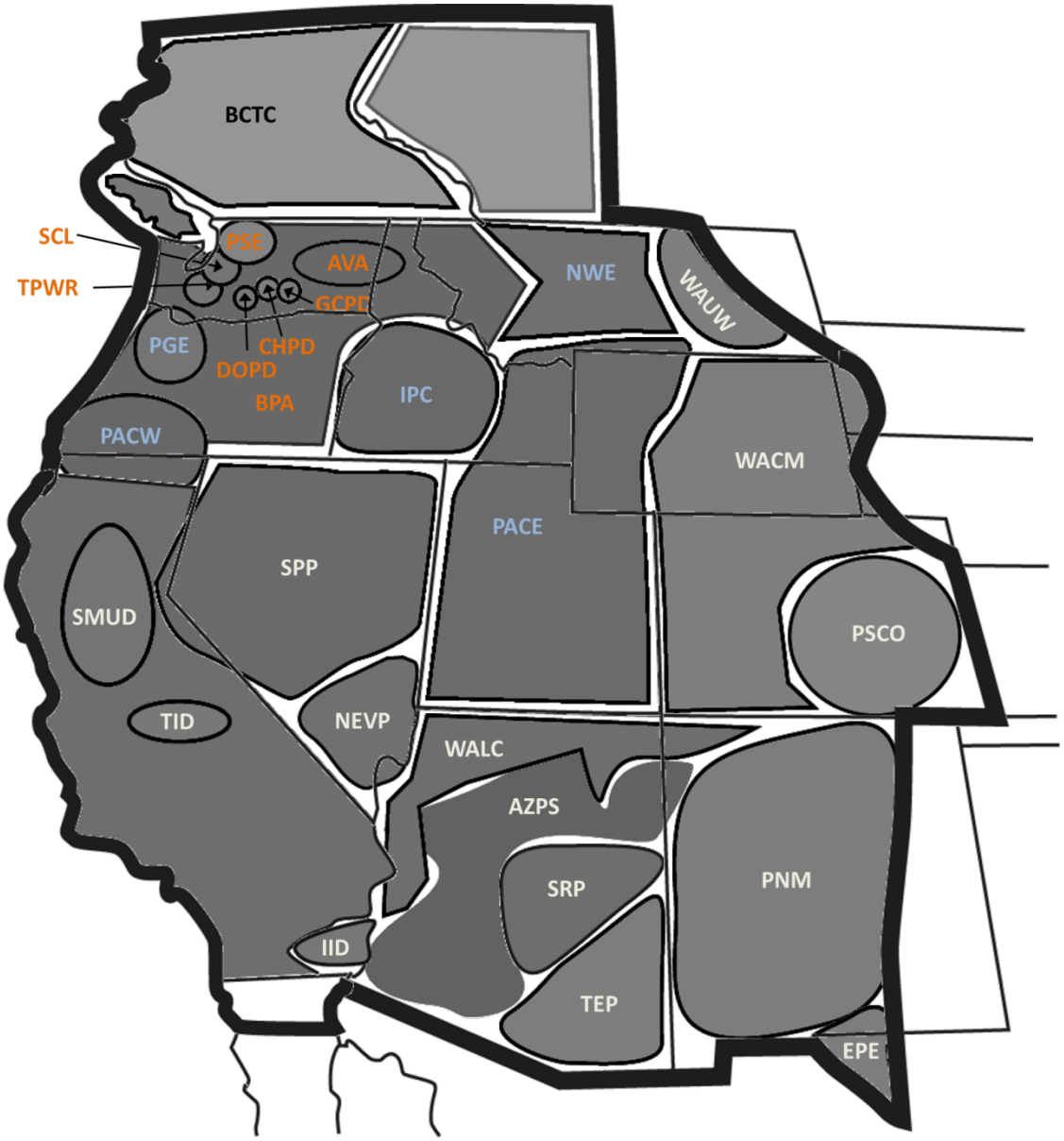
Geographic Spread of Wind Power Projects in the United States Is Reasonably Broad



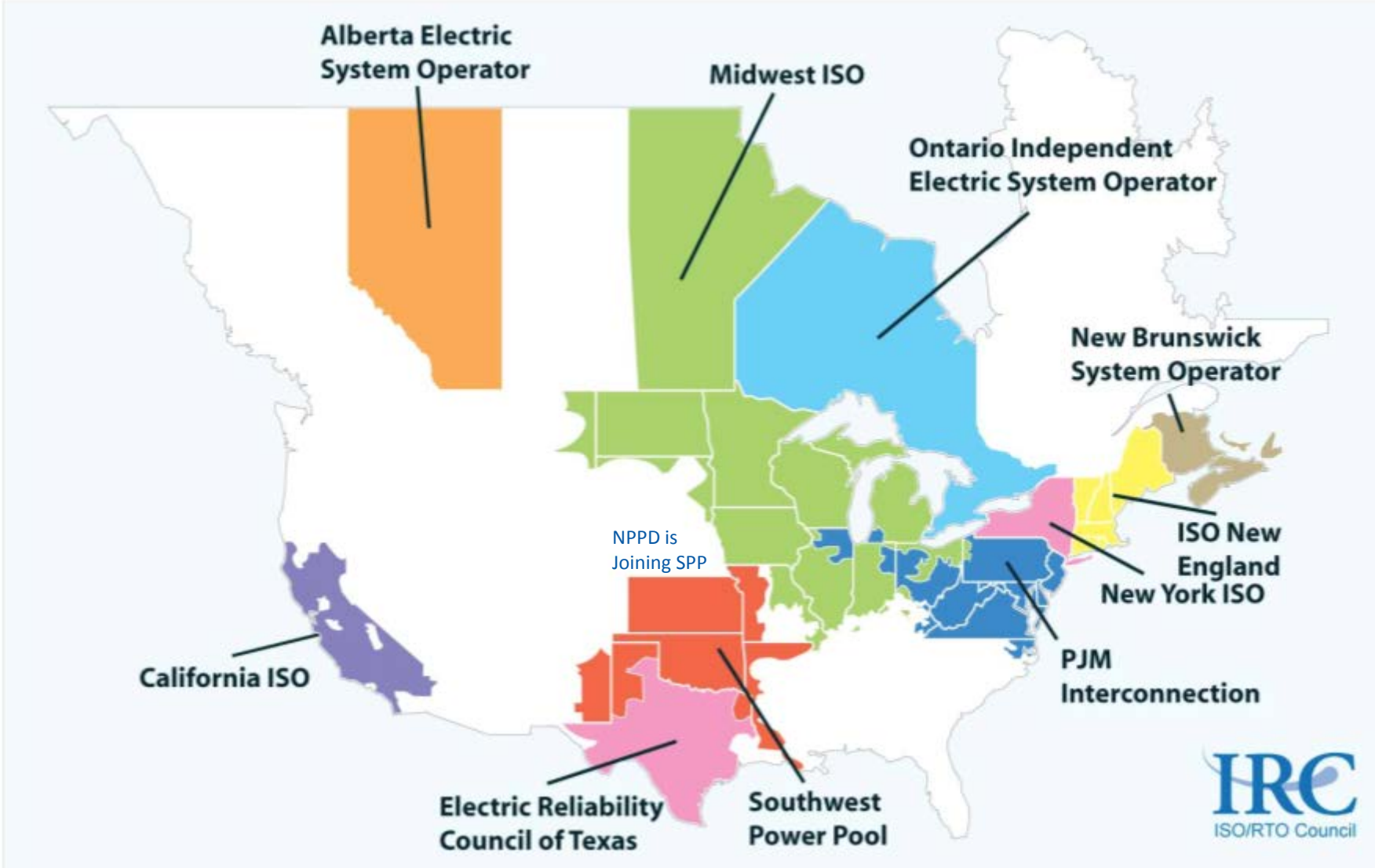
There are 3 interconnections in the U.S.



There are many control areas (balancing areas) in the West

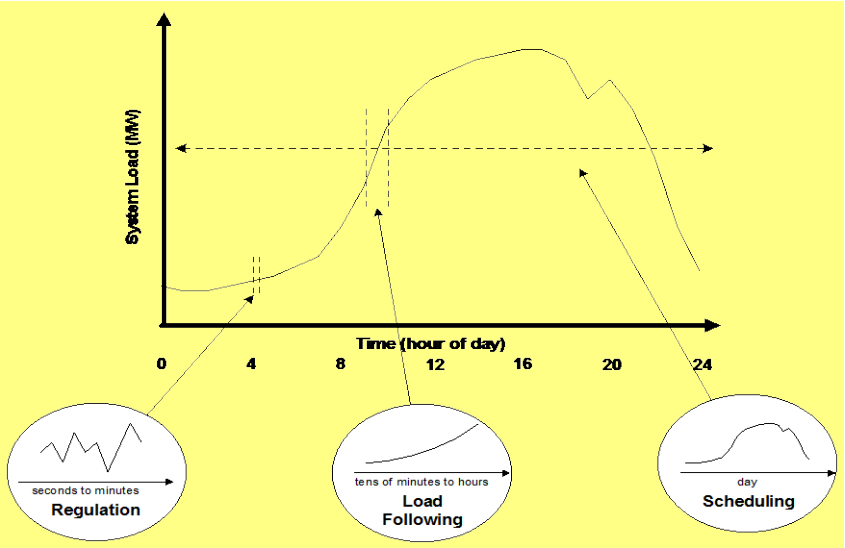


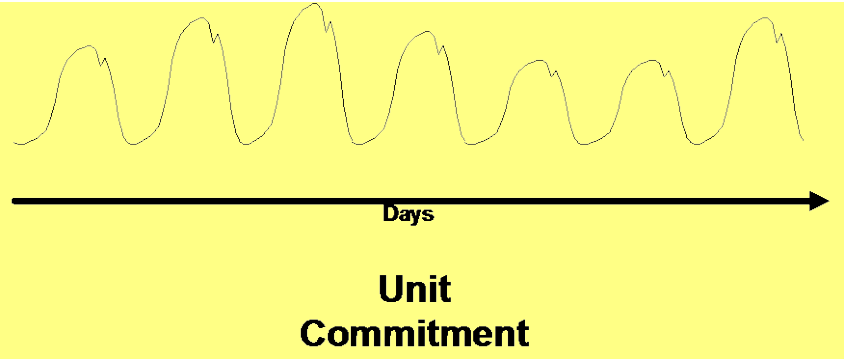
Markets cover part of the U.S.



Power System Basics

- Portfolio of different type of generators are managed so that the sum of all output = load at each moment.
- Base-load generators run at constant output.
- Intermediate/cycling units pick up daily load swings.
- Peaking units are seldom run but provide peak capacity when needed.

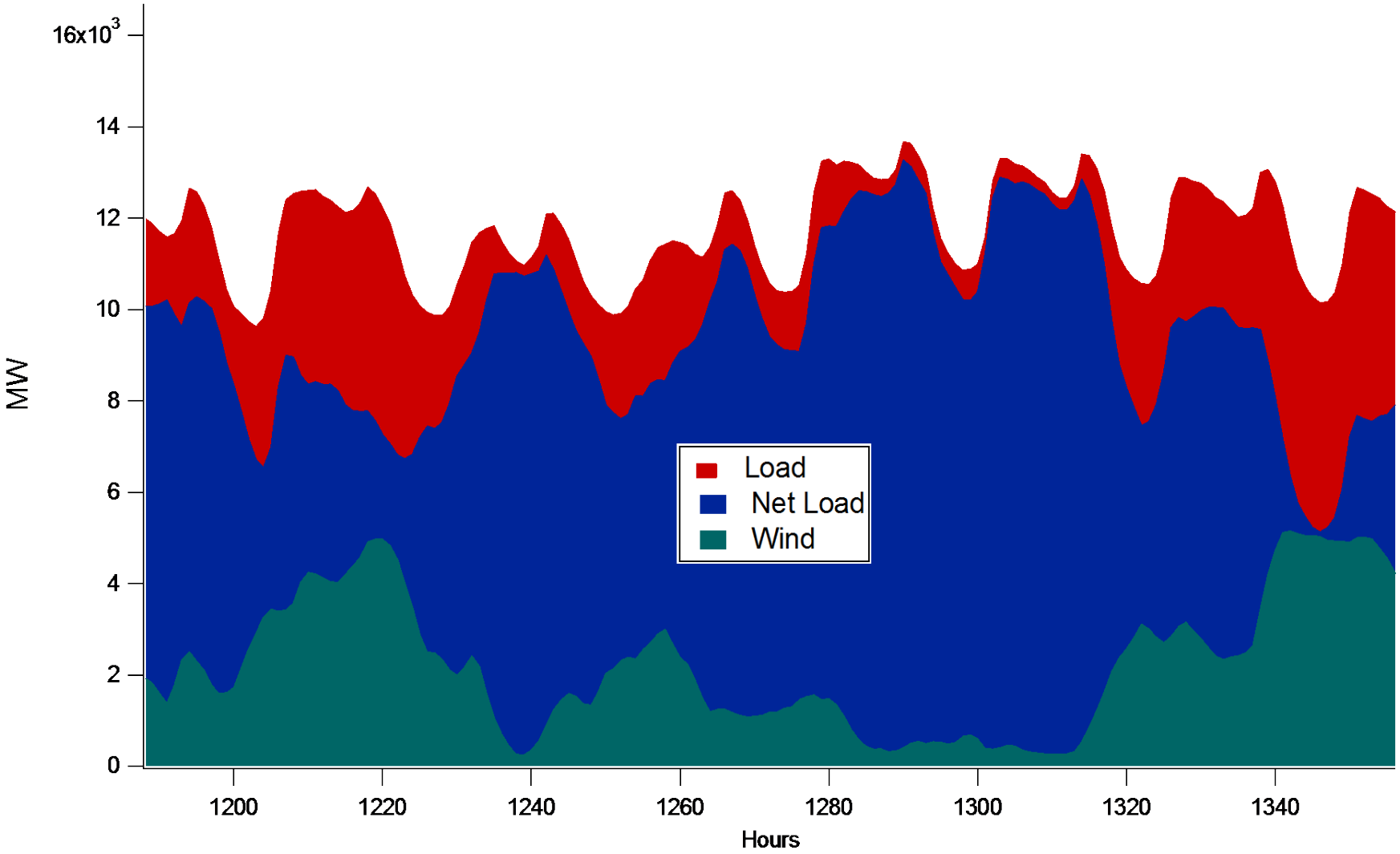




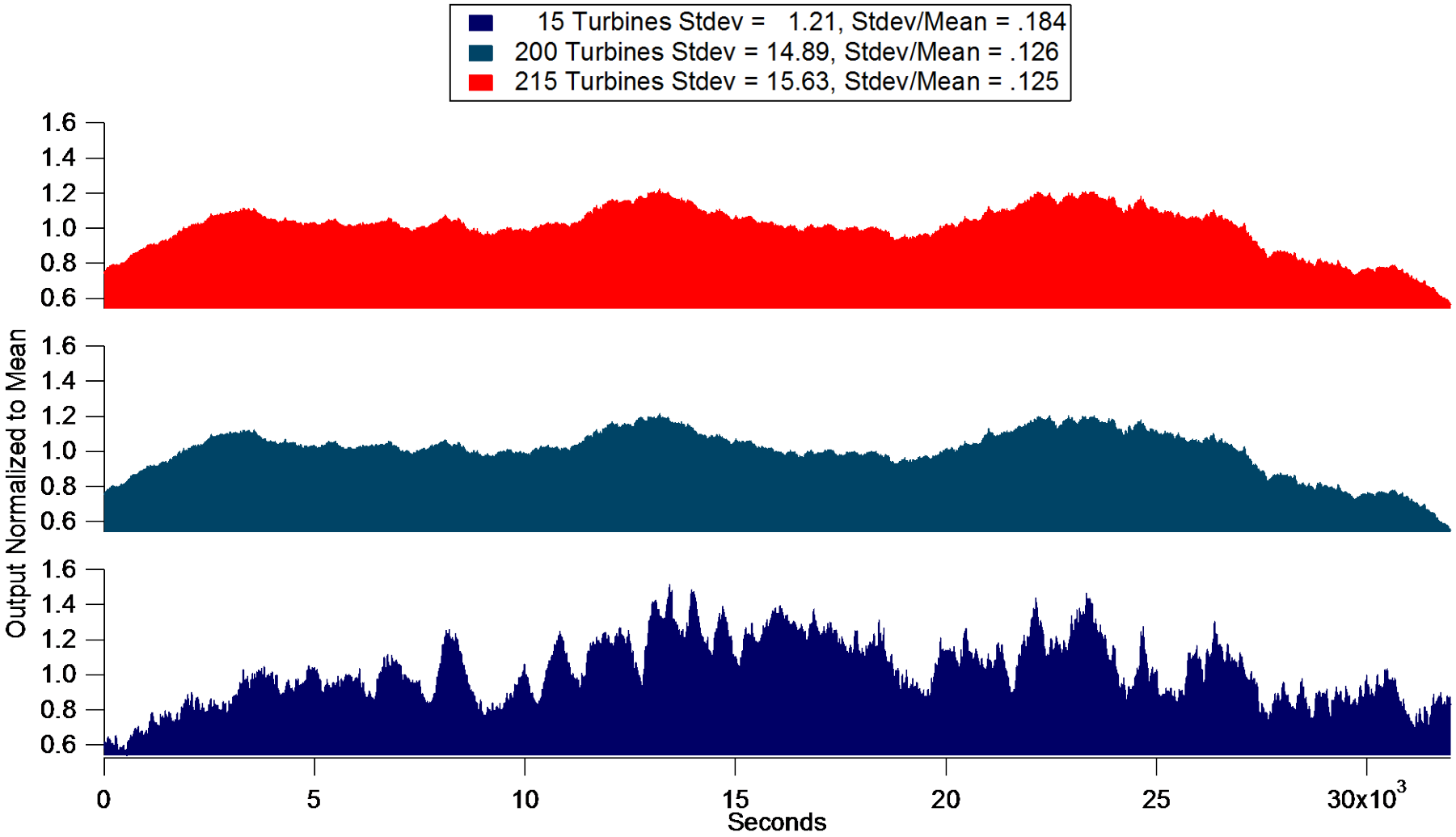
Power System Basics (cont)

- Extra generation – reserves – available in case of generator or transmission outage: *Contingency reserves.*
- Some generators can change output and are used to manage ***variability*** in load (demand).
- The demand for power is not known with certainty so may influence the level of reserves for managing this ***uncertainty.***
- Wind increases the level of ***variability*** and ***uncertainty*** that the power system operator must manage.

Load-less-wind = net load



Wind output is smoothed with geographical dispersion



(Approximately 8 hours)

Large-Scale Wind Integration Studies

- Sponsored by U.S. DOE, managed by NREL.
- Eastern Wind Integration and Transmission Study, released Jan 20, 2010. www.nrel.gov/ewits
- Western Wind and Solar Integration Study, released in Mar 2010. www.nrel.gov/wwsis.
- These studies show that up to 30% (and 5% solar in the west) can be integrated reliability and economically if operational practices can provide additional flexibility thru institutional changes.

Integration Studies

Detailed power system simulations follow operational practice.

Data from power system industry

Wind data.

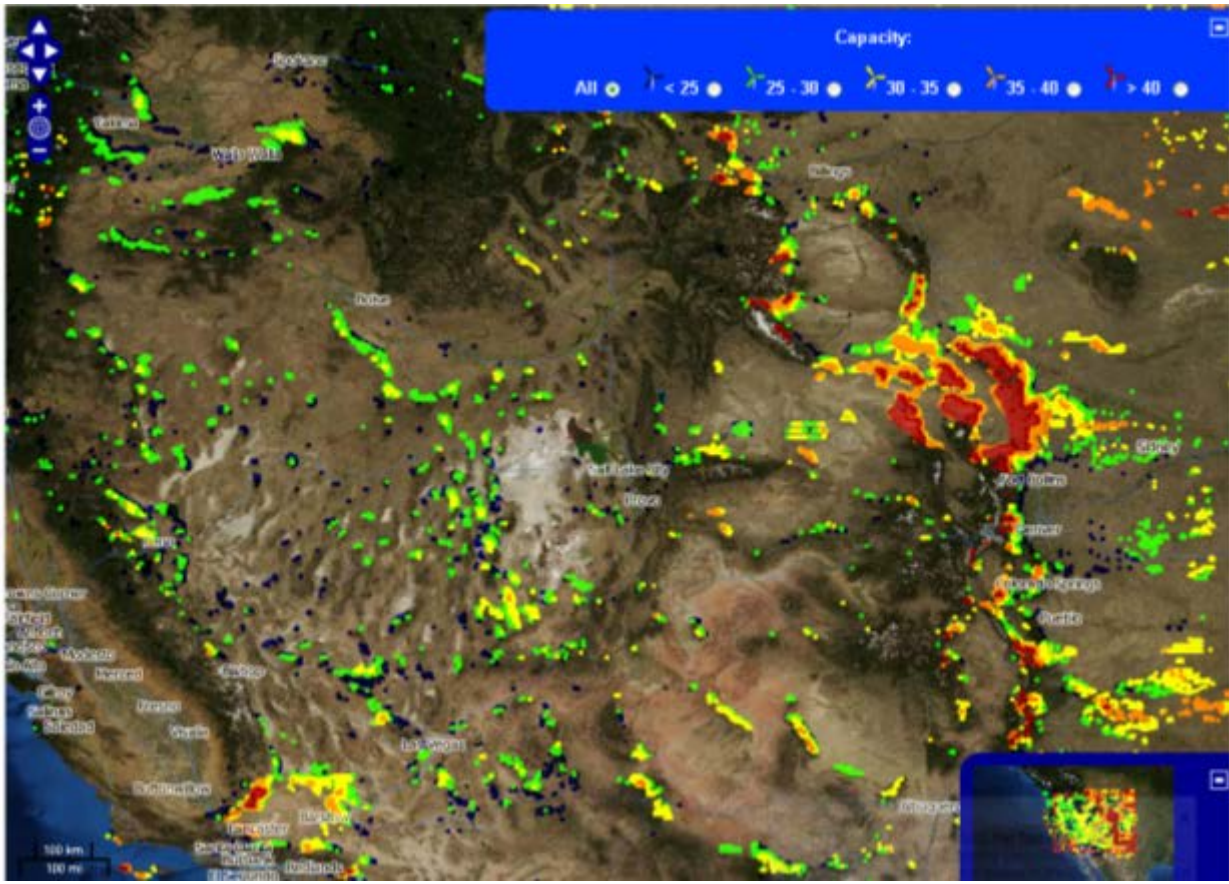
- Actual wind plant data.
- Simulated wind data for future wind build-out.

Data requirements are stringent so that the variability of wind plants is accurately represented in the power system operations modeling.

Other power system data must be consistent, robust, accurate.

Atmospheric models

- Mesoscale meteorological modeling that can “re-create” the weather at any space and time.
- Maximum wind power at a single point ~ 30 MW to capture geographic smoothing.
- Model is run for the period of study and must match load time period.
- Wind plant output simulation and fit to actual production of existing plants.
- See www.nrel.gov/wwsis for details and validation



Integration Study Results

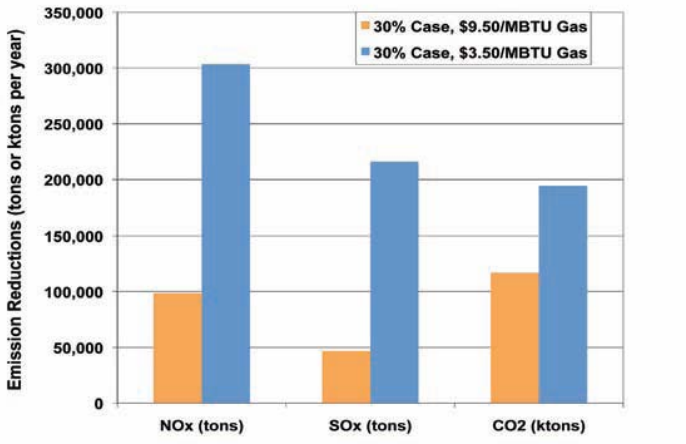
Study results show that wind energy can be integrated into power systems reliably and economically; in some cases operational practice must change.

Most studies have rigorous technical review teams, comprised of power system industry experts.

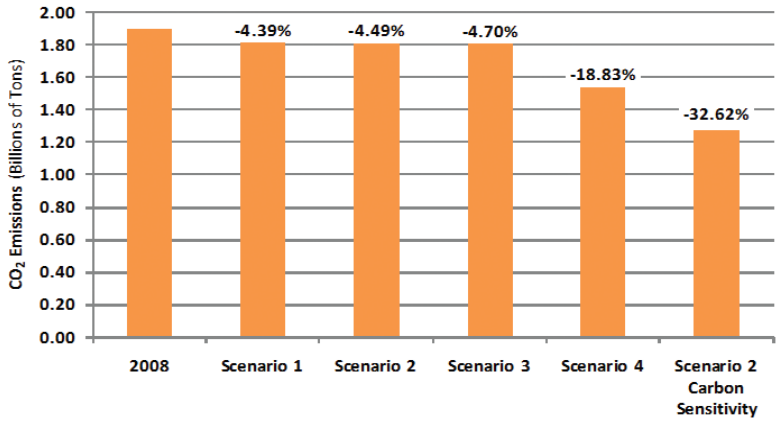
Utility Wind Integration Group: Industry Exchange for wind integration challenges and solutions.

www.uwig.org contains most integration study results.

Wind reduces emissions, including carbon



At high prices natural gas is displaced by renewable generation, leaving coal plants to handle variability at lower emissions reductions. When coal is displaced instead, greater emission reductions are observed.



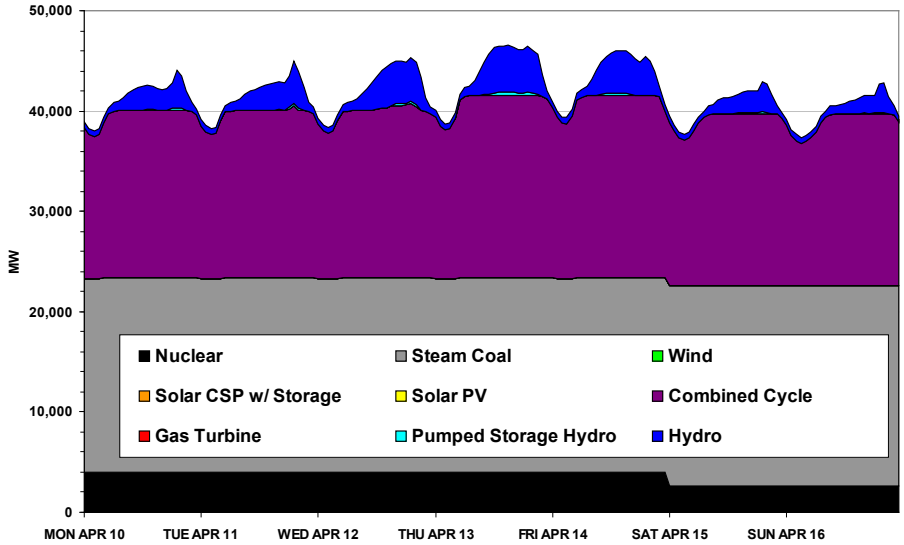
Scenarios 1-3 are for 20% wind power penetration, with various combinations of new transmission and offshore wind farms, while Scenario 4 is for 30% wind power penetration. Scenario 2 Carbon Sensitivity includes the results if a $100/ metric ton carbon tax were imposed.

Western Wind and Solar Integration Study, www.nrel.gov/wwsis.
Every 3 wind-generated MW reduces thermal commitment by 2 MW.

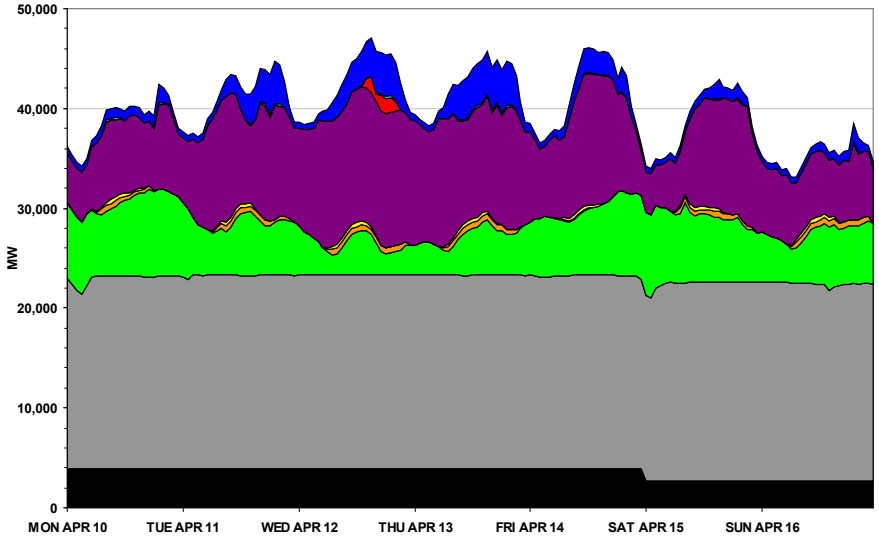
Also see *Impact of Frequency Responsive Wind Plant Controls on Grid Performance*, Miller, Clark, and Shao. 9th International Workshop on Integration of Wind Power into Power Systems, Quebec, Canada, October 2010.

Results show decline from 2008, also eliminating any increase in carbon from 2008-2024. www.nrel.gov/ewits. Overall reduction in emissions in study year is estimated to be approximately 33-47%, depending on wind energy penetration scenario.

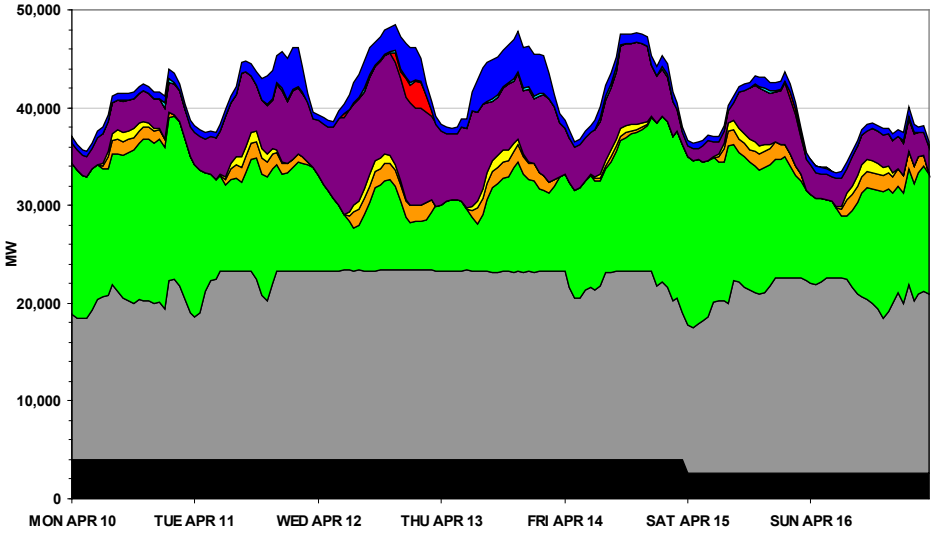
Study Area Dispatch - Week of April 10th - No Wind



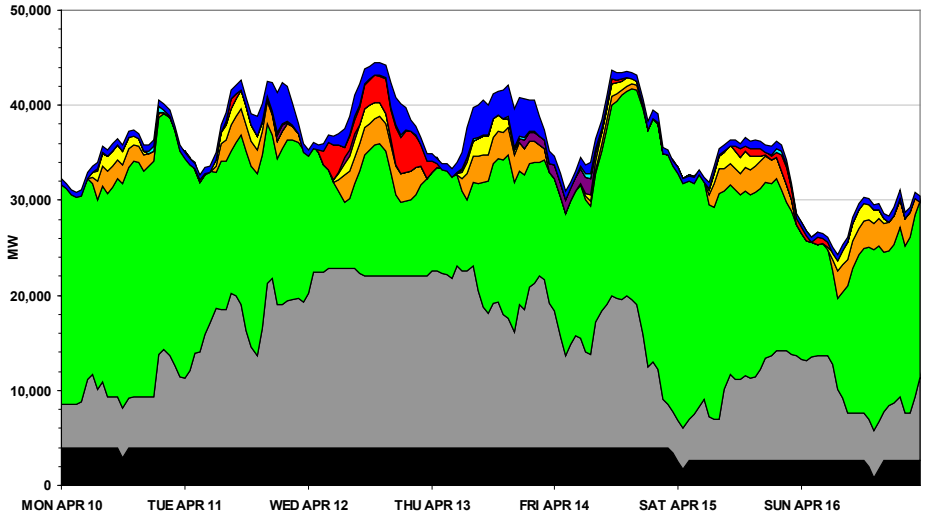
Study Area Dispatch - Week of April 10th - 10%R



Study Area Dispatch - Week of April 10th - 20%R

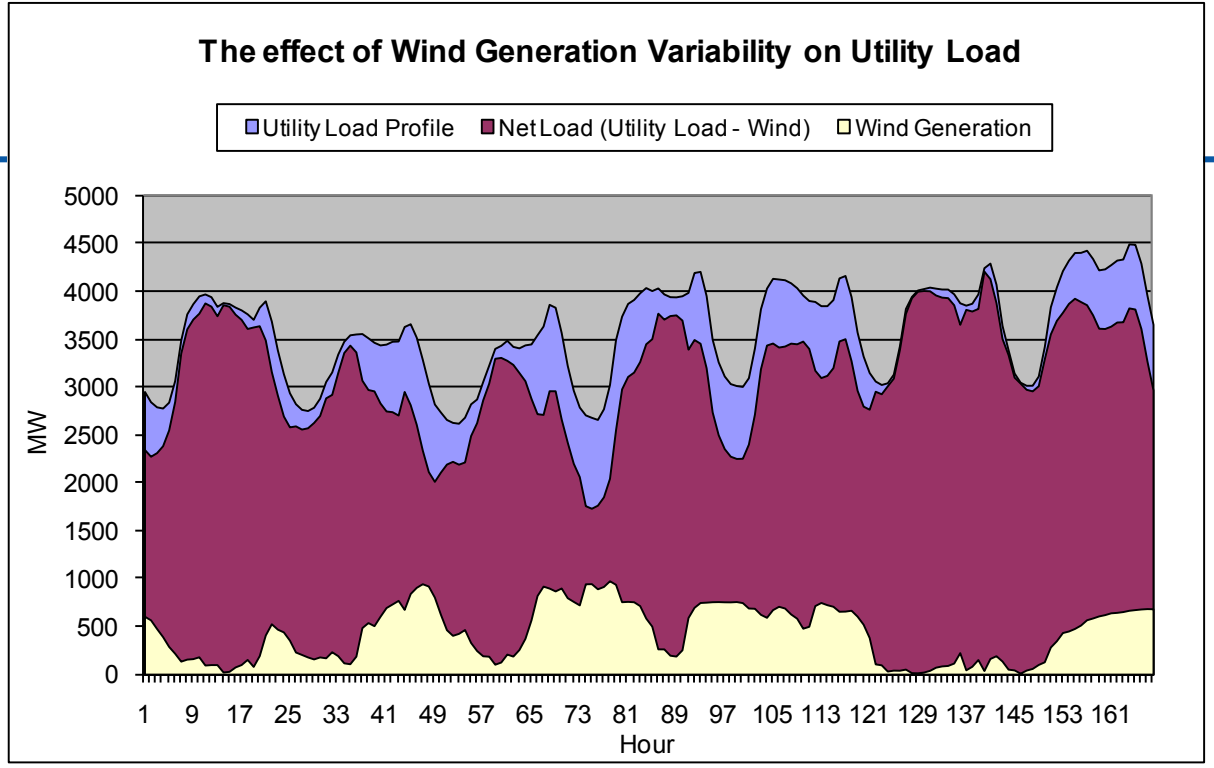


Study Area Dispatch - Week of April 10th - 30%R

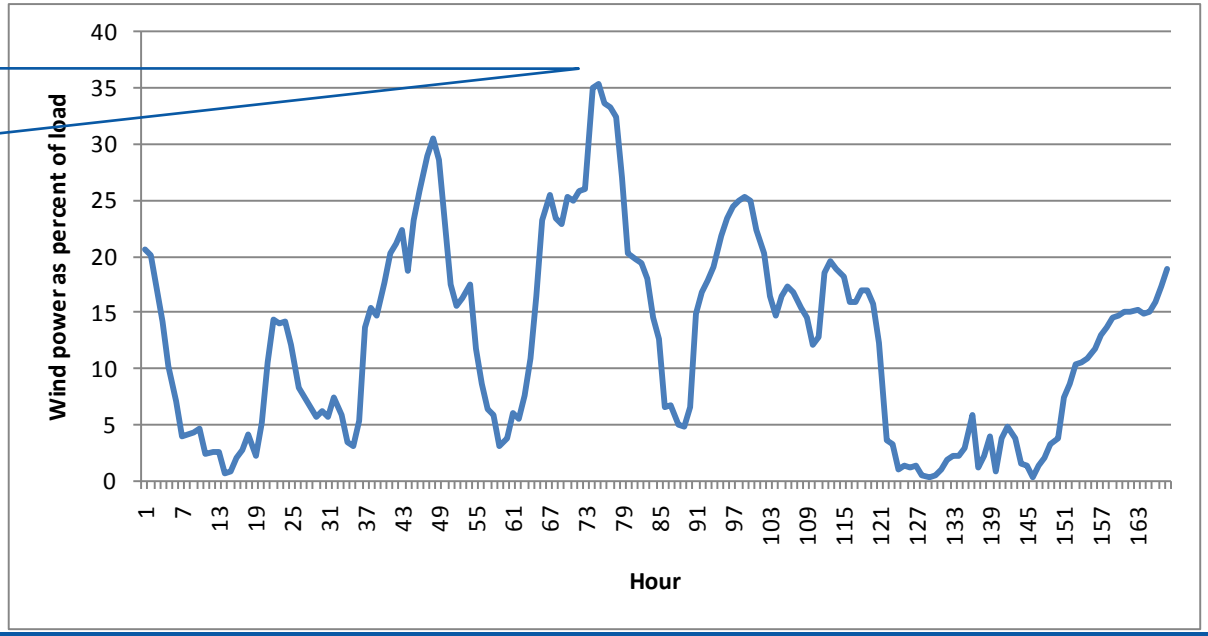


Selected Events

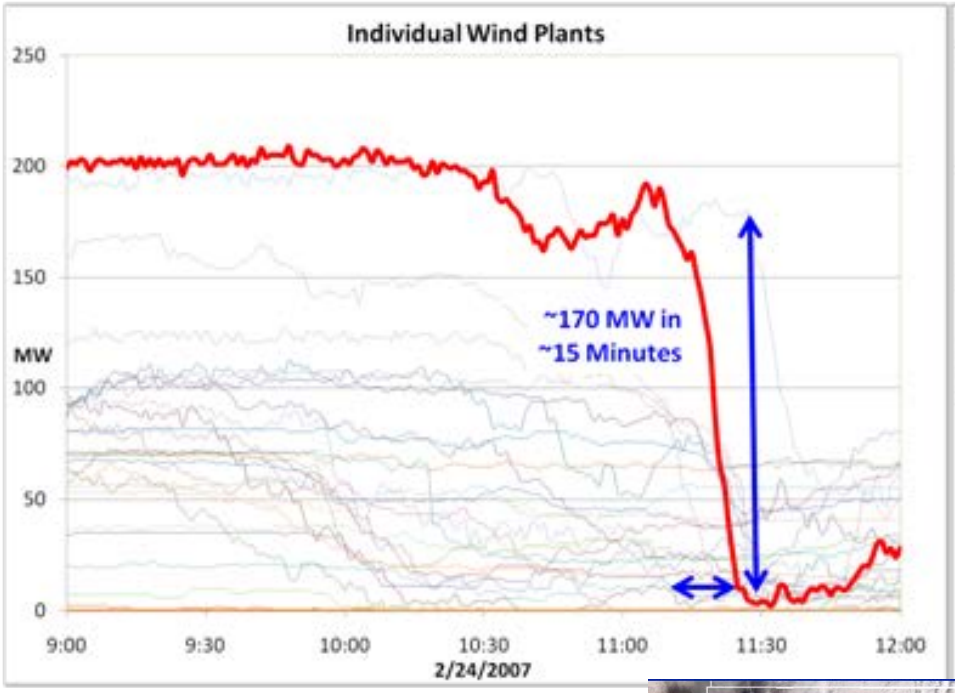
Example week, utility in the Western U.S.

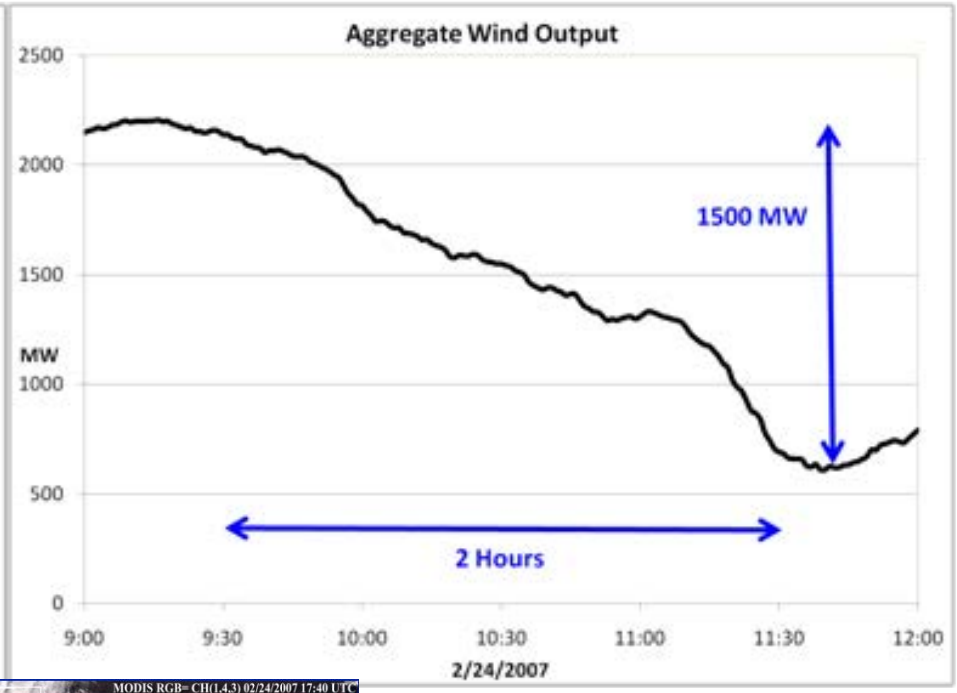


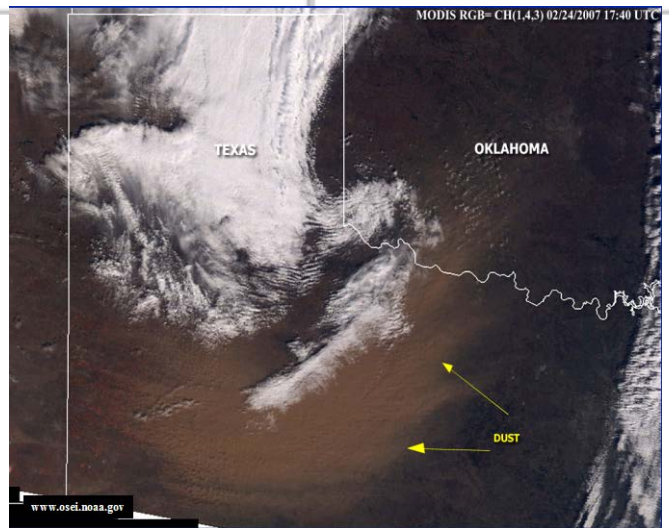
35% instantaneous penetration



Texas events show wind is slower than contingency

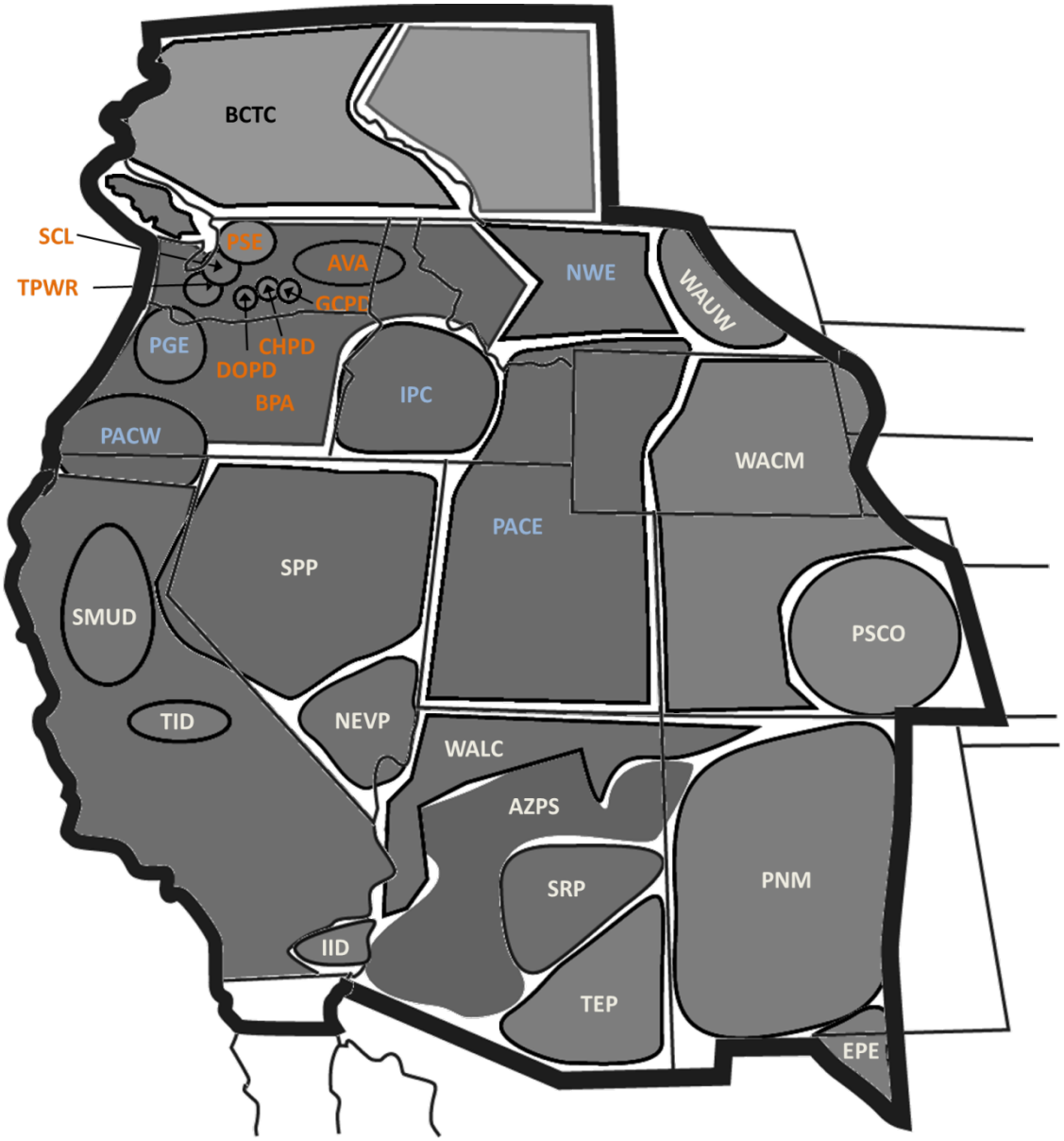




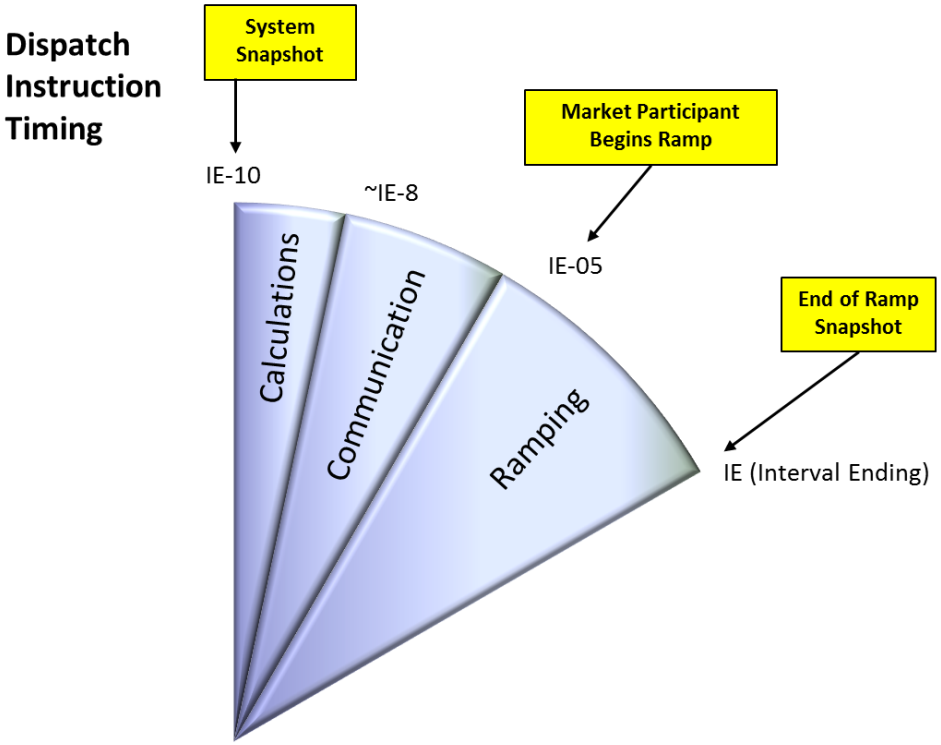


Source:
NREL/TP-500-43373, ERCOT, and WindLogics

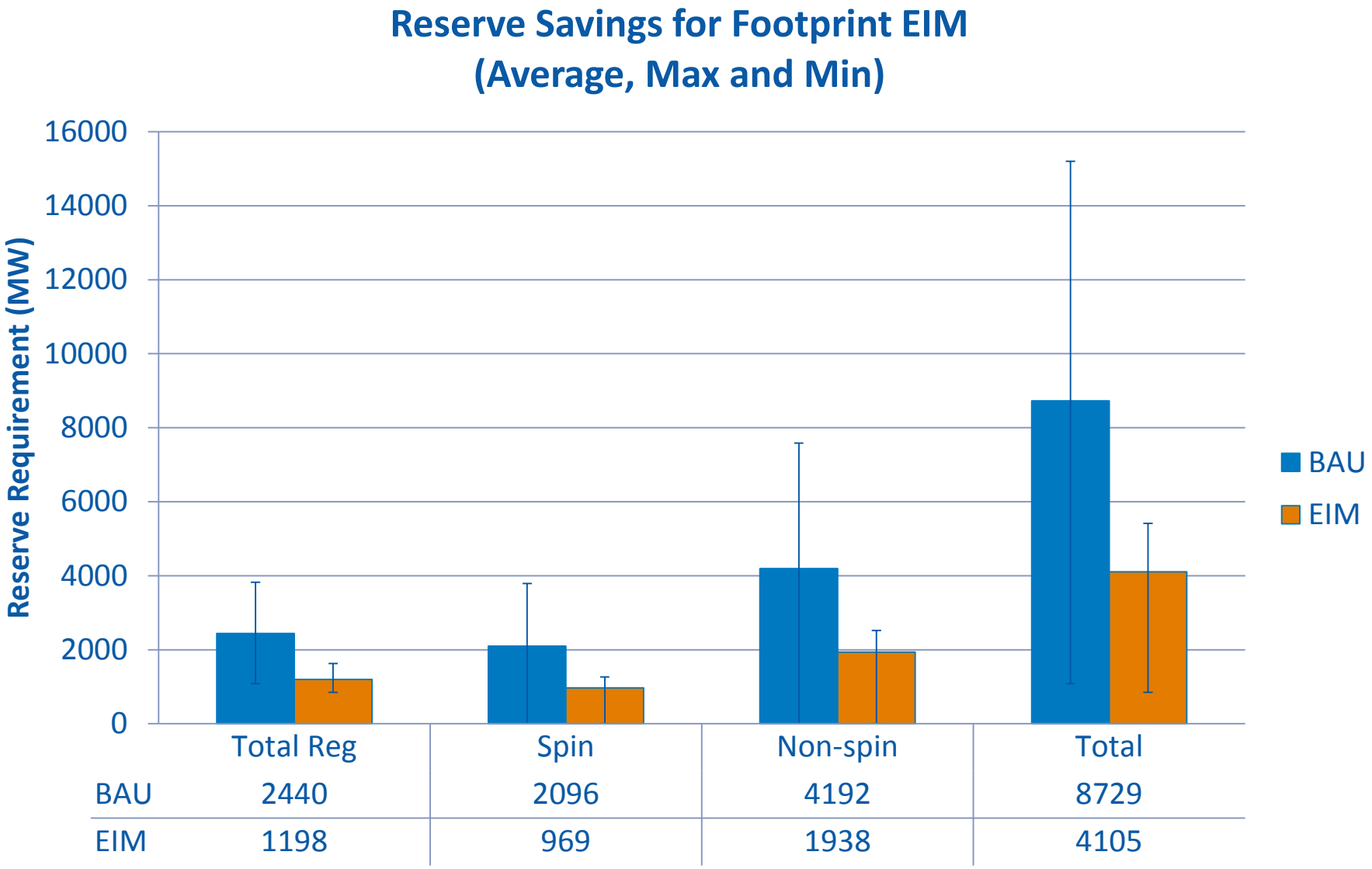
The Western Interconnection is proposing an Energy Imbalance Market



Ten-Minute Deployment Interval



NREL is calculating reserve deployment impacts

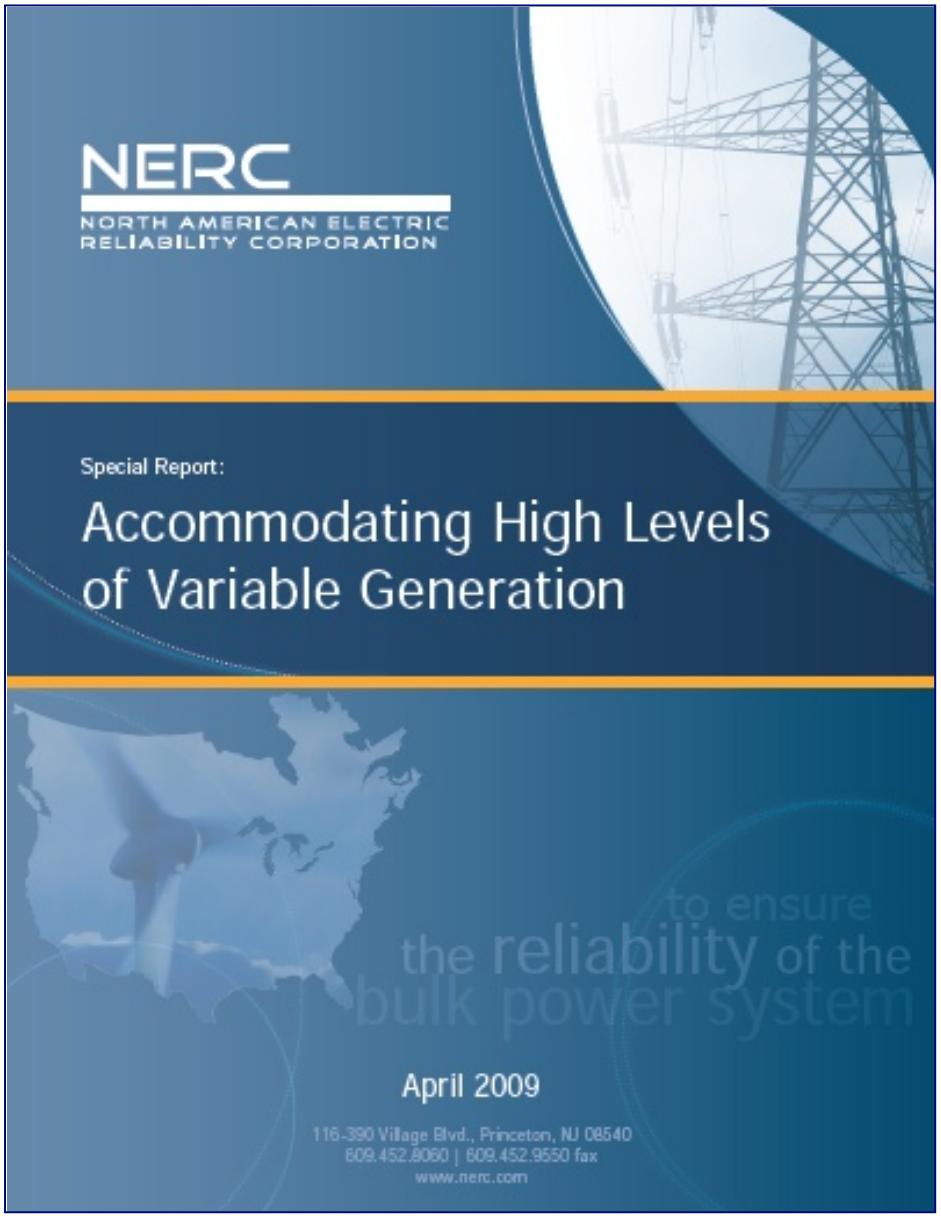


Reliability Organization Task Force

Not a question of “if.”

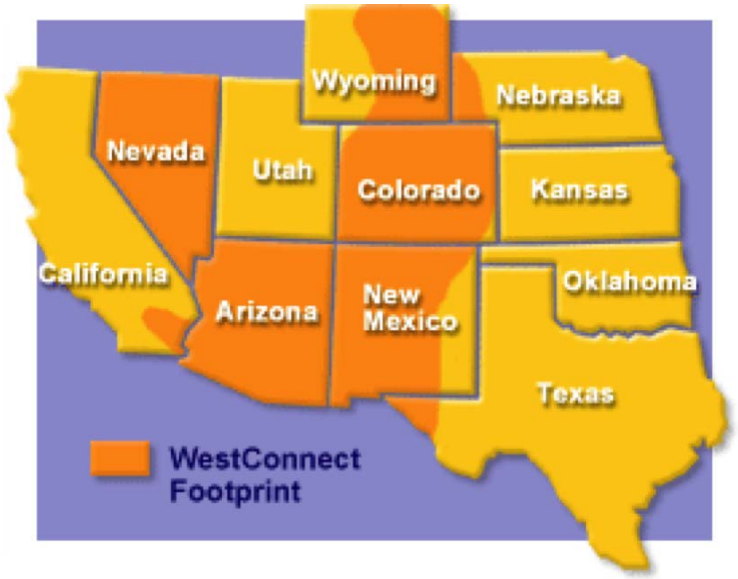
It is a question of “how.”

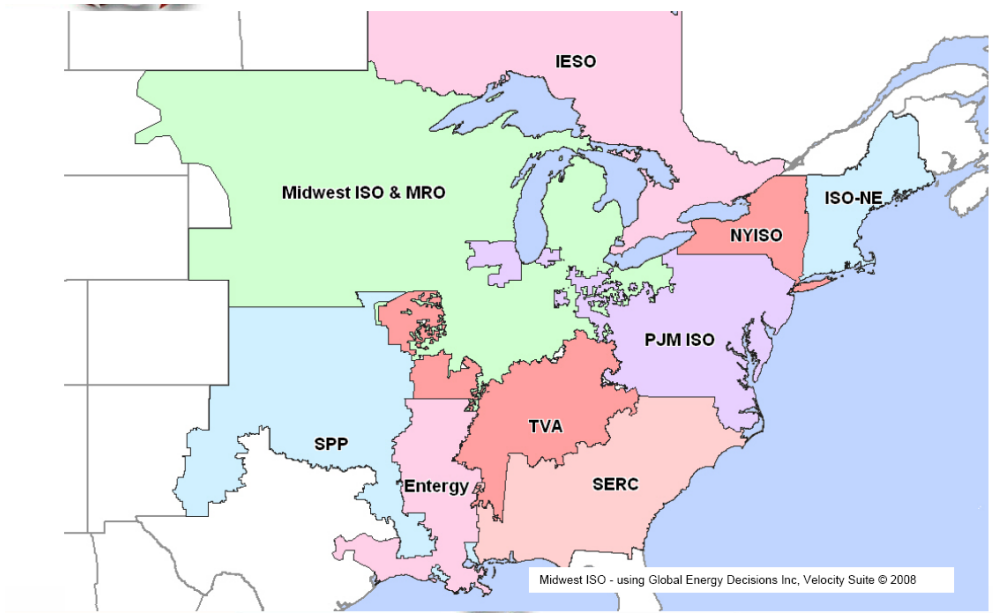
Numerous NERC Task Force reports can be found at: http://www.nerc.com/filez/ivgtf_Interconnection.html (click on individual topical area to find reports).



In Process…

- NREL's EWITS and WWSIS Phase 2
  - Focus on thermal cycling impacts
  - Demand response
  - More solar energy in the West



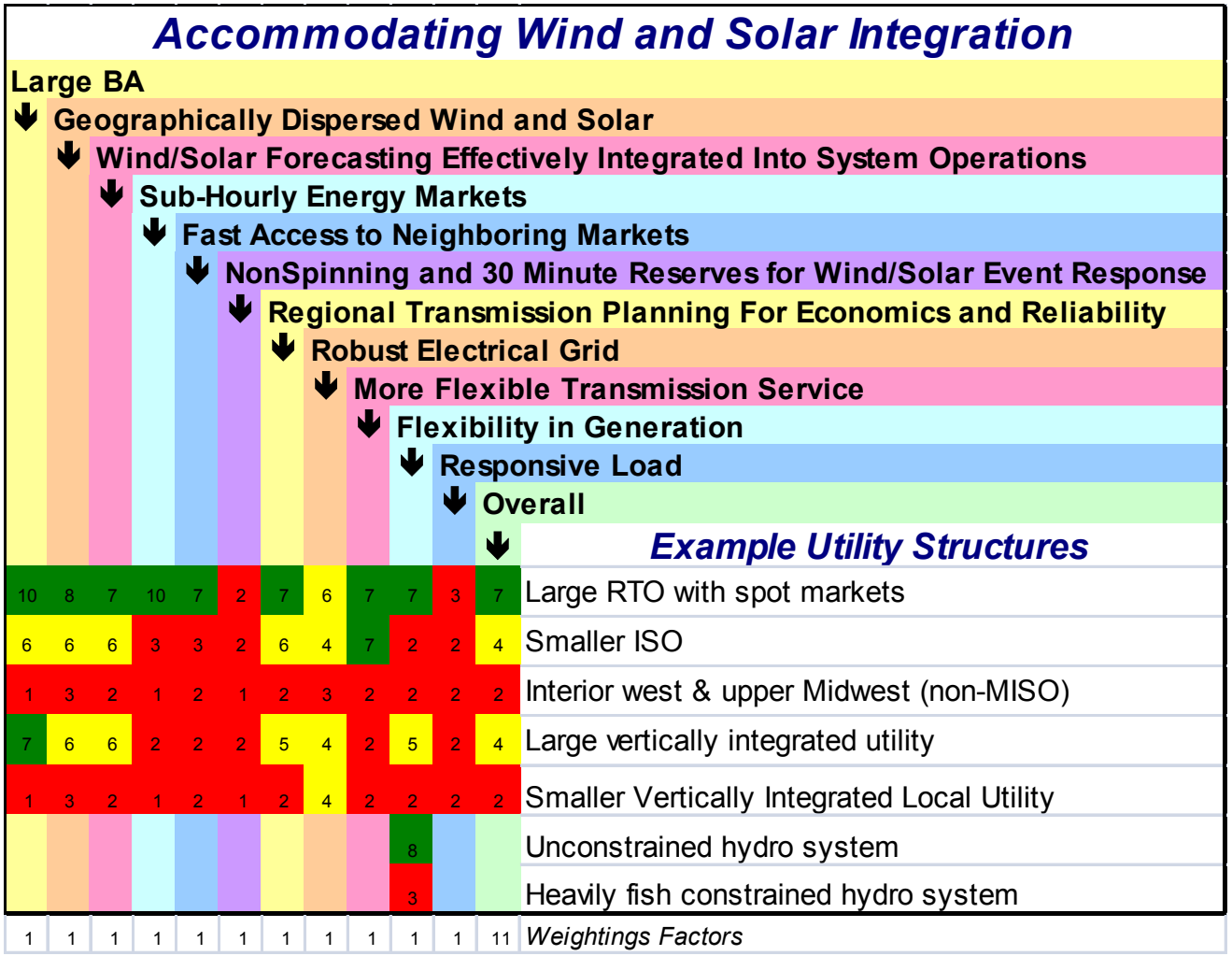


Additional efforts underway

- Energy Imbalance Market in the West;
- Western Electricity Coordinating Committee's Variable Generation Subcommittee;
- Seams issues; inter-BA deliveries;
- Concern regarding insufficient revenue from energy-only markets;
- Wind-provided frequency regulation;
- Reserves analysis;
- Impact on balancing costs.

Milligan, M.; Ela, E.; Hodge, B. M.; Kirby, B.; Lew, D.; Clark, C.; DeCesaro, J.; Lynn, K. (2011). Cost-Causation and Integration Cost Analysis for Variable Generation. 37 pp.; NREL Report No. TP-5500-51860.

Ability to integrate wind/solar is a function of many factors



Adapted from Milligan, M.; Kirby, B.; Gramlich, R.; Goggin, M. (2009). Impact of Electric Industry Structure on High Wind Penetration Potential. 31 pp.; NREL Report No. TP-550-46273. http://www.nrel.gov/docs/fy09osti/46273.pdf

Capacity Value (= Capacity Credit)

Topics

- Operational vs. Planning/System Adequacy;
- Capacity Value as Contribution to Adequacy: Effective Load Carrying Capabilit;y
- LOLP, LOLE;
- Wind ELCC and modeling approaches;
- Recent selected U.S. results and methods;
- Recommended approaches.

Two Views of Capacity Value

- Operational: how much capacity will wind produce at a given date/time?
- Resource adequacy;
- Is there enough installed capacity in year X to reliably serve load? How does wind contribute?
- These are two very different questions.

Photo from Moorhead Public Service, NREL/PIX 11602



Photo by Warren Gretz, NREL/PIX 00070



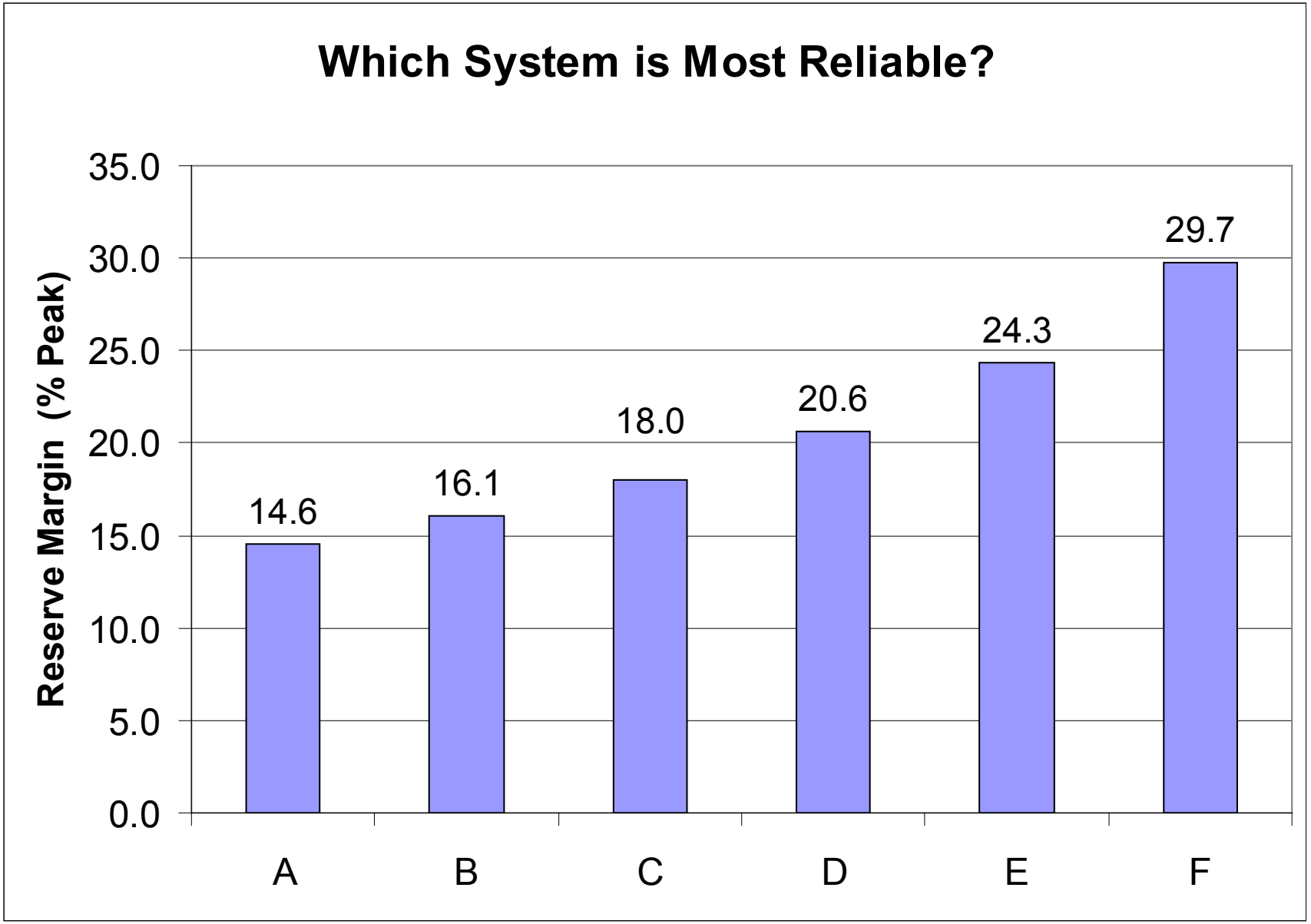
Photo by Warren Gretz, NREL/PIX 10930



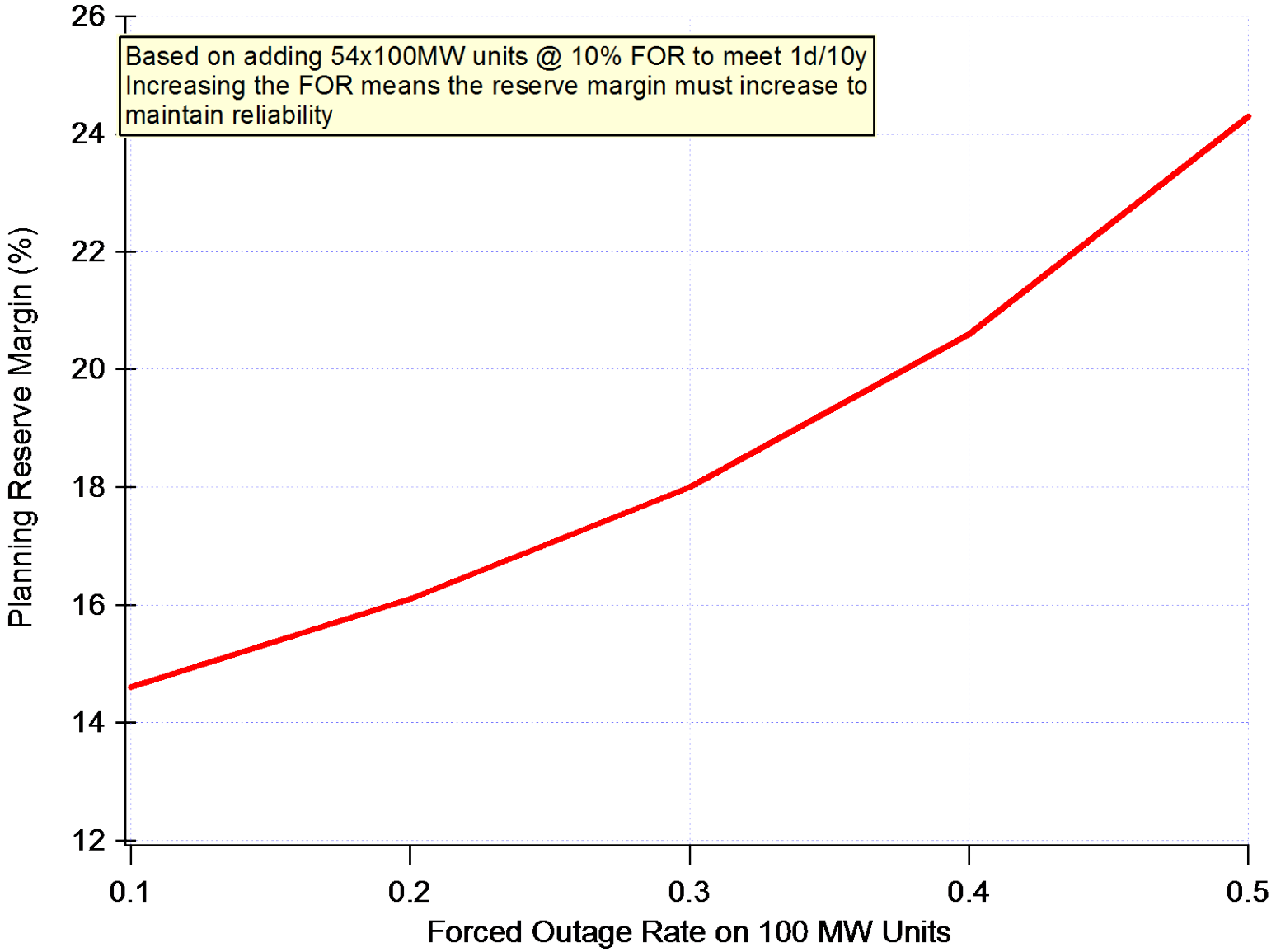
Resource Adequacy

- Often measured based on installed capacity, peak load, and a planning reserve;
- A fixed planning reserve margin (15%) does not in itself provide a measure of adequacy;
- No system can be perfectly adequate;
- How adequate is adequate enough?
- Quantify the number of times system will be inadequate – often measured as hours/year; days/year (1d/10y ≈ 99.97%).

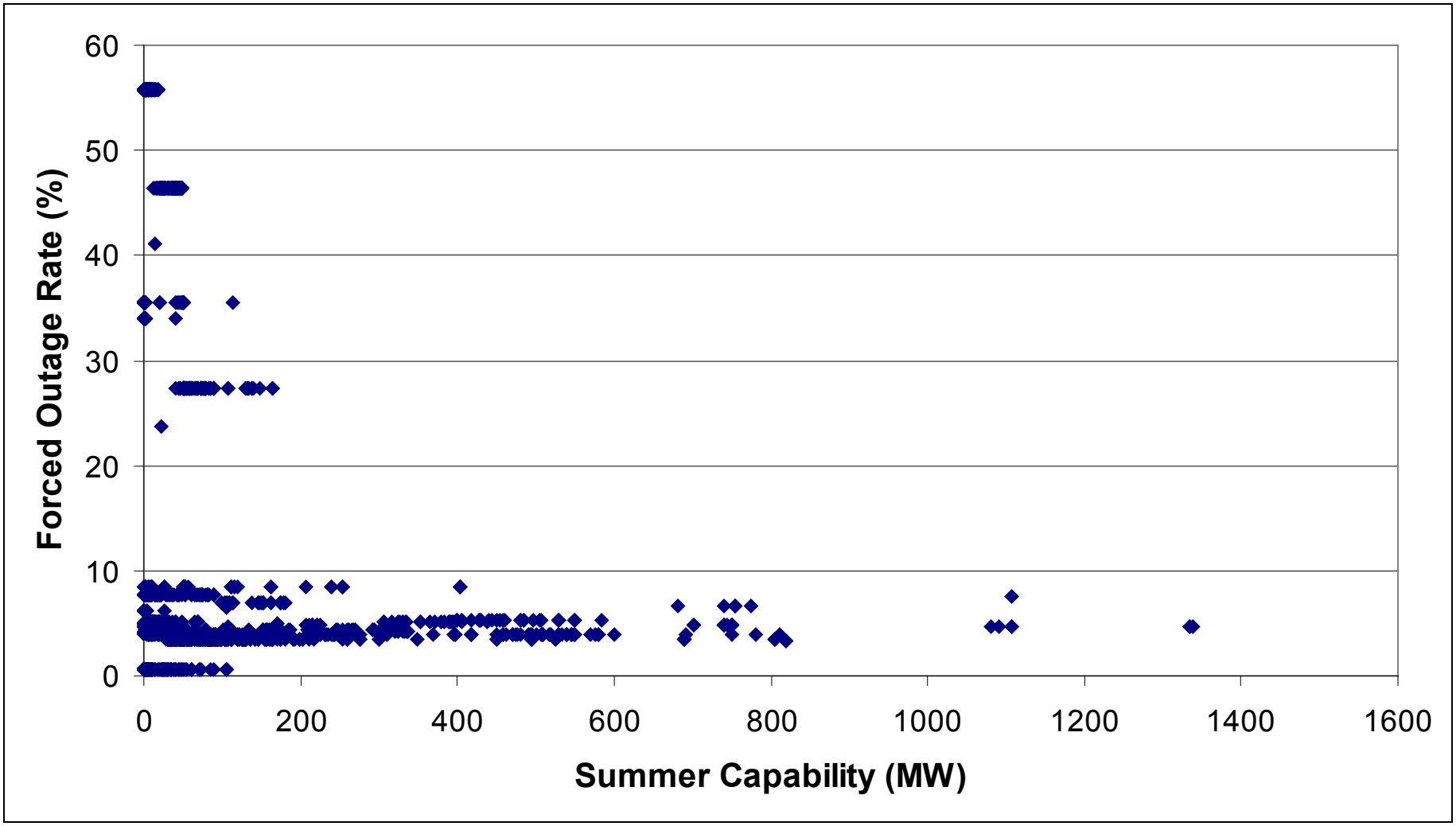
Planning reserve as % of peak is not a good metric



Reserve Margins Don't Directly Address System Adequacy



WECC data

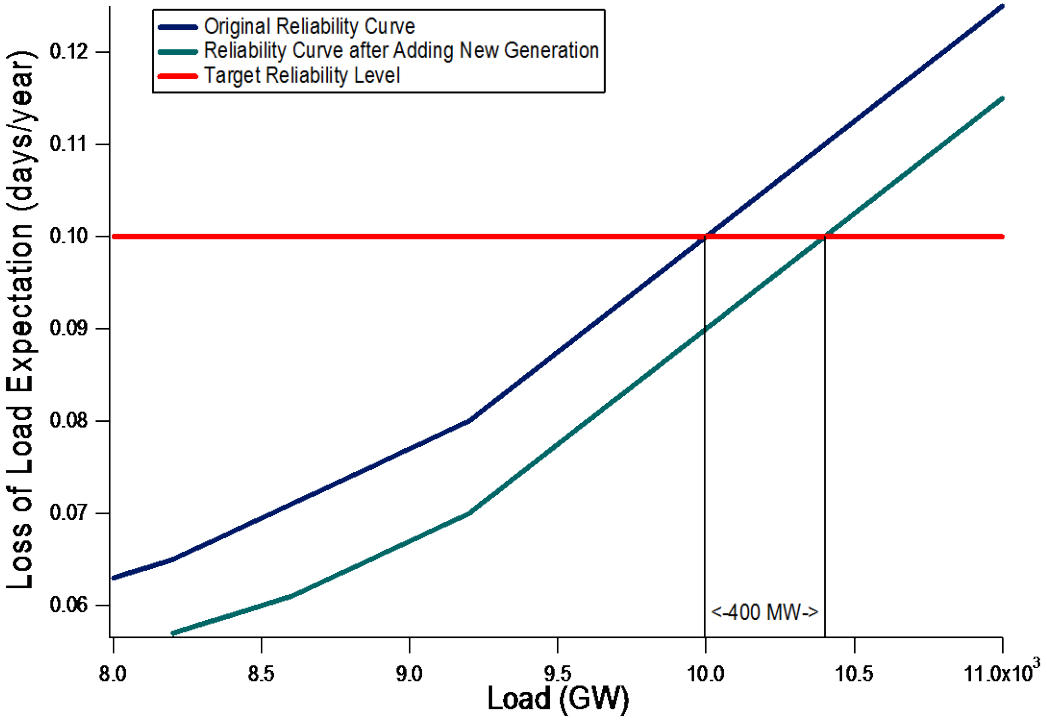

Forced Outage Rate (%)
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
Summer Capability (MW)

Are There Metrics For Resource Adequacy?

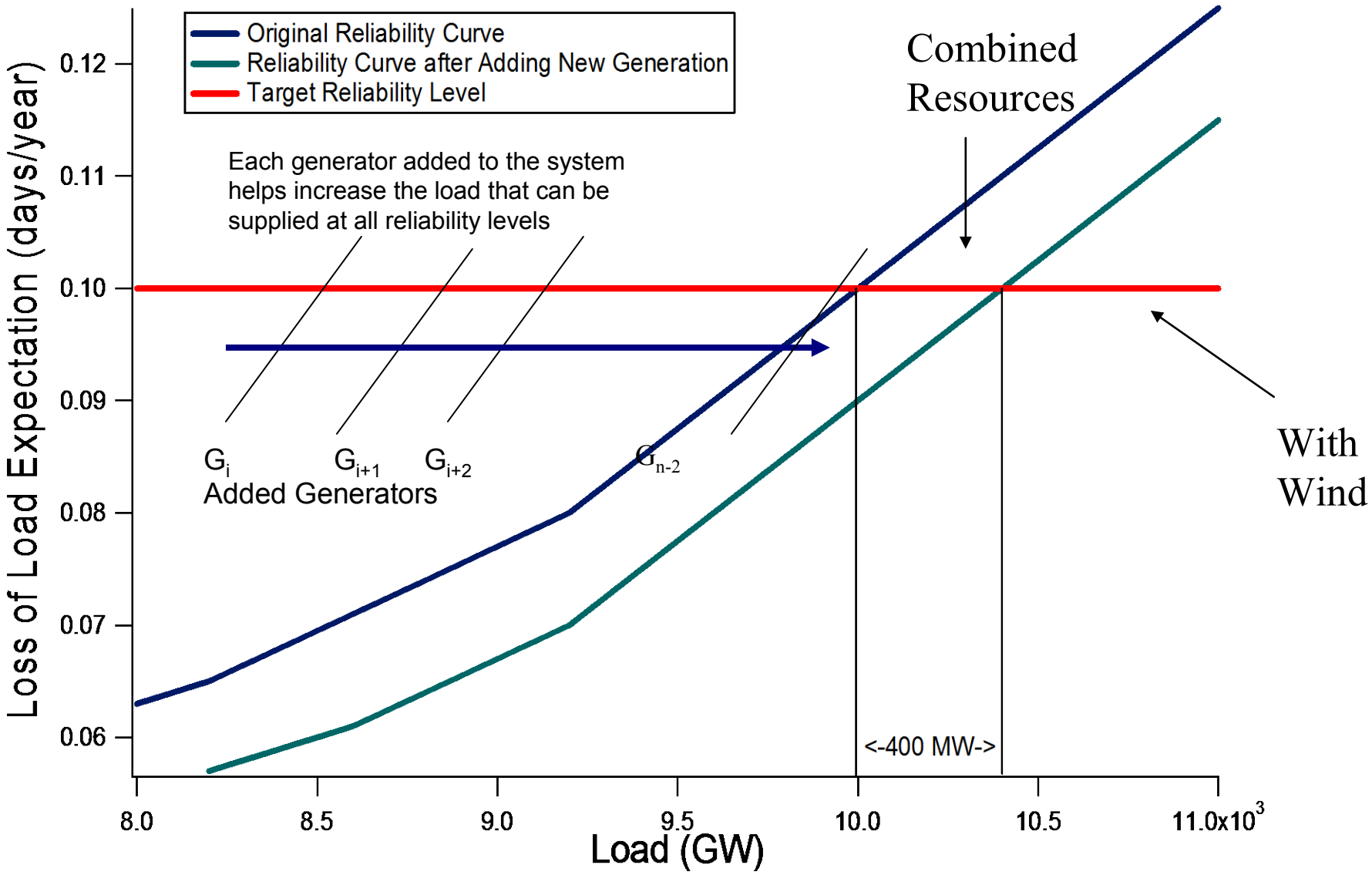
- Loss of load probability:
  - Probability of insufficient generation to cover load;
  - Not necessarily load shedding; covers the probability of unforeseen/spot imports.
- Loss of load expectation = probability x time.
- Expected unserved energy:
  - Measures the *amount* of potential shortfall, not just the likelihood.
- All of these measures capture varying levels of risk – something that is missing from fixed planning reserve margin approaches (15%) unless they have been 'trued up' with reliability results.

Individual Generators' Contribution to Adequacy can be Measured

- Effective load carrying capability (ELCC);
- Applies to all generators, not just wind;
- De-composes each individual generator's contribution to resource adequacy.



Effective Load Carrying Capability (ELCC)



What is ELCC?

- What ELCC is *Not:*
  - a minimum generation value.
  - a schedule or forecast for wind.

- ELCC *is:*
  - Measure of wind (or other resource's) contribution to overall system adequacy.
  - Decomposition of the generator's contribution to adequacy (planning margins).

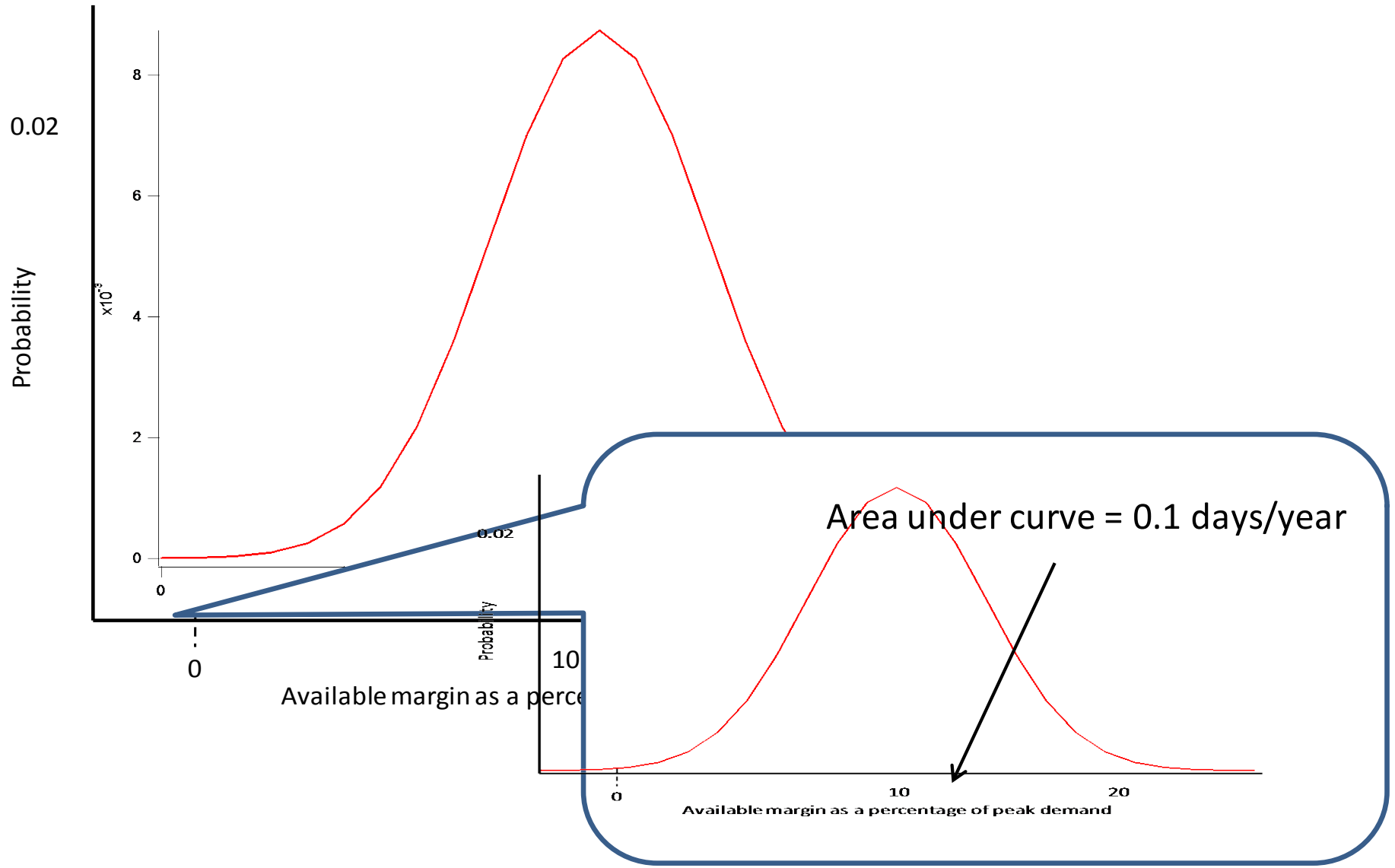
Capacity Credit (ELCC) Properties

- Not unique to wind, and can be adapted to wind generators.
- Wind capacity credit depends on output profile (hourly for *at least* one year):
  - Low when wind contributes small amount to reliability;
  - High when wind contributes large amount to reliability;
  - Depends on system and wind characteristics;
  - Values can range from approximately 10%-40%, depending on system and wind characteristics;
  - Capacity credit outside this range are possible;
  - *Use multiple years of data if available.*

How Does ELCC Work?

- Holds the system at constant annual risk level with/without wind;
- Can be measured relative to a perfect unit or selected benchmark unit;
- Utilizes reliability/production simulation model:
  - Hourly/daily loads;
  - Generator characteristics;
  - Wind generation pattern (hourly for >= 1 year);
  - Calculates hourly/daily LOLP (loss of load probability).
- Conventional units ELCC is primarily a function of FOR and unit size.

Another view of ELCC



Representations of wind in reliability models

- Hourly wind production (real or simulated).
- Time-synchronized with load (more later).
- This captures the actual variability in wind output.

Capacity Table: Simple Convolution Example

- Assume 6-50 MW units, each with FOR=.08

	MW-Out	MW-In	Probability	LOLP
0	0.0000	300.0000	0.60635500	1.00000000
1	50.0000	250.0000	0.31635913	0.39364500
2	100.0000	200.0000	0.06877372	0.07728587
3	150.0000	150.0000	0.00797377	0.00851214
4	200.0000	100.0000	0.00052003	0.00053838
5	250.0000	50.0000	0.00001809	0.00001835
6	300.0000	0.0000	0.00000026	0.00000026

LOLP is the cumulative probability function

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LOLP is the cumulative probability function

LOLP Calculation with 50-MW Wind Plant

Step 1

- Assume 6-50 MW units, each with FOR=.08

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Outage table with no wind

LOLP Calculation with 50-MW Wind Plant

Step 2

- Assume 6-50 MW units, each with FOR=.08

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5	250.0000	50.0000	0.00001809	0.00001835
6	300.0000	0.0000	0.00000026	0.00000026

Move to 150 MW load less 50 MW wind in outage table

LOLP Calculation with 50-MW Wind Plant

Step 2

- Assume 6-50 MW units, each with FOR=.08

	MW-Out	MW-In	Probability	LOLP
0	0.0000	300.0000	0.60635500	1.00000000
1	50.0000	250.0000	0.31635913	0.39364500
2	100.0000	200.0000	0.06877372	0.07728587
3	150.0000	150.0000	0.00797377	0.00851214
4	200.0000	100.0000	0.00052003	0.00053838
5	250.0000	50.0000	0.00001809	0.00001835
6	300.0000	0.0000	0.00000026	0.00000026

Move to 150 MW load less 50 MW wind in outage table

Alternative underlying reliability metrics

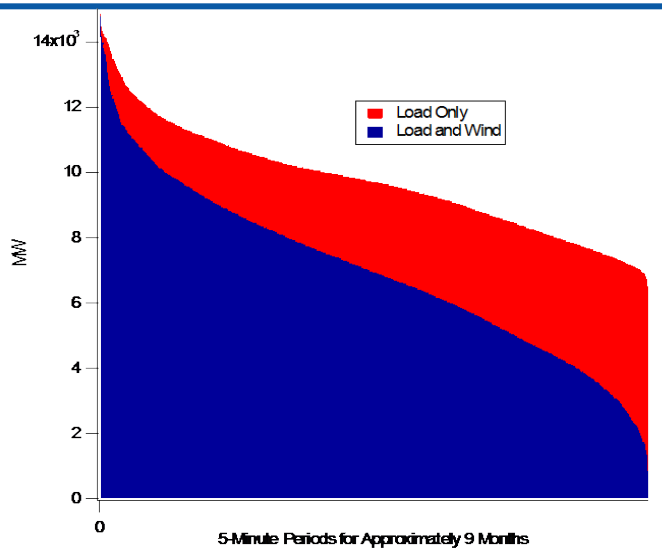
- ELCC can be based on:
  - LOLP/LOLE – daily;
  - LOLH (hourly LOLP);
  - EUE – expected unserved energy.

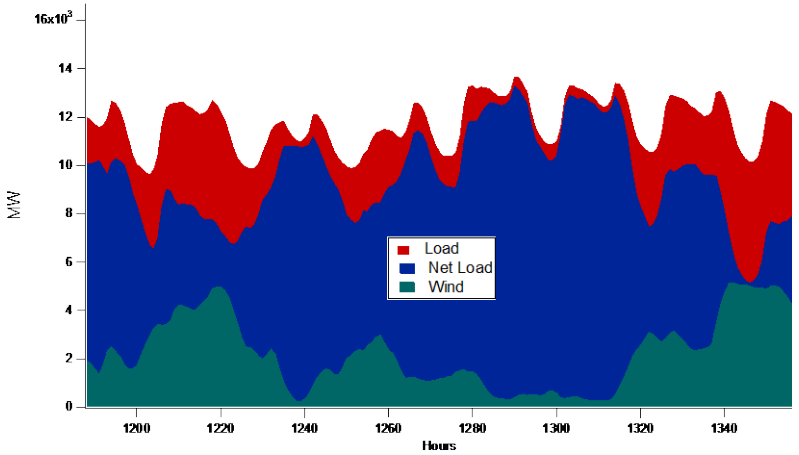
- LOLP/LOLE measures count time periods but ignore the energy risk.

- EUE does not count, but aggregates energy risk.

Types of assessments

- Frequency distribution/duration curves for load and wind (fewer computation requirements but can't be easily justified.
- Chronological simulation: best approach.
- Simplified approaches: use with caution; benchmark with ELCC required.





Data required

- Hourly load and wind/solar (VG), ***synchronized.***
- Generation capacities, forced outage rates.



Photo from Kodiak Electric Association, NREL/PIX 16799



Photo by Warren Gretz, NREL/PIX 02368

Representations of VG in reliability models

- Hourly VG production (real or simulated).
- ***Time-synchronized*** with load.
- This captures the actual variability in VG output.
- Multiple years (just like thermal units).

Conventional Stochastic Approaches: Multiple-block Unit

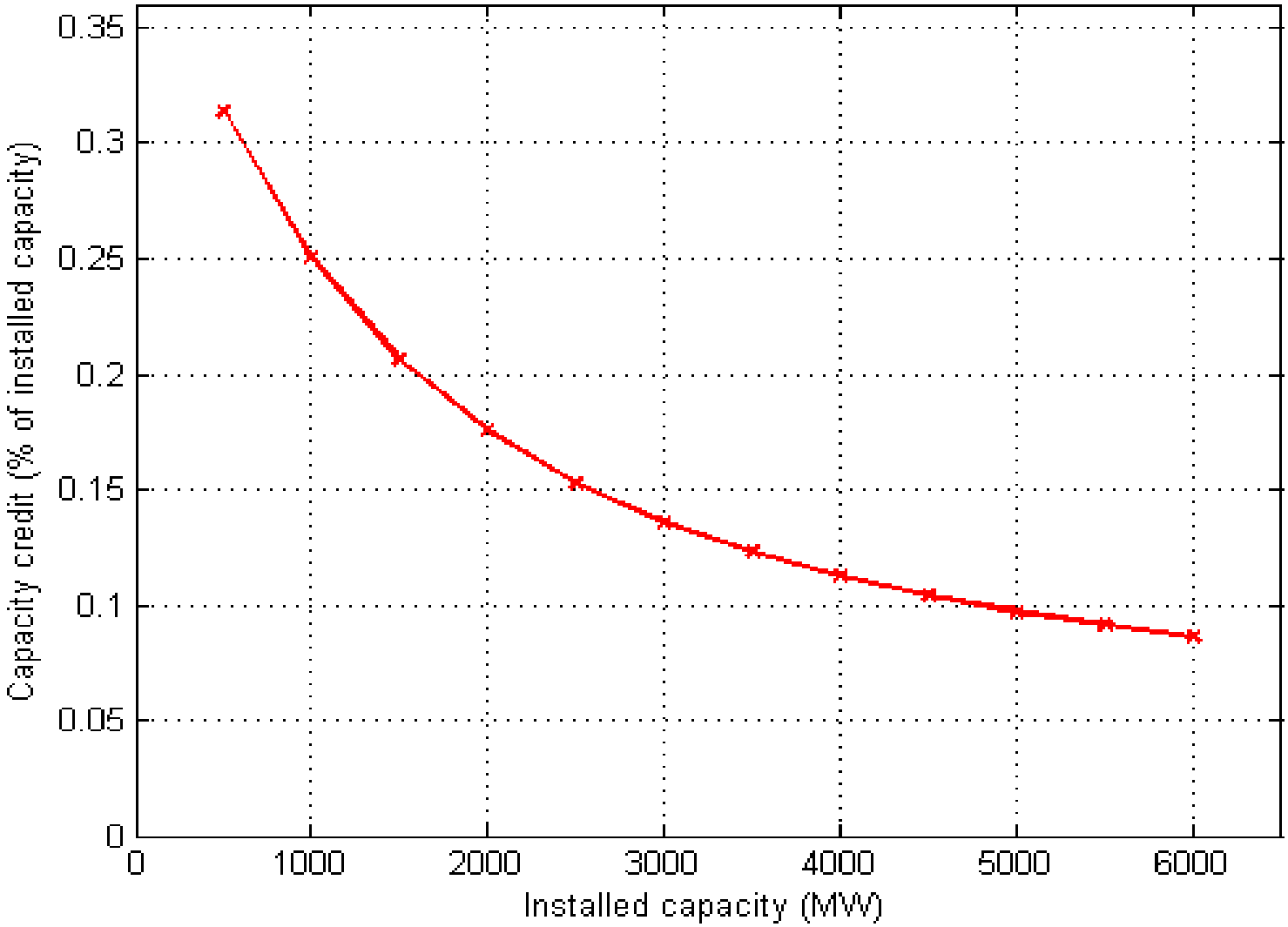
- Wind as a multiple-block generator.
- For each month, calculate several discrete generation levels and frequency of occurrence according to reliability model requirements.
- Partition by hour of day.
- Result: 24 distributions per month, each representing a given hour of the day.
- ***Does not preserve underlying "weather" of VG and load.***

Sequential Monte Carlo: Use with Care

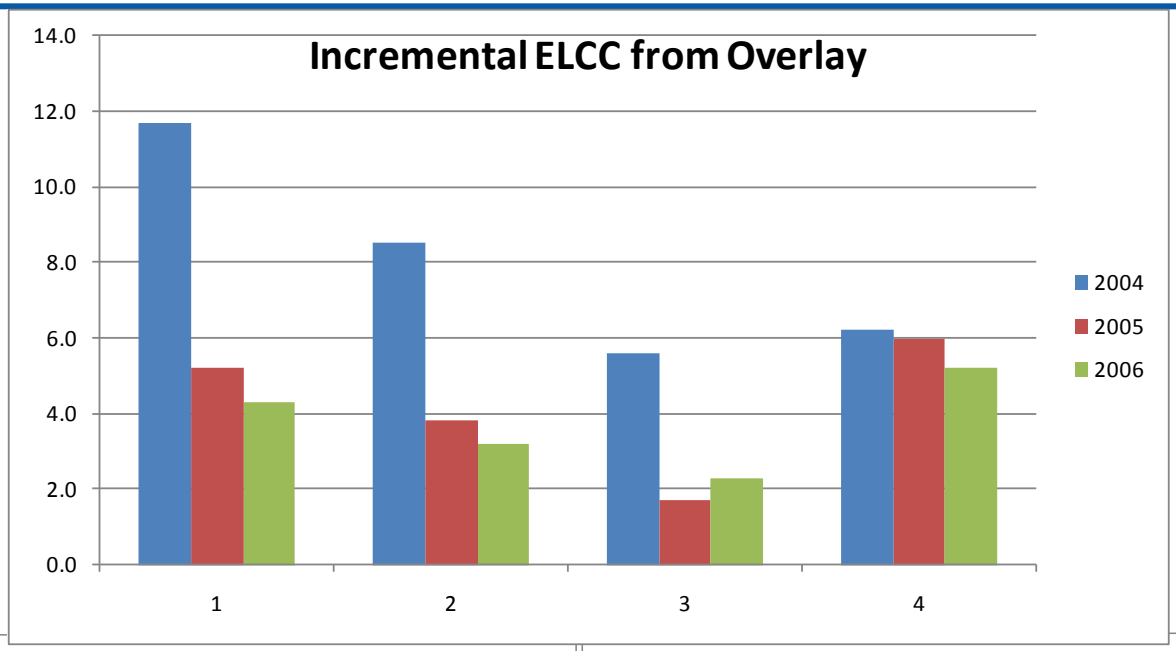
- Basic Approach:
  - Build probabilistic model of wind resource or wind generation;
  - Repeatedly sample from the family of distributions;
  - Run reliability model for each simulated year of wind data;
  - Collect results.
- Computationally expensive:
  - ***May not adequately capture wind-load synergies;***
  - Can be difficult to obtain synthetic time series that adequately represent the complex correlation and auto-correlation structure in the real wind generation patterns.

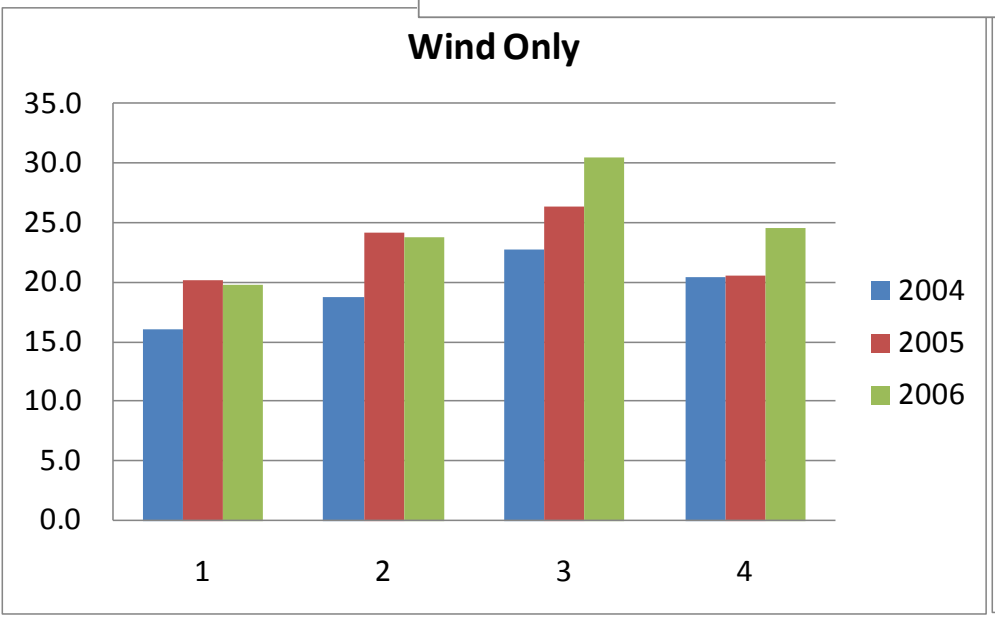
Characteristics and Overview of Findings

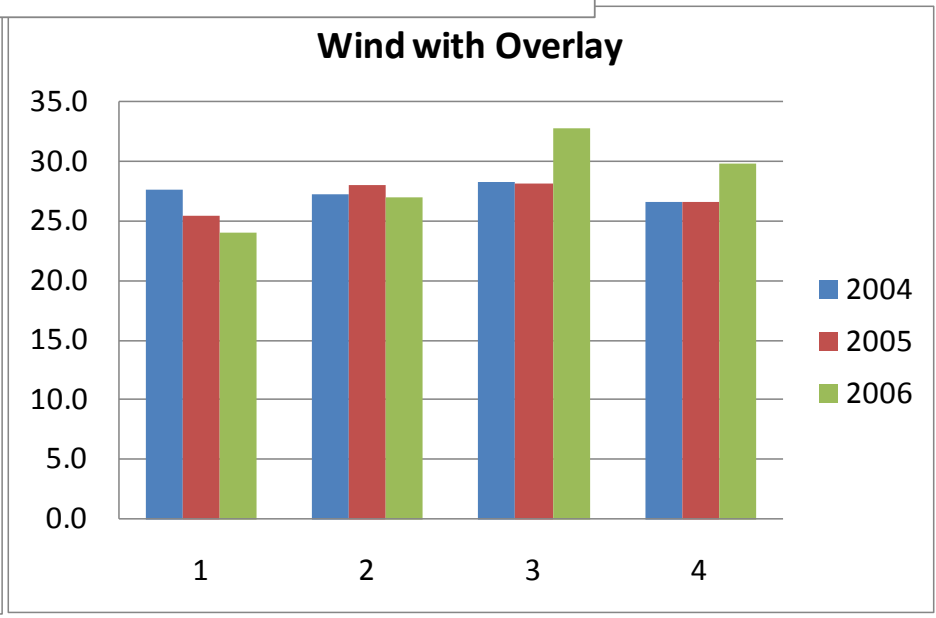
Capacity value declines with more wind



ELCC and LOLP depend on electrical footprint

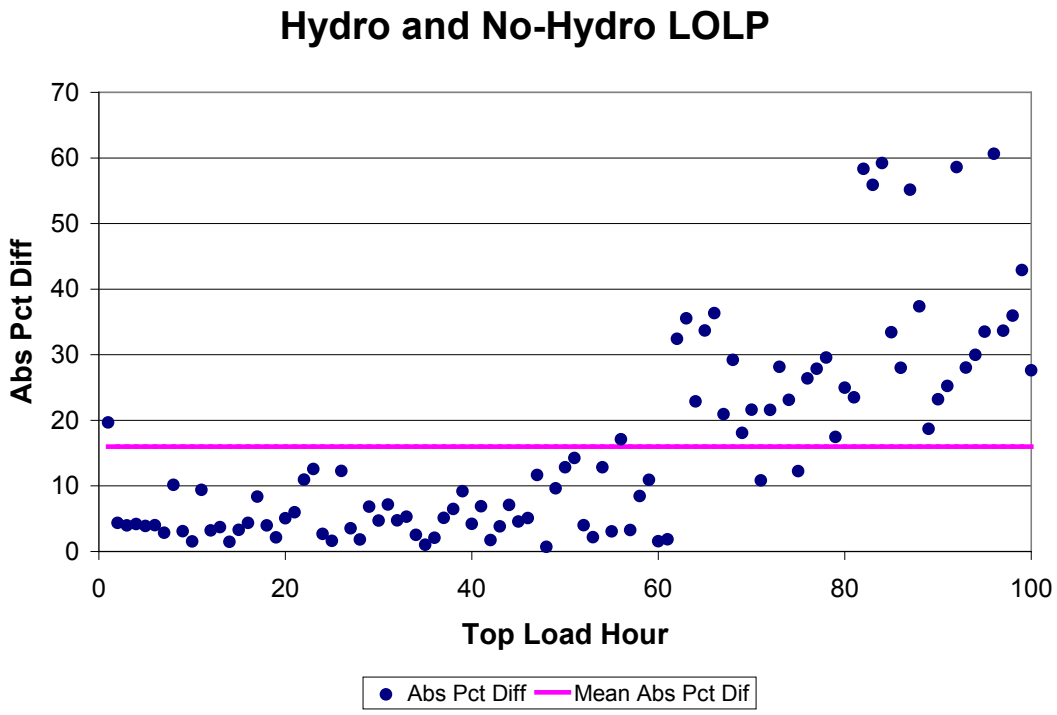




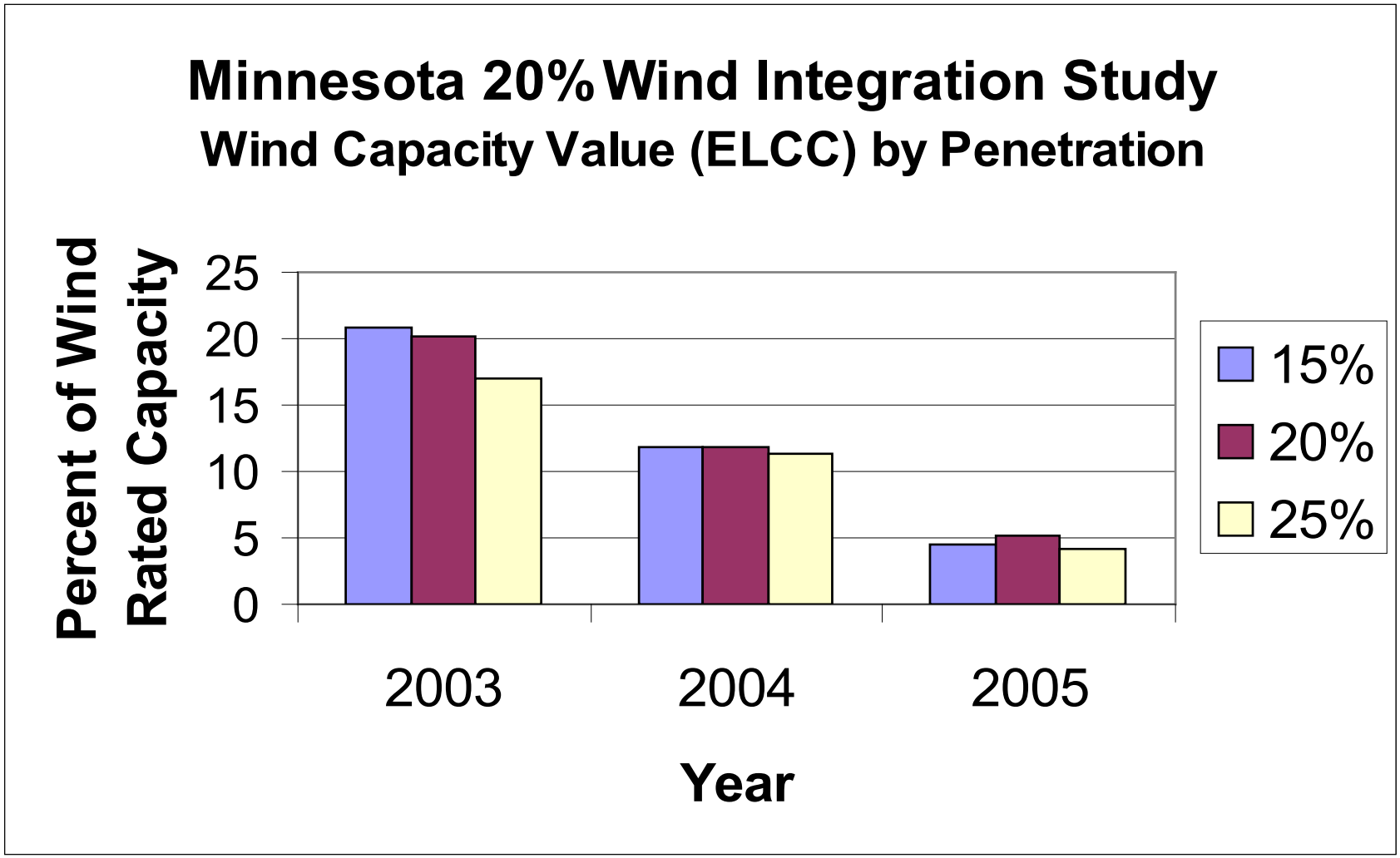


ELCC also depends on

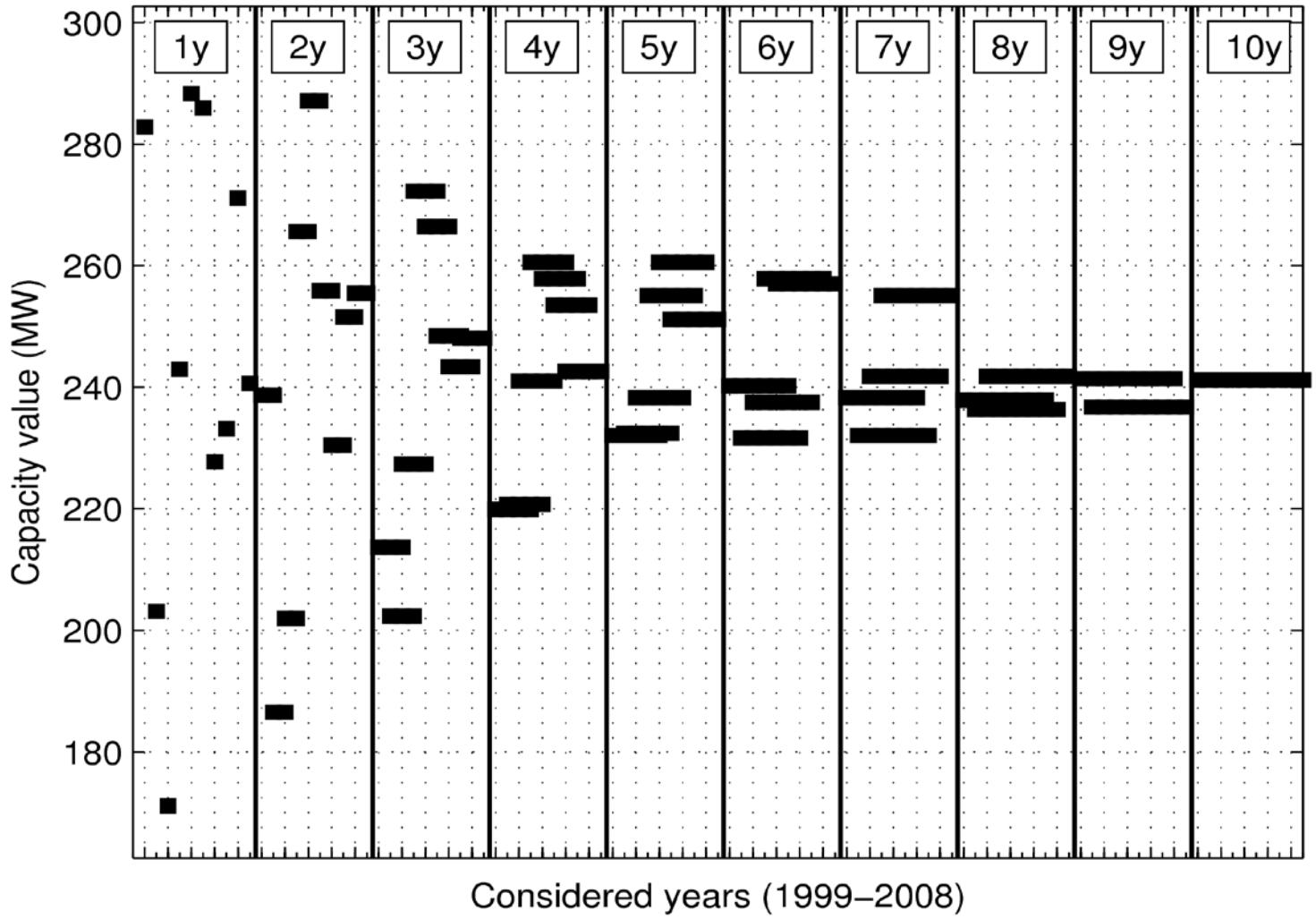
- Relationship of wind to load;
- Generator maintenance schedules;
- Hydro run of river, peak shaving;
- Import schedules and control area boundaries.



If you use one year of data you may be in trouble

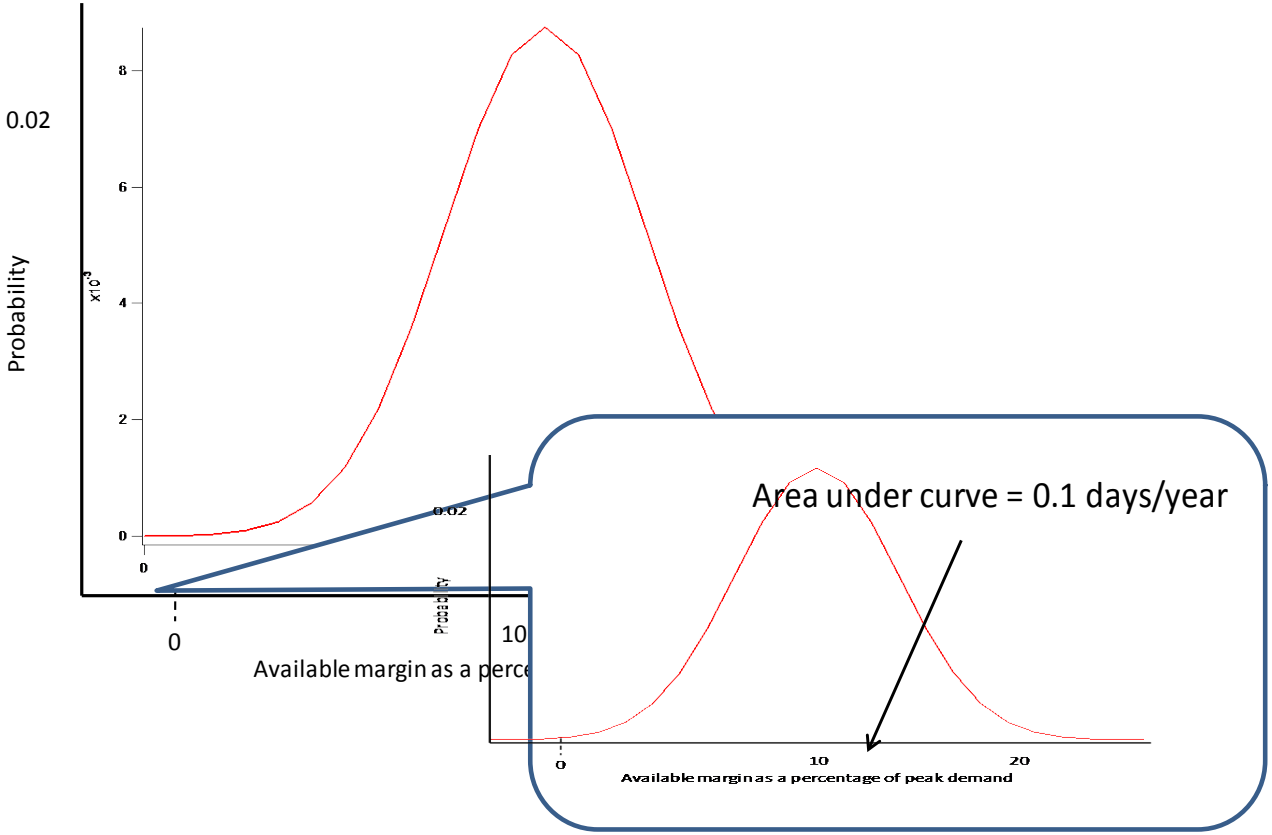


8 years of data appears safe (so far)

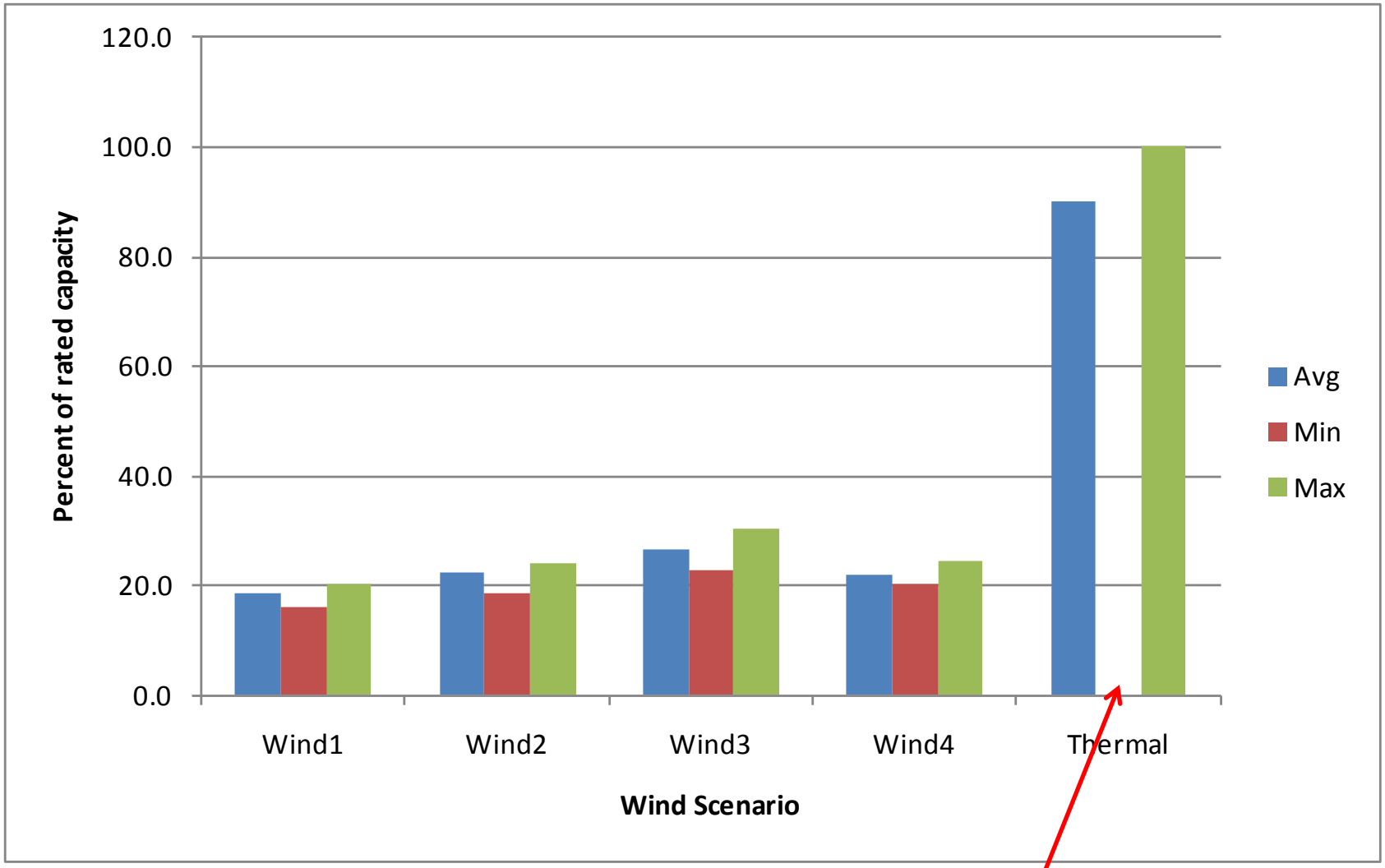


Observations

- Concern regarding inter-annual variability of capacity value of wind.
  - Range of wind variation less than thermal units.



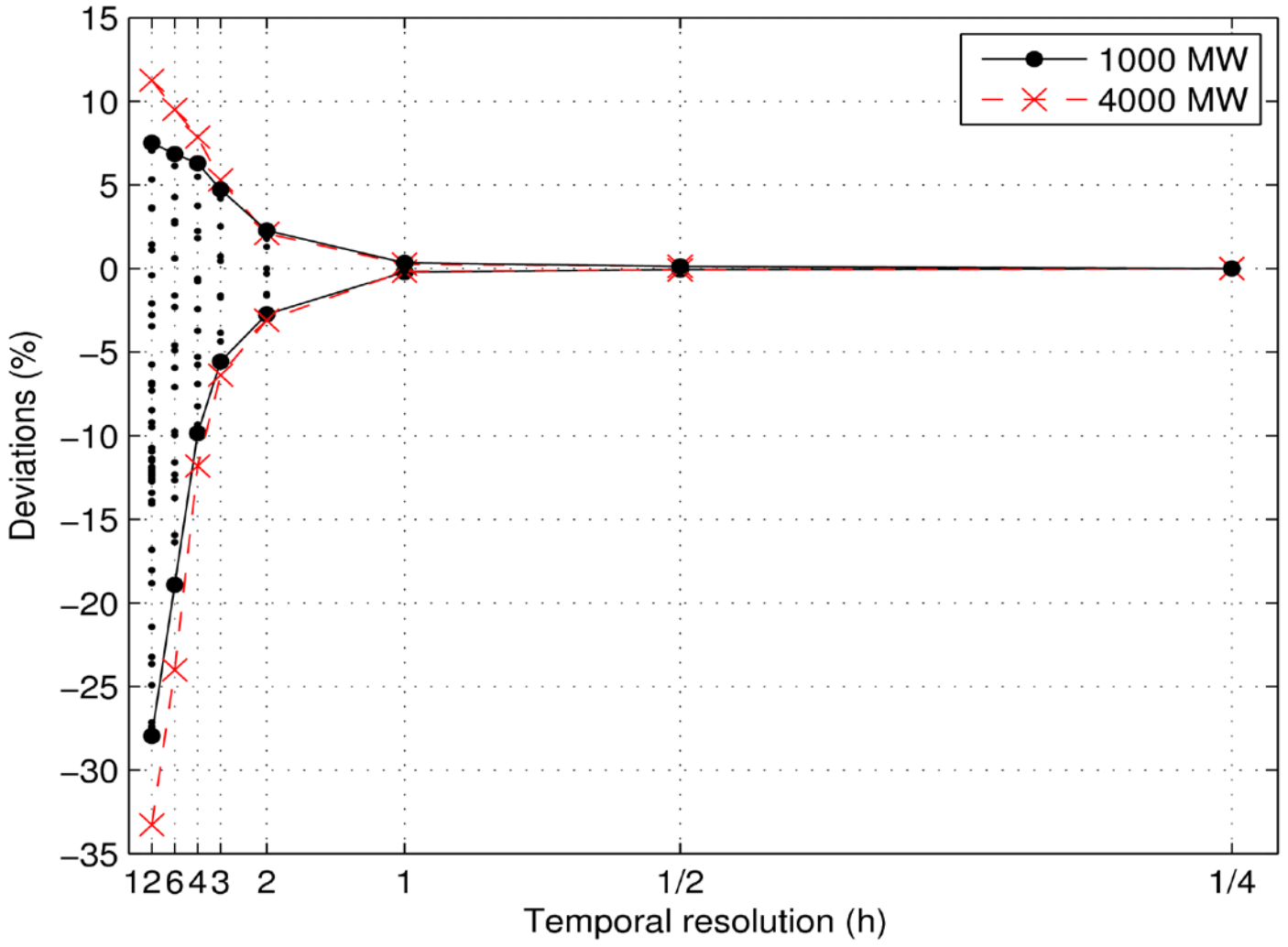
Range of capacity value (ELCC), EWITS



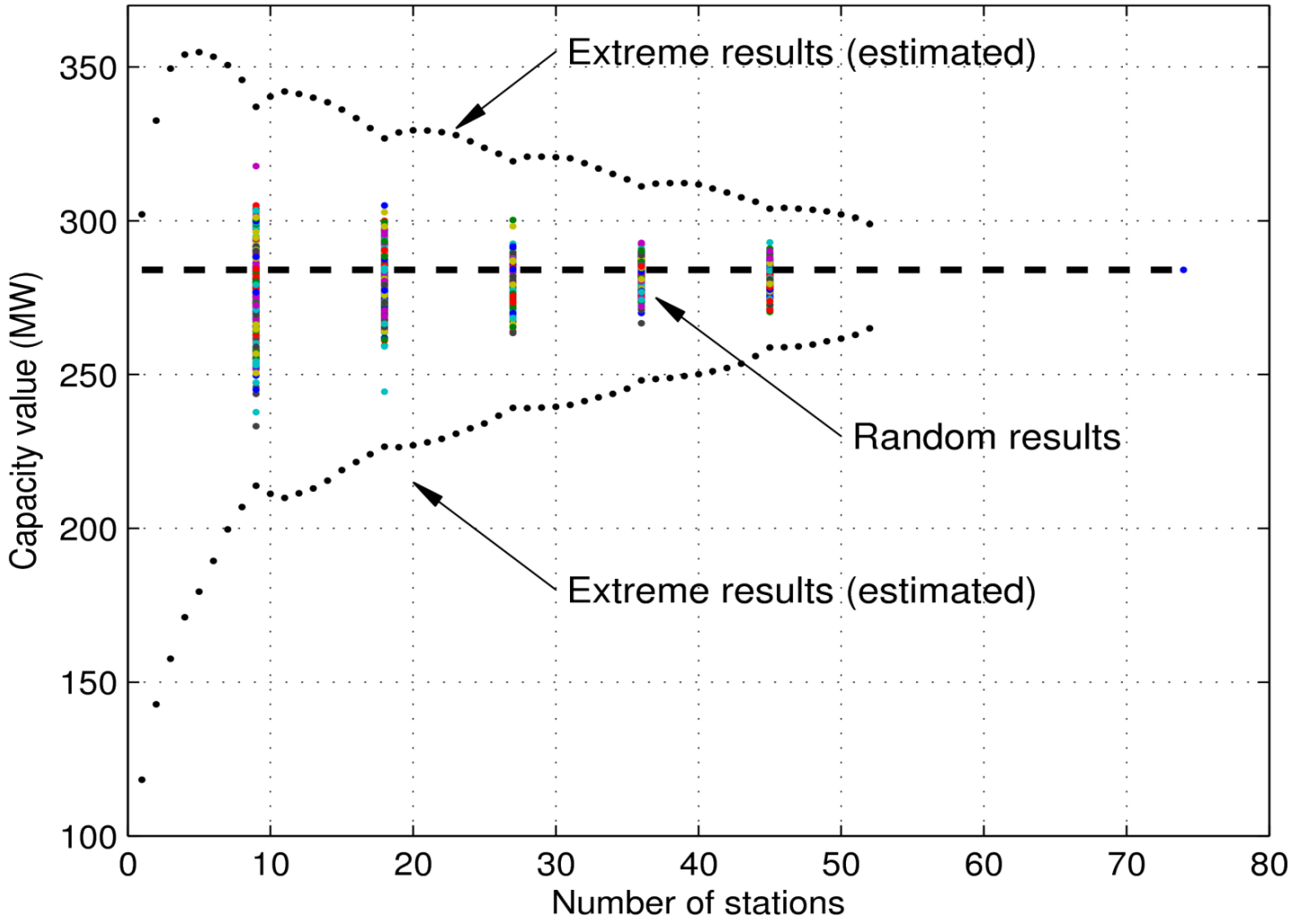
MW size also important!

Minimum = 0

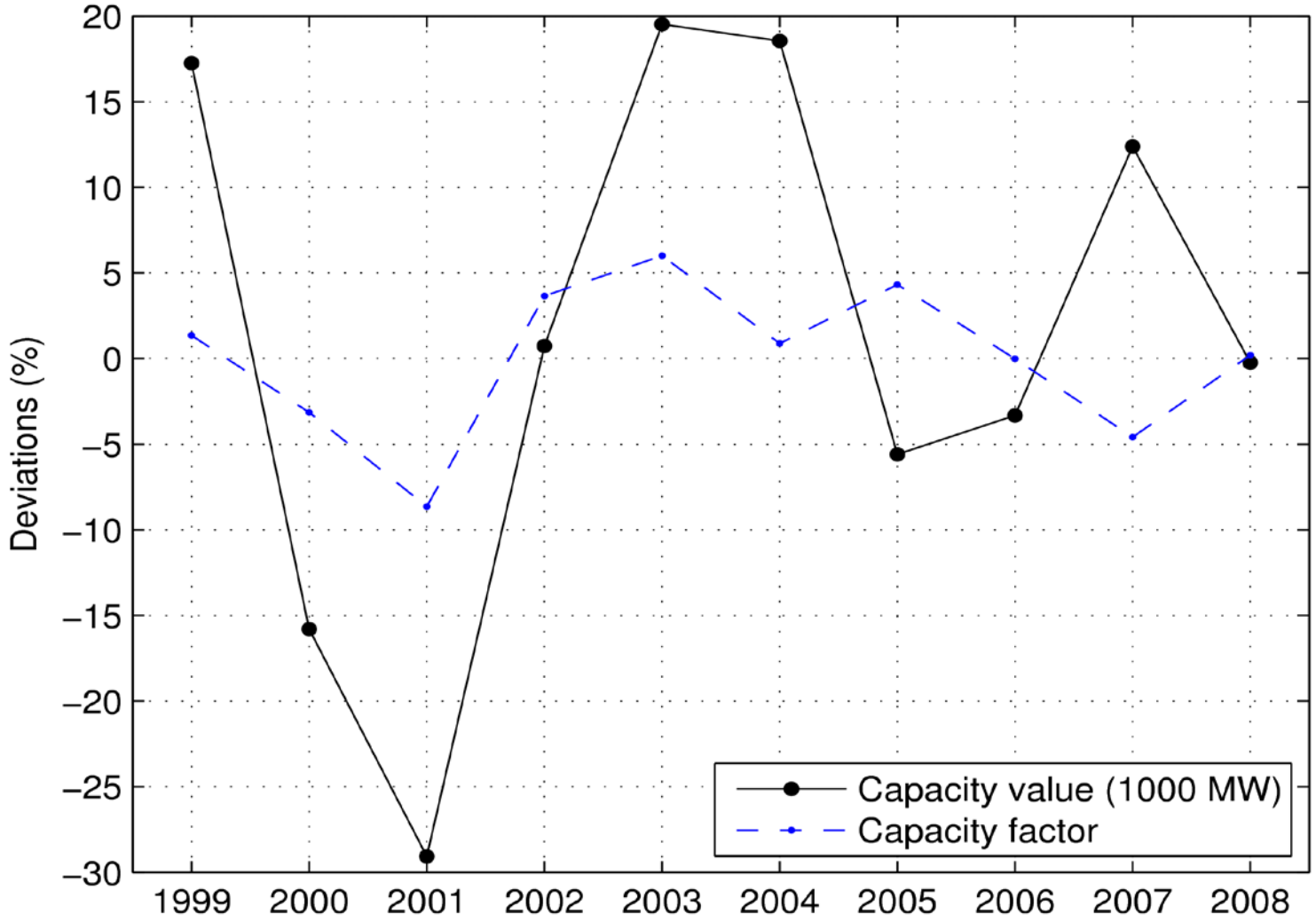
Hourly data (or faster) is required



For large penetrations you need data from multiple locations



ELCC is not just a function of capacity factor



Other (non-reliability) Approaches

- Many entities use an approximation method.
- Common approximation is wind capacity factor over some defined peak period.
- Most have not compared the approximation to a reliability-based metric.



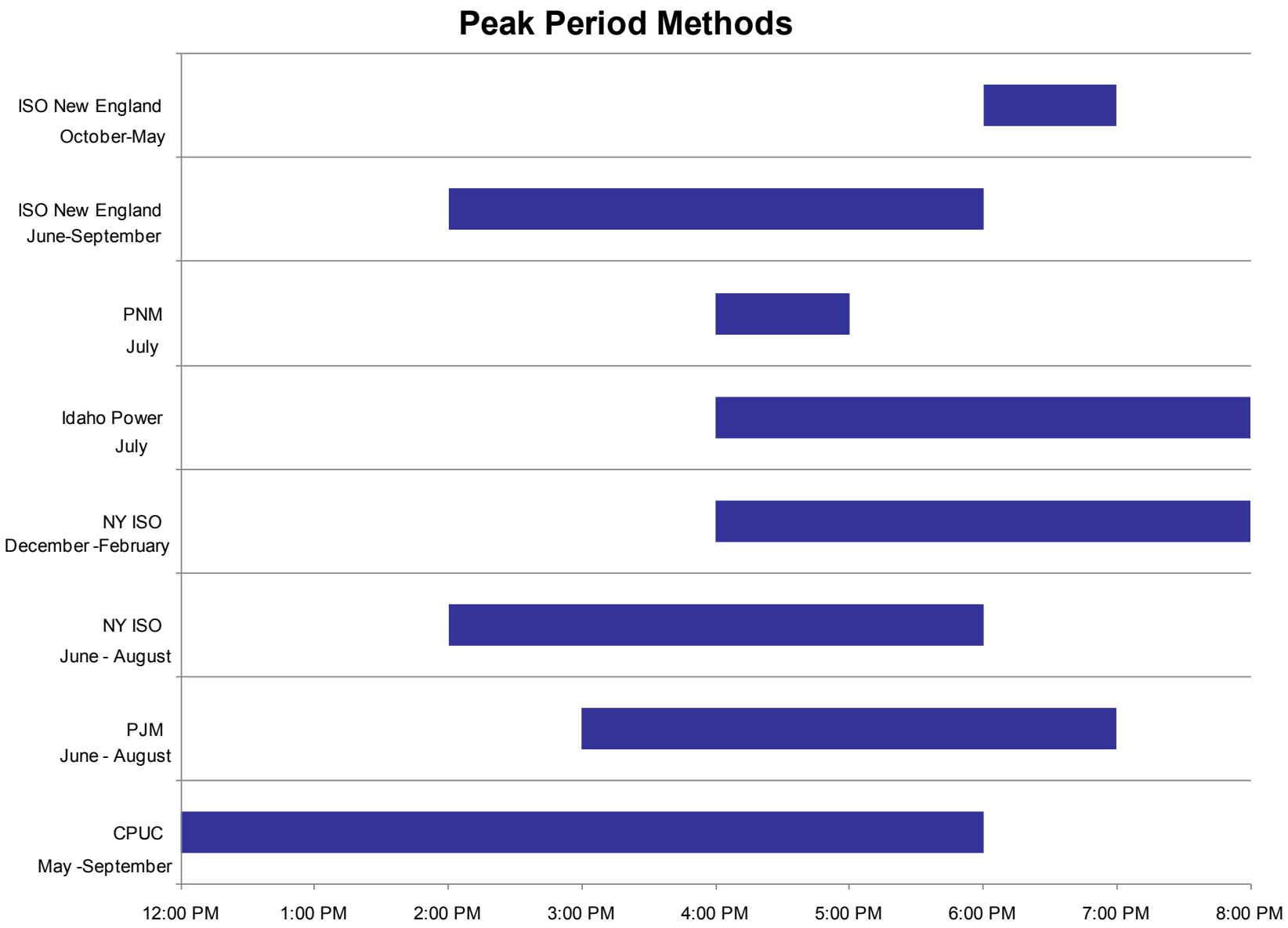
Photo from Tennessee Valley Infrastructure Group Inc., NREL/PIX 12087

Approximations and different methods

- Approximations to ELCC:
  - Approximations may be needed due to lack of data;
  - Computational time is not a reason;
  - Approximations will have errors;
  - Important to establish reliability target.

- Different methods:
  - Not calculating capacity value;
  - Should not be compared (except to benchmark simple methods).

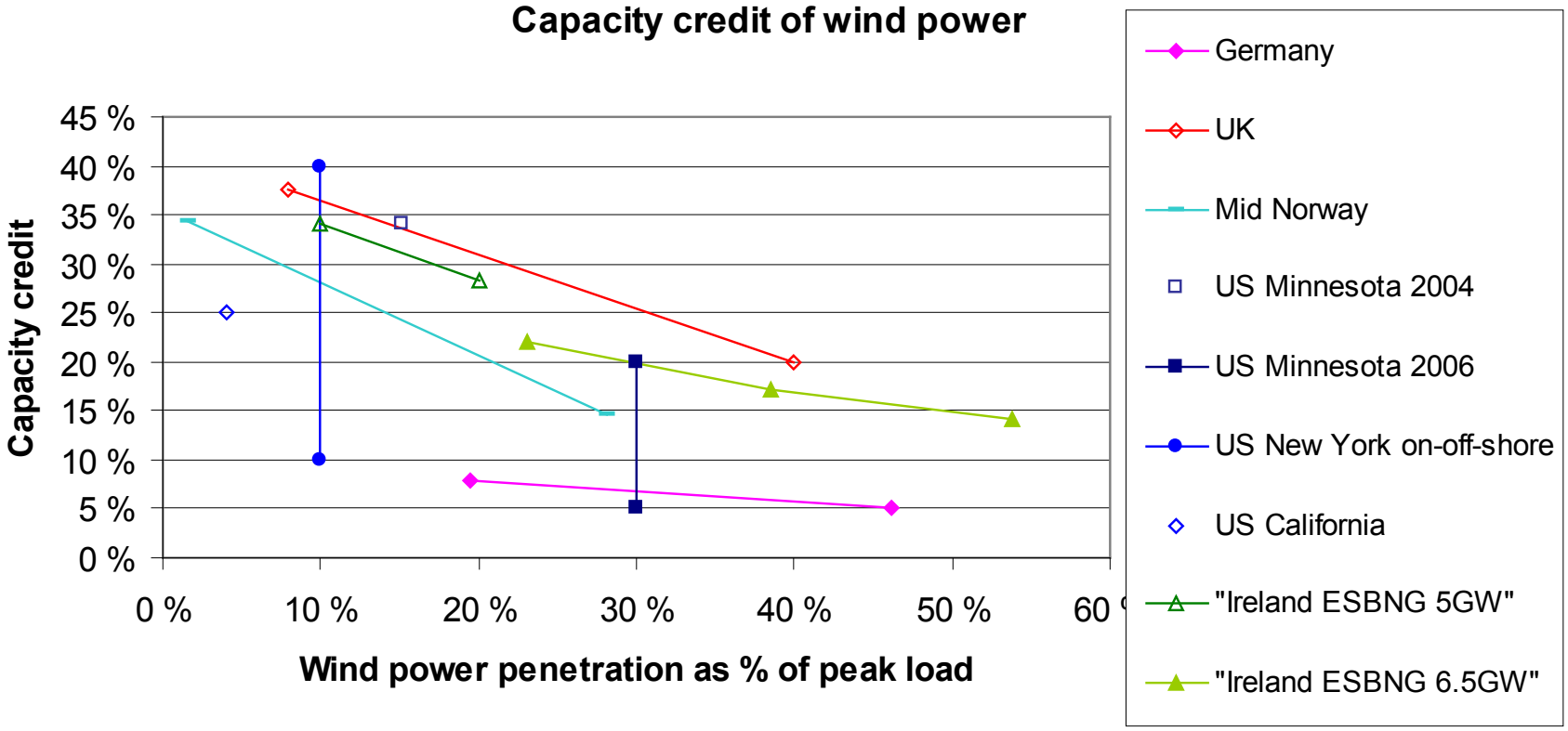
Peak period capacity factor simple approaches have not been benchmarked with ELCC



International Comparisons

Country values have wide range

…but that depends on methods, and real differences in wind-load correlations



Wind capacity value decreases at larger penetrations, faster for smaller areas.

Differences: wind resource at peak loads, reliability level, methodology.

Common findings

- Declining marginal contribution to planning reserves as a function of penetration;
- Capacity value increases with geographic diversity;
- Capacity value is relatively small fraction of wind installed capacity;
- Multiple years of data required – just like thermal units.

NERC Integrating Variable Generation Task Force 1.2: Scope & Objectives

- Consistent and accurate methods are needed to calculate capacity values attributable to variable generation.

- Technical considerations for integrating variable resources into the bulk power system.

NERC IVGTF 1.2 Scope & Objectives (continued)

- Specific actions, practices and requirements, including enhancements to existing or development of new reliability standards:
  - Calculations and metrics, including definitions and their applications used to determine capacity contribution and reserve adequacy.
  - Contribution of variable generation to system capacity for high-risk hours, estimating resource contribution using historical data.
  - Probabilistic planning techniques and approaches needed to support study of bulk system designs to accommodate large amounts of variable generation.

NERC Report Outline

- Introduction;
- Traditional Resource Adequacy Planning;
- Data Limitations;
- Approximation Methods;
- Ongoing Variable Generation Actions;
- Conclusion and Recommendation.

IEEE Wind Capacity Value Task Force paper in press

- Recommends ELCC.
- Discussion of alternative targets: 0.1 d/y ≠ 2.4h/y.
- Careful benchmarking of simple approaches to ELCC.

Capacity Value of Wind Power

Task Force on the Capacity Value of Wind Power, IEEE Power and Energy Society

Andrew Keane, *Member, IEEE*, Michael Milligan *(Vice-Chairman)*, *Member, IEEE*, Chris Dent *Member, IEEE* , Bernhard Hasche, Claudine D'Annunzio, *Student Member, IEEE*, Ken Dragoon, Hannele Holttinen, Nader Samaan, *Member, IEEE* , Lennart Söder, *Member, IEEE*, and Mark O'Malley *(Chairman)*, *Fellow, IEEE*

Abstract-- **Power systems are planned such that they have adequate generation capacity to meet the load, according to a defined reliability target. The increase in the penetration of wind generation in recent years has led to a number of challenges for the planning and operation of power systems. A key metric for generation system adequacy is the capacity value of generation. The capacity value of a generator is the contribution that a given generator makes to generation system adequacy. The variable and stochastic nature of wind sets it apart from conventional energy sources. As a result, the modeling of wind generation in the same manner as conventional generation for capacity value calculations is inappropriate. In this paper a preferred method**

lacks information on the importance and duration of the outage. LOLE is the expected number of hours or days, during which the load will not be met over a defined time period. The effective load carrying capability (ELCC) is the additional load which the system can support on addition of new generation, while maintaining the same LOLE level [3].

The topic of capacity value of wind power has been attracting attention in recent times with a number of publications dealing with this issue. In [4] methods for capacity value are described, and classified as either chronological or probabilistic. A range of methods for the calculation of capacity value are assessed in [5, 6]. A

Recommended Approaches (similar to IEEE Working Group)

- Adopt a reliability target *such as* 1d/10y;
- Derive the percentage reserve margin that corresponds to the reliability target
- To determine any generator's contribution, use ELCC;
- Benchmark wind ELCC with other performance metric such as capacity factor over a peak period;
- Use multiple years of data;
- As more wind plant data become available, re-visit and tweak as necessary;
- Interconnection or regional analysis.

Summary

- Resource adequacy assessment should explicitly consider risk.
- ELCC captures each generators' contribution to resource adequac.y
- On their own, reserve margin targets as a percent of peak can't capture risks effectively.
- Recommend benchmarking reliability-based approaches with others.



Other references

- NERC Report: http://www.nerc.com/docs/pc/ivgtf/IVGTF1-2.pdf
- IEEE Task Force Paper: Keane, Milligan, et al, IEEE Transactions on Power Systems, Vol 26, No 2. May 2011. p 564.
- Milligan and Porter, "Determining the Capacity Value of Wind: An Updated Survey of Methods and Implementation." Presented at WindPower 2008. Available at http://www.nrel.gov/docs/fy08osti/43433.pdf
- Milligan and Porter, "Determining the Capacity Value of Wind: A Survey of Methods and Implementation." Presented at WindPower 2005. Available at http://www.nrel.gov/docs/fy05osti/38062.pdf
- Billinton and Allan: Reliability Evaluation of Power Systems, 2nd Ed. Springer, 1996.



Photo by Michael Mulligan, NREL/PIX 13367