Integrating Renewable Electricity into the Grid

Results of the RenewElec Project

Jay Apt, Paulina Jaramillo, and Stephen Rose

Carnegie Mellon Electricity Industry Center (CEIC)'s RenewElec Project
www.cmu.edu/electricity and www.RenewElec.org

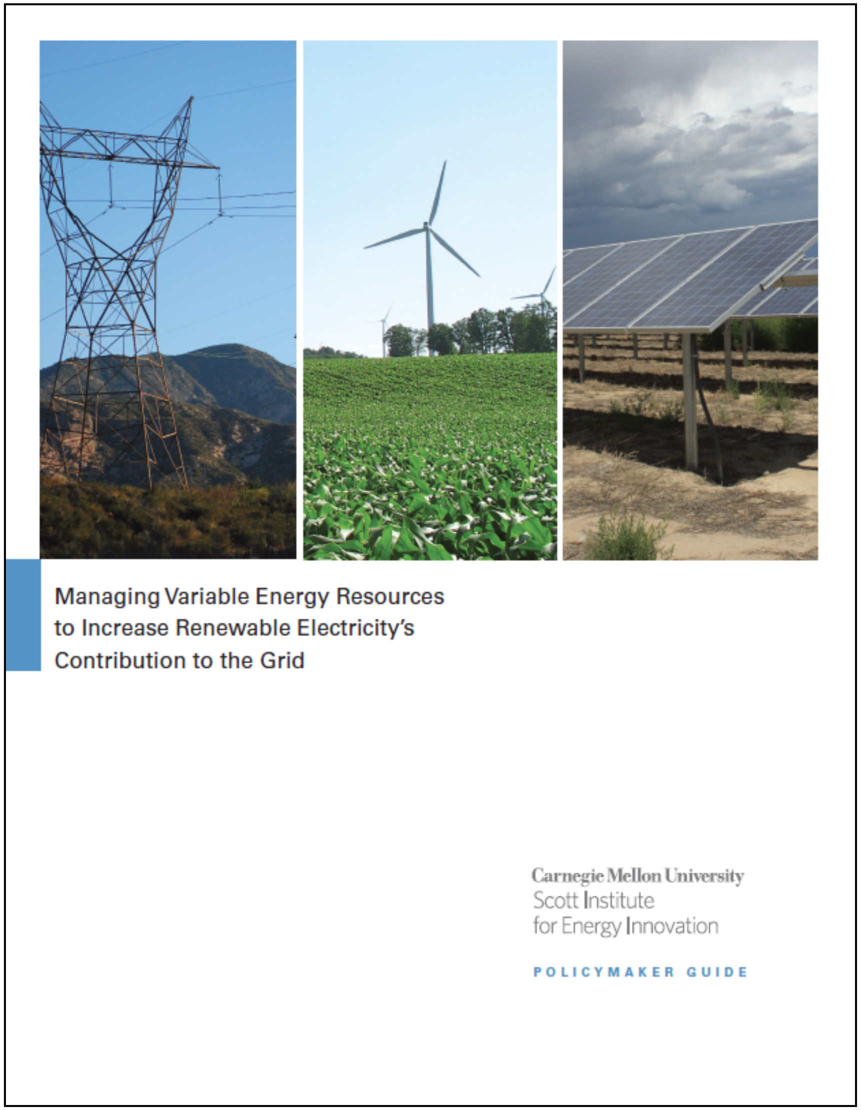
May 10, 2013

Carnegie Mellon University
Scott Institute for Energy Innovation

- Using and delivering the energy we already have far more efficiently
- Expanding the mix of energy sources in a way that is clean, reliable, affordable and sustainable
- Creating innovations in energy technologies, regulations and policies

Scott Institute Policymaker Guide

- Primer on renewable electricity
- Carnegie Mellon University research on the integration of renewables into the grid
  - State and Federal policies
    - Prospects for meeting goals
  - Challenges
  - Good opportunities
    - Better prediction
    - Operations of power plants and storage
    - Planning of sites
    - New rules and standards



Paulina Jaramillo, Ph.D.

Assistant Professor, Dept. of Engineering & Public Policy
Executive Director, RenewElec Project

The RenewElec Project

- A dispassionate systems approach to the issues surrounding a much expanded role for variable & intermittent renewables.
- Considers and anticipates the many changes in power system design and operation that will be required to make high market penetration possible.
- A broad consideration of the technical and regulatory responses to those issues.

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Doris Duke Charitable Foundation
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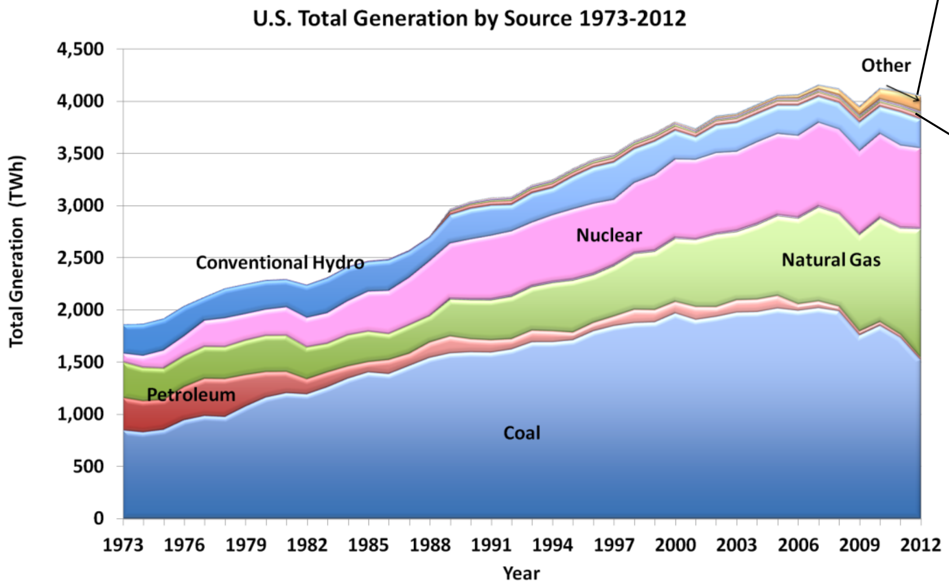
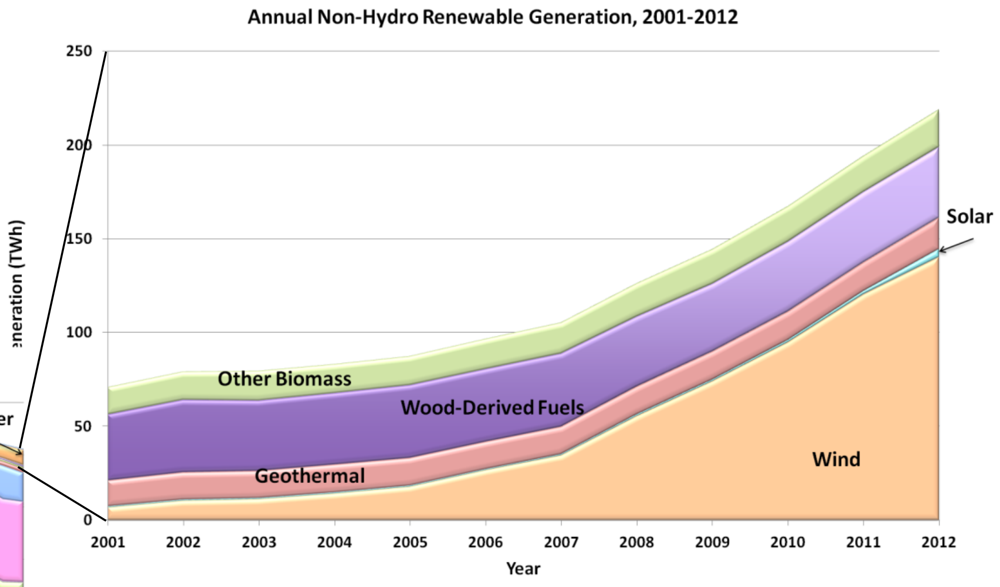
Heinz Endowments
National Science Foundation

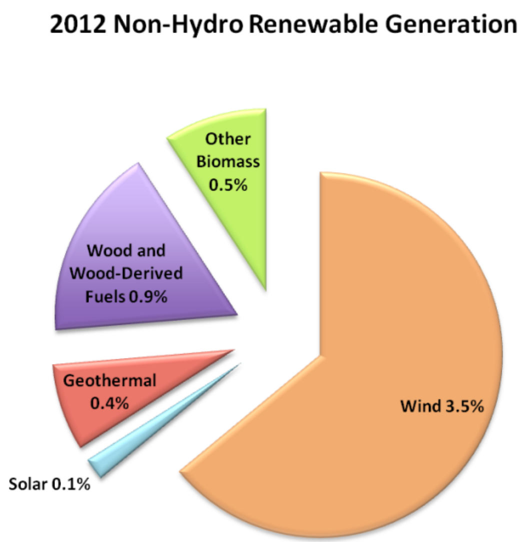
Image: Google Earth

Historical Electricity Generation



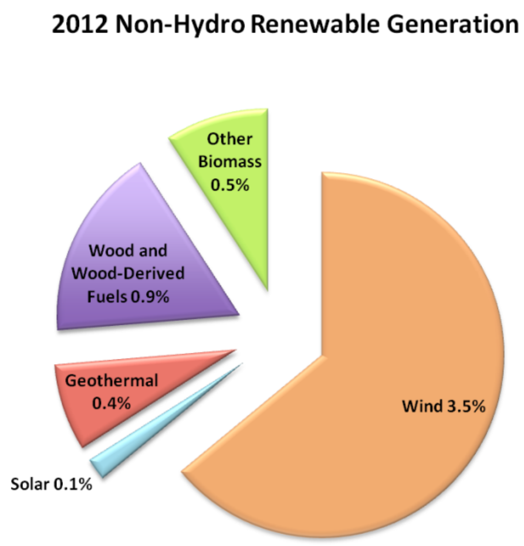


Renewable Electric Generators



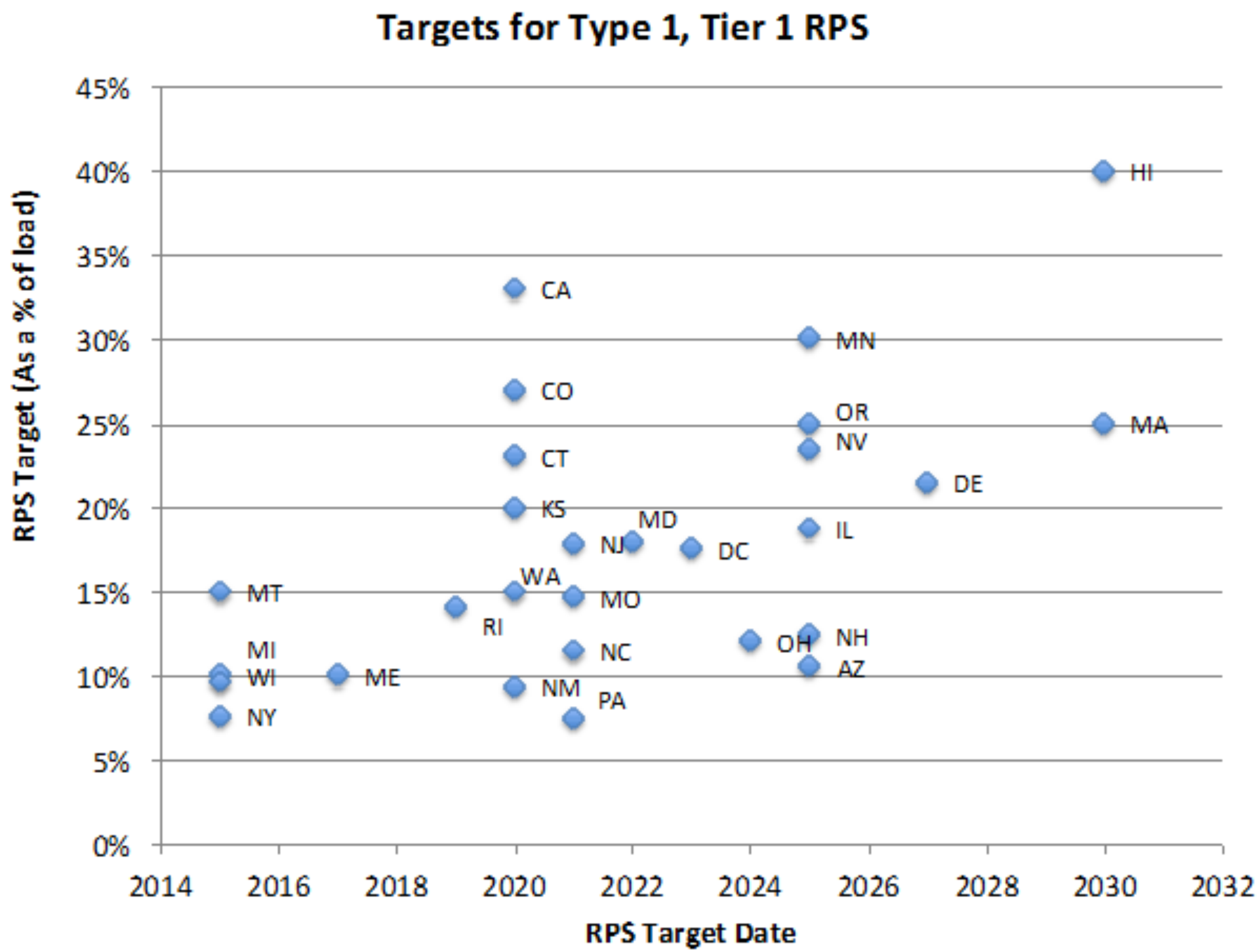
- Wood: largely in pulp & paper mills as co-generation from the chemical process used to make paper.
- Other biomass:
  - mill wood waste, used along with coal in 9 US power plants.
  - Municipal solid waste-to-energy.
  - Landfill methane.
- Geothermal: heated water from underground magma piped to the surface and used in steam generation of electricity.

Renewable Electric Generators



- Wind: at 7 to 9 cents per kWh, one of the least costly low-pollution electric generators.
- Solar:
  - Photovoltaic (solar panels)
  - Solar thermal (concentrated solar with mirrors to heat a fluid that then heats water to steam used in a generator)
  - Utility-scale PV produces power at 15-20 cents per kWh.
    - If installed prices fall 40%, PV can match the current price of wind.

Can Renewable Portfolio Standards be met?



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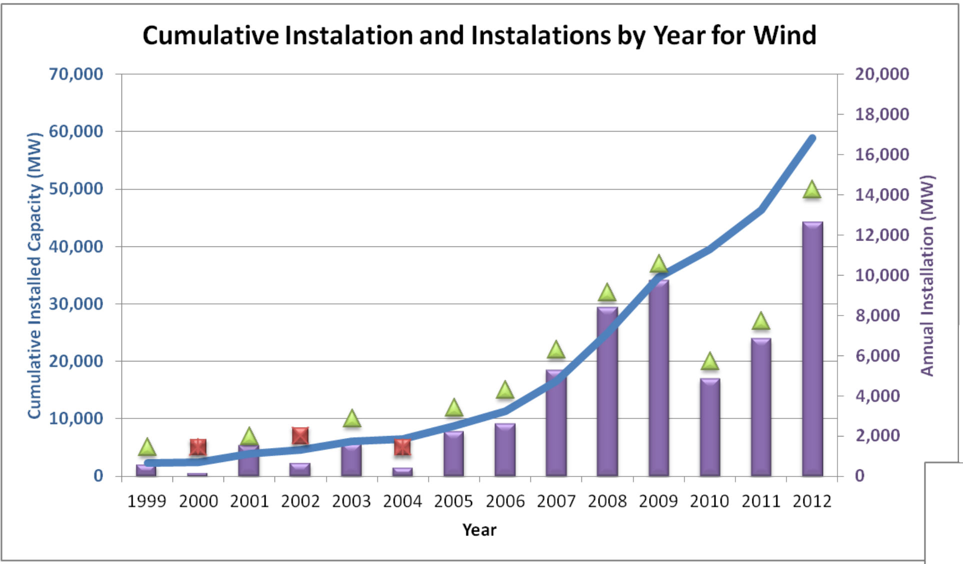
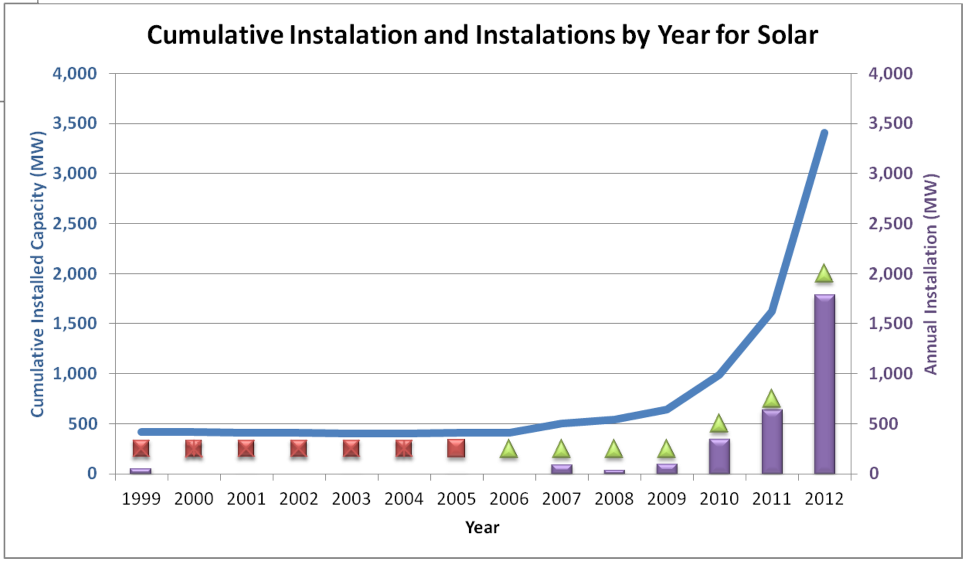
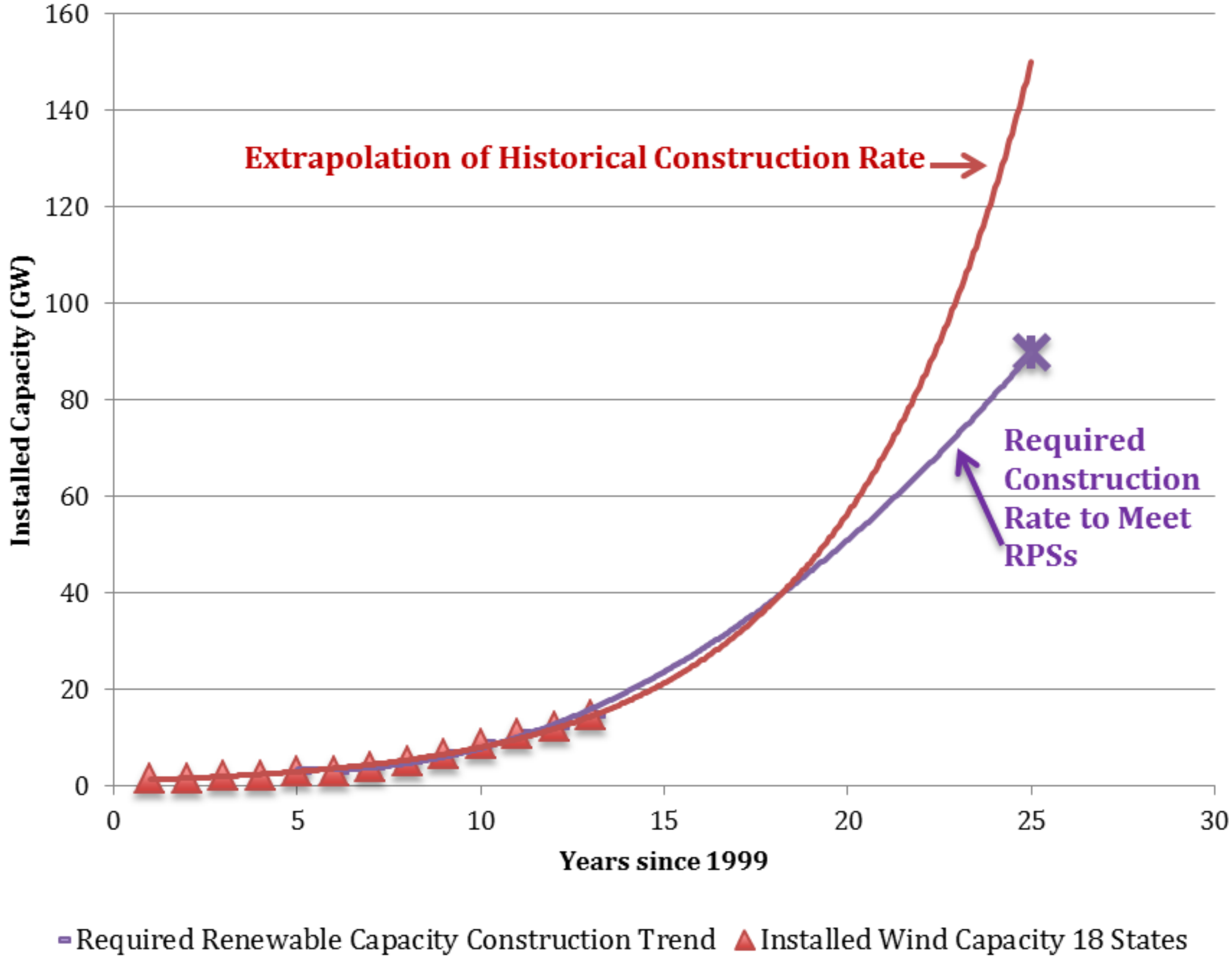


The vertical scale is 20 times smaller than in the wind figure



Green and red markers indicate the status of the Federal production tax credit (PTC) supporting wind projects and the investment tax credits (ITC) supporting solar projects.

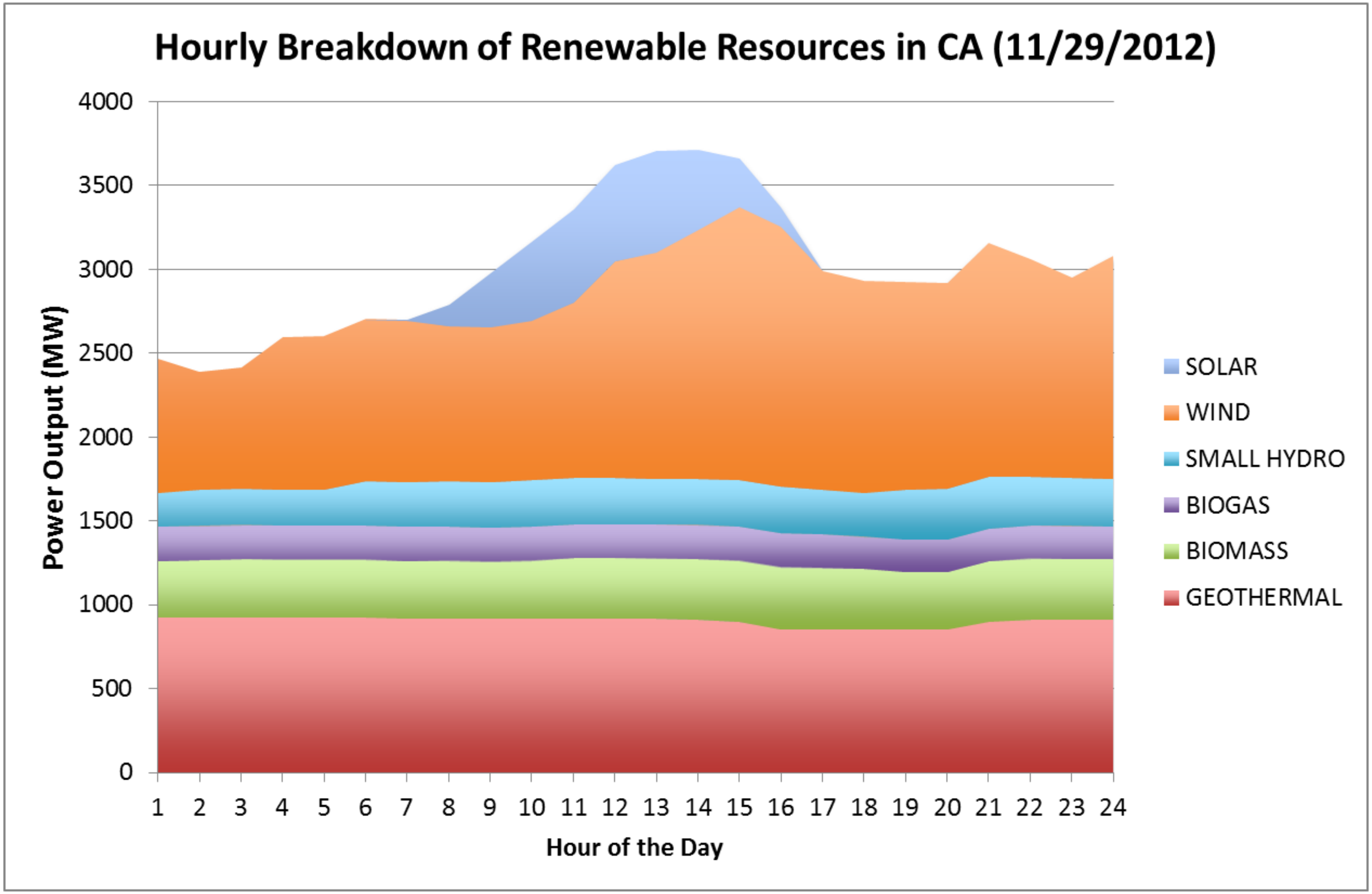
Can Renewable Portfolio Standards be met?



Jay Apt, Ph.D.

Professor, Tepper School of Business
Professor, Department of Engineering & Public Policy
Director, RenewElec Project
Director, Carnegie Mellon Electricity Industry Center

Challenges in Integrating Wind & Solar



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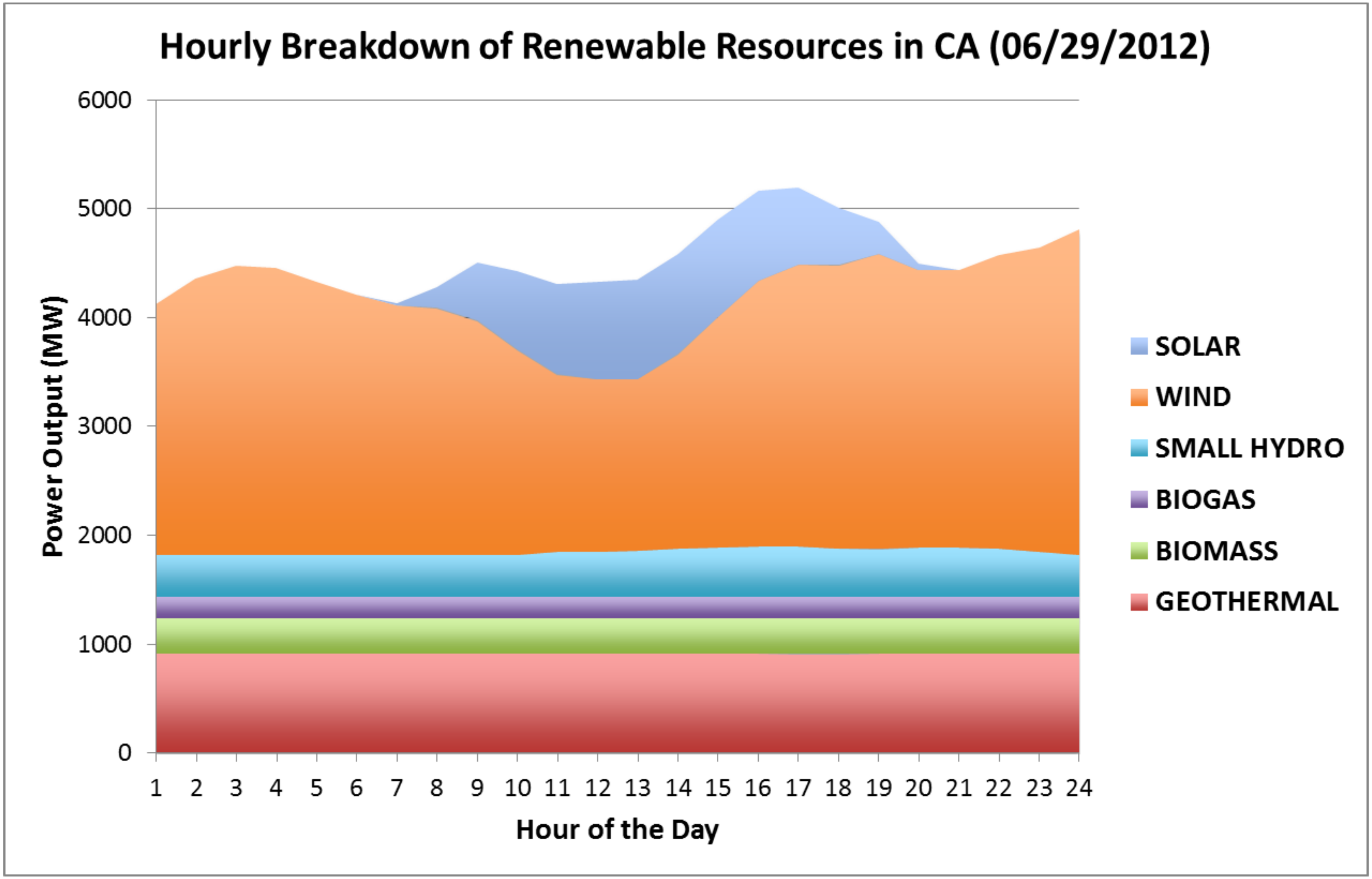

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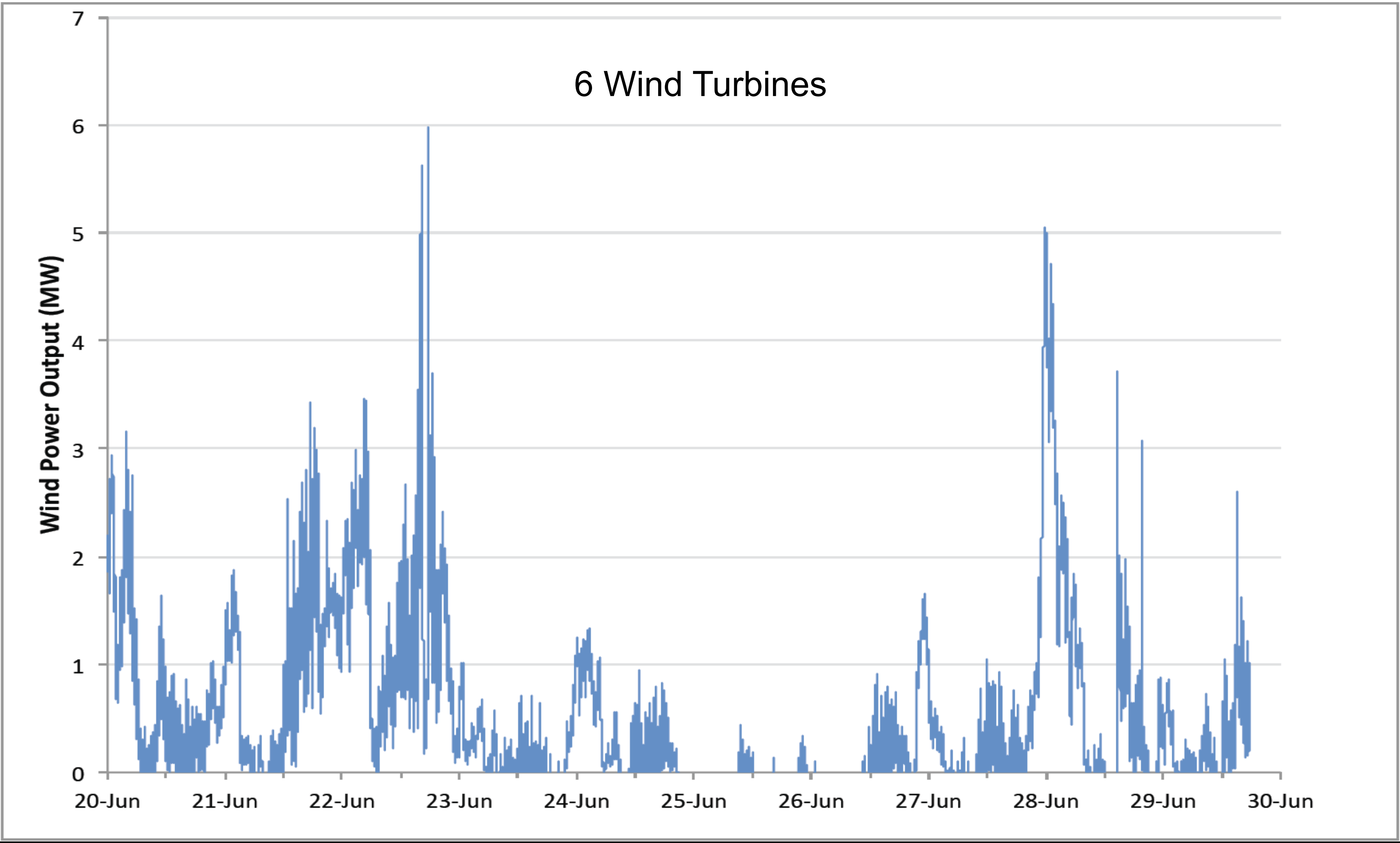

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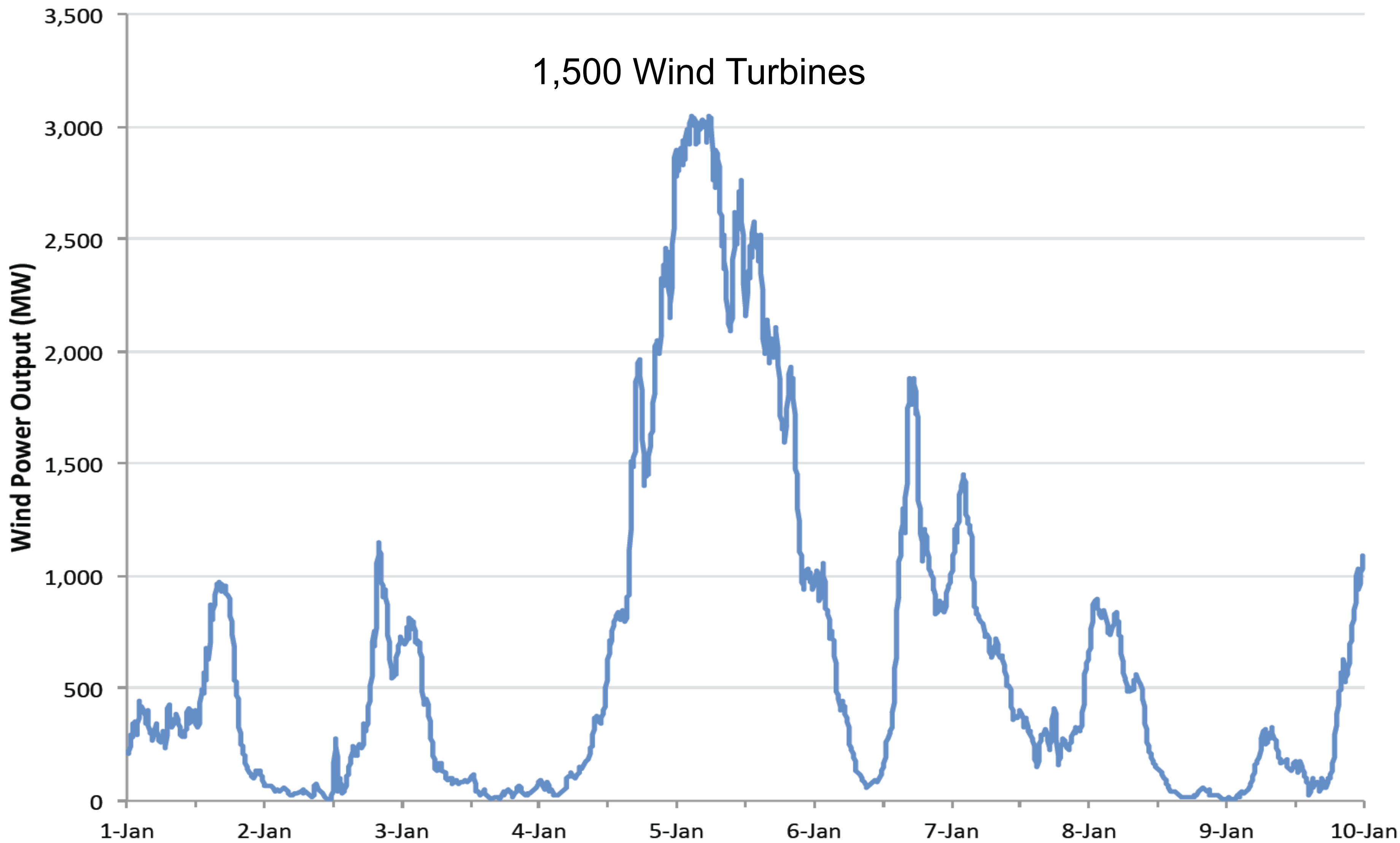
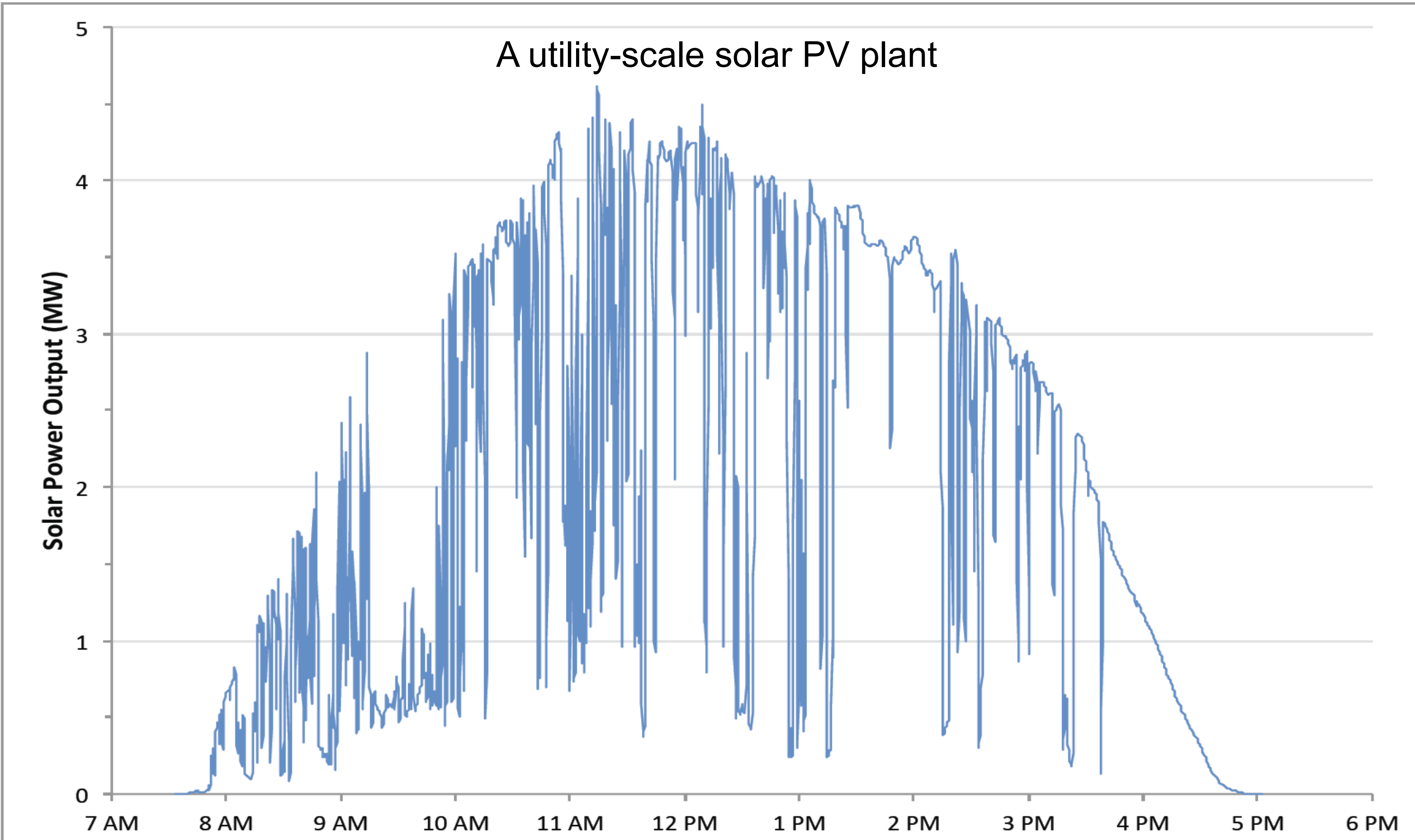
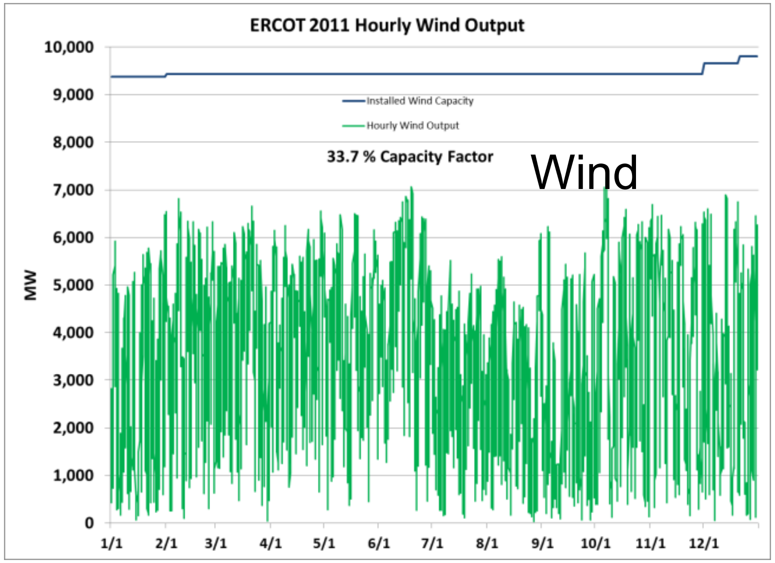


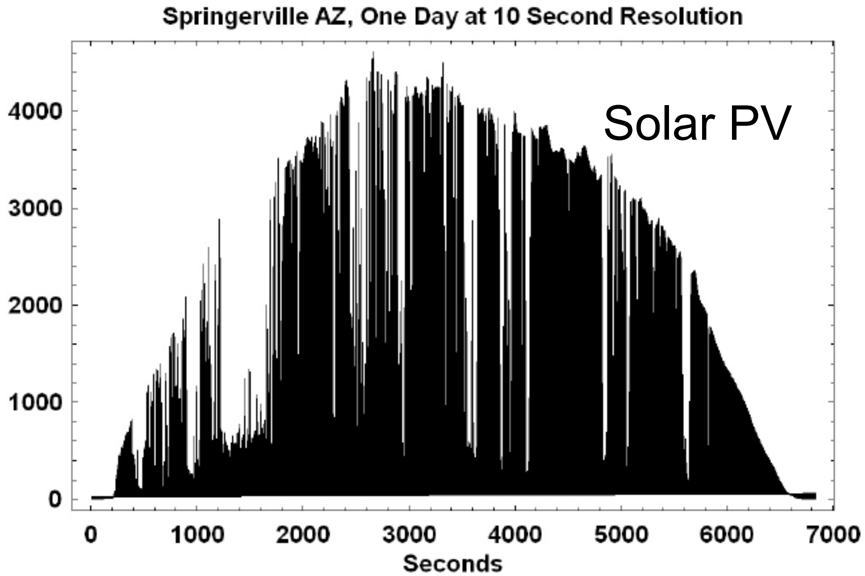
Challenges in Integrating Wind & Solar



What we have learned that can improve grid integration of wind & solar

Wind and solar plants' variability is not equally strong at short & long times.



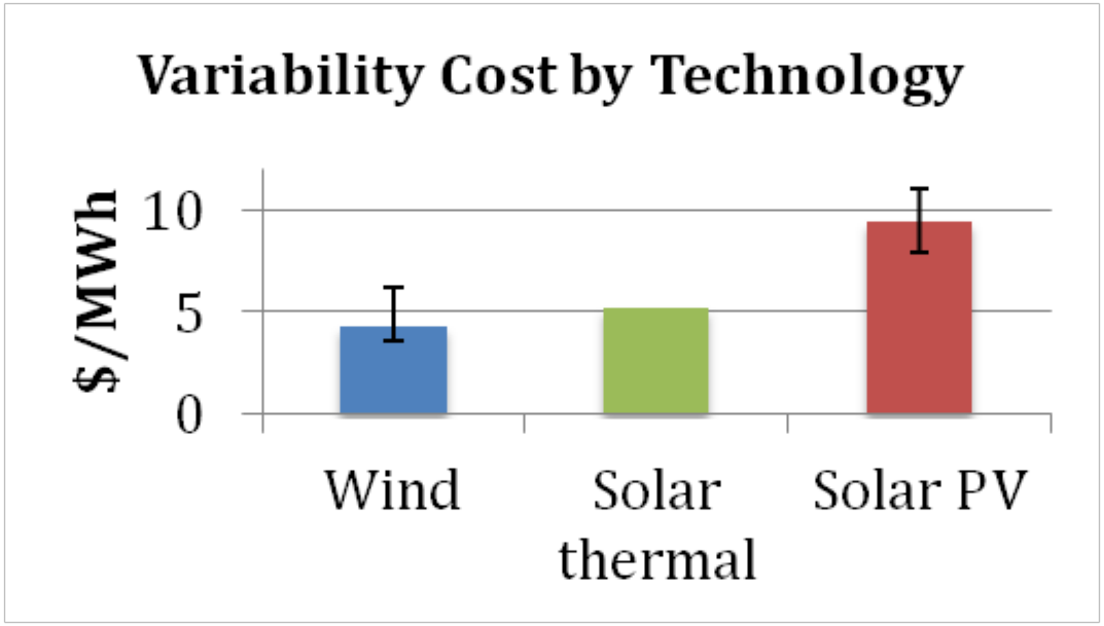


- If it were, the grid would need a lot of very fast-adjusting power to compensate.
- But, we found that the fluctuations are a thousand times larger at long periods than at short, so slow fossil fuel plants can compensate, and very few batteries are needed.

Wind and solar thermal are much less expensive to integrate than PV

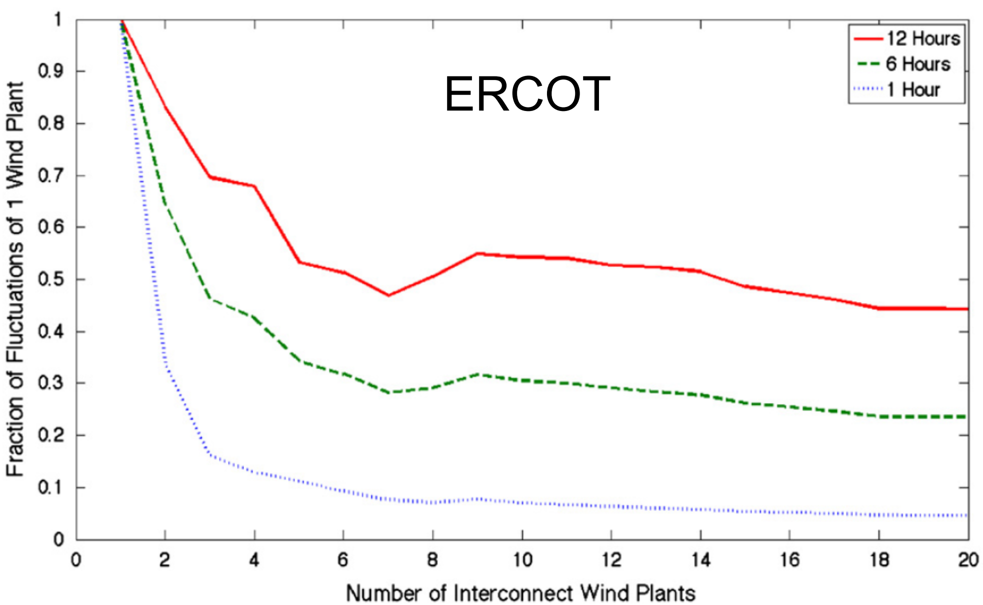
- Concentrating solar thermal systems have much lower variability than do solar PV systems, and so compensating for their fluctuations is less expensive.

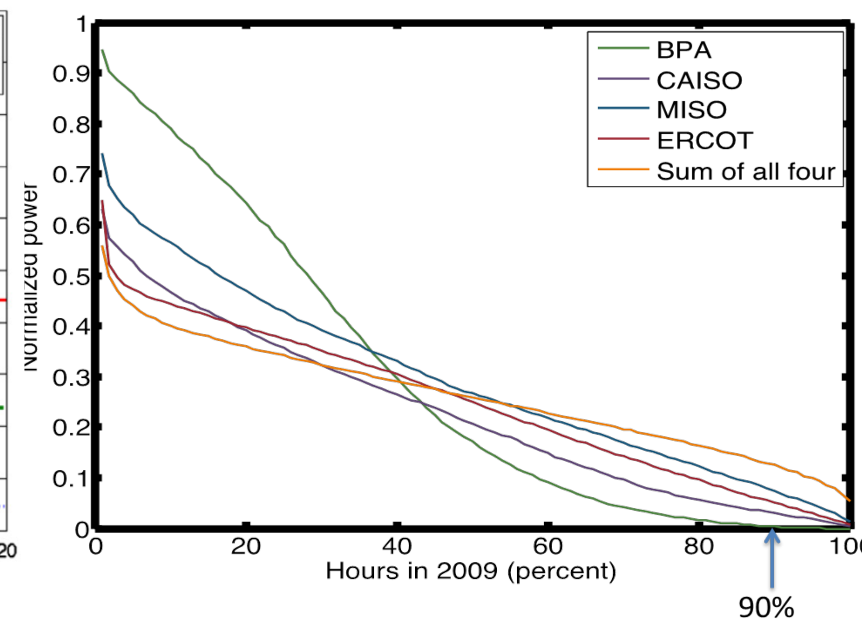

Photo: Solar Industries Association



Large-scale transmission is <u>not</u> required to smooth wind's variability

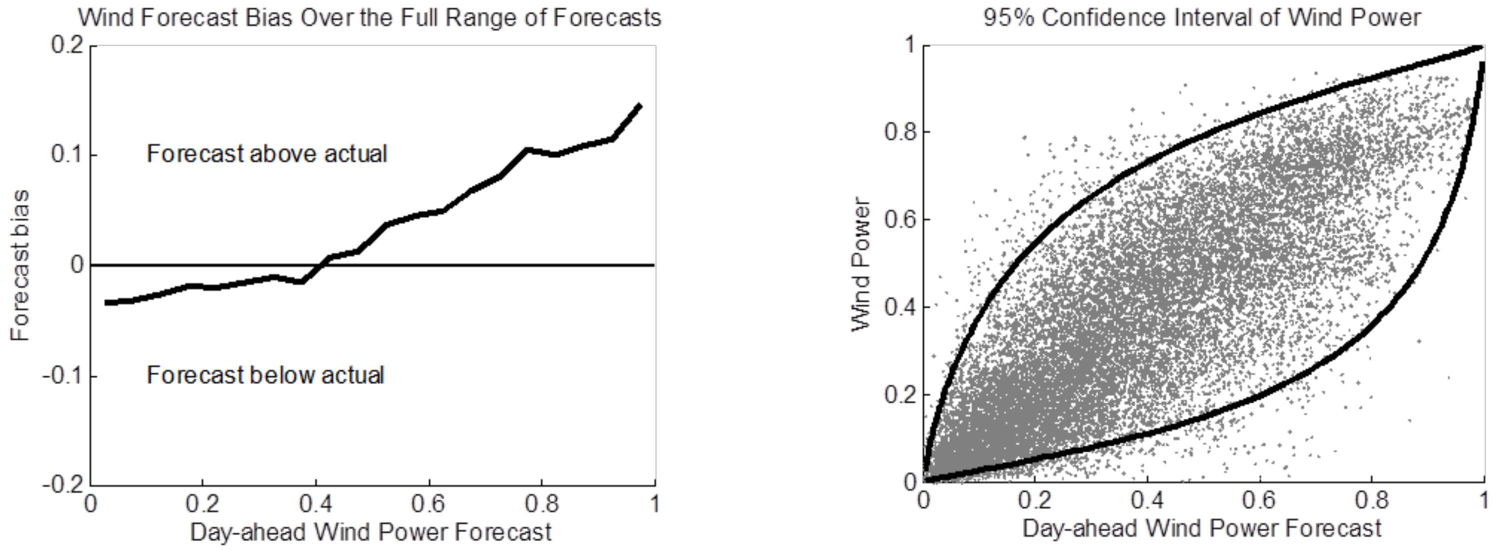
- The time scale matters.
- The point of diminishing returns in ERCOT is reached after about 4 wind farms have been connected.
- Connecting many states together does increase the firm power capacity provided by wind, but the transmission construction costs are higher than building a natural gas plant to get the same benefit.





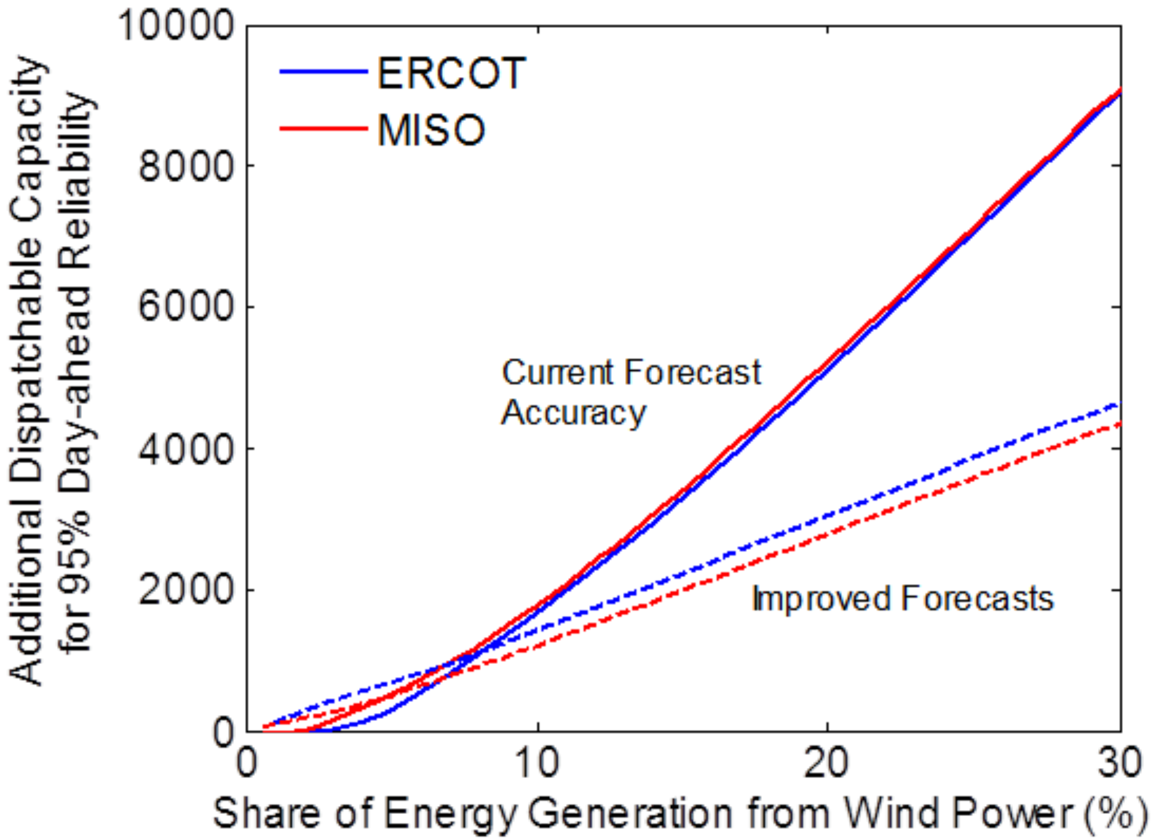
Wind Forecasts

- Forecasts of wind power under-predict wind during periods of light wind, and over-predict when the wind blows strongly.
  - We developed a simple mathematical model that allows grid operators to accurately and easily account for wind power forecast uncertainty



Day-Ahead Reserves Required by Wind

We have developed methods to compute the additional generation that must be standing by in case the wind does not follow its forecast.



Batteries

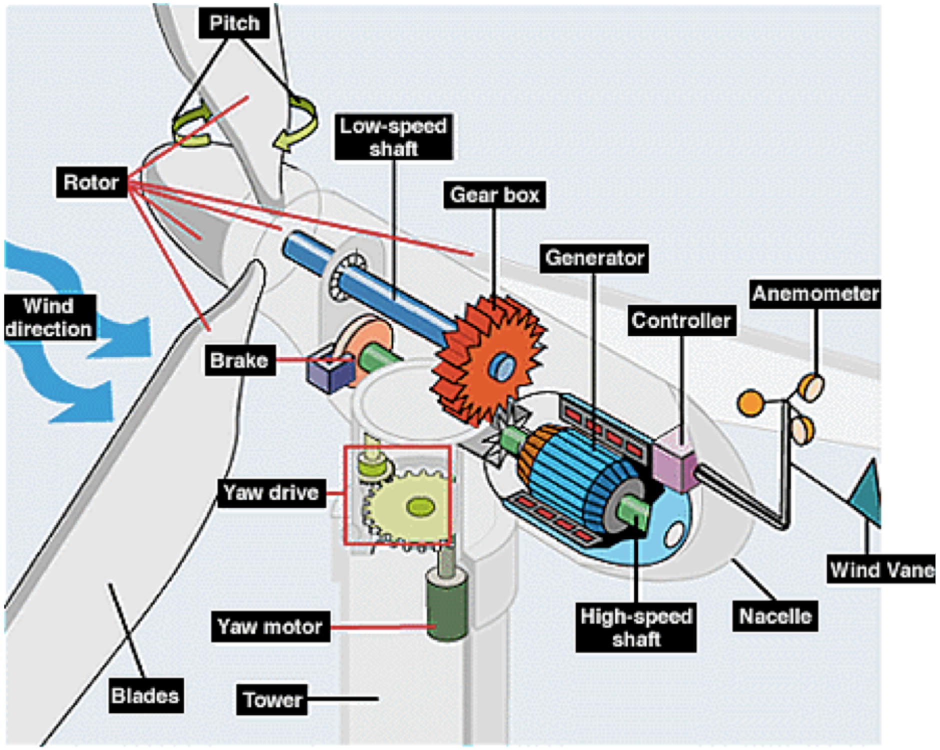
- A very small complement of batteries can remove a great deal of variability from wind power. A few batteries can greatly increase the amount of wind that can be integrated economically.
- Battery vehicles are not of much use in compensating for wind or solar power’s variability.

Stephen Rose, Ph.D.

Post-Doctoral Fellow, Dept. of Engineering & Public Policy

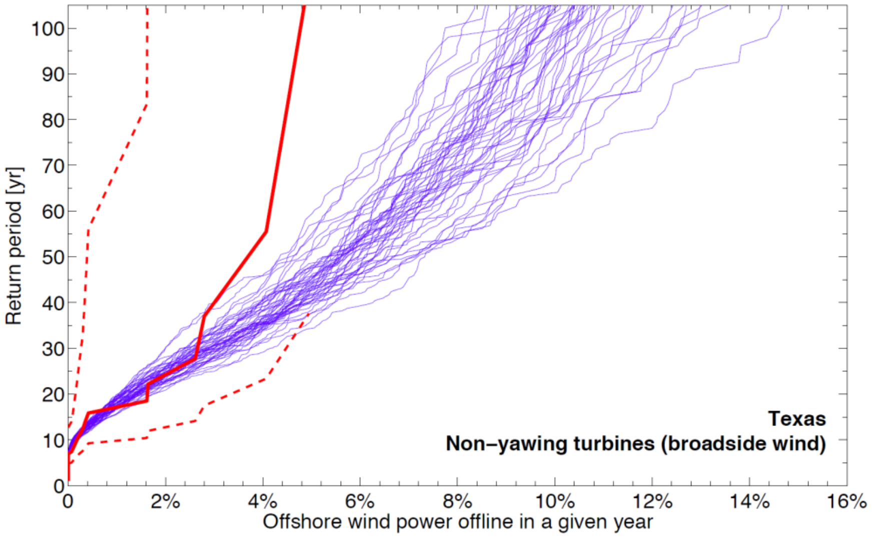
Curtailing Wind Power

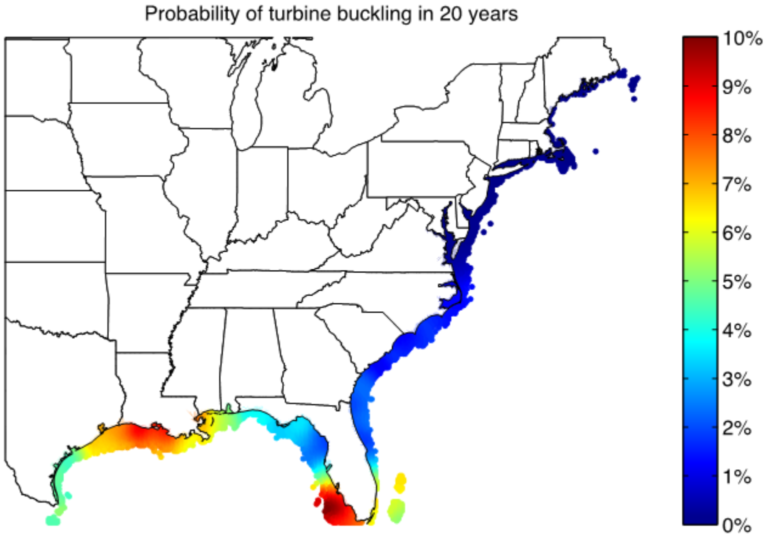
- Creating reserve of power by curtailing wind turbines (mandated in some countries) is generally more costly than other ways of stabilizing the electrical grid.



Hurricane Risk to Offshore Wind

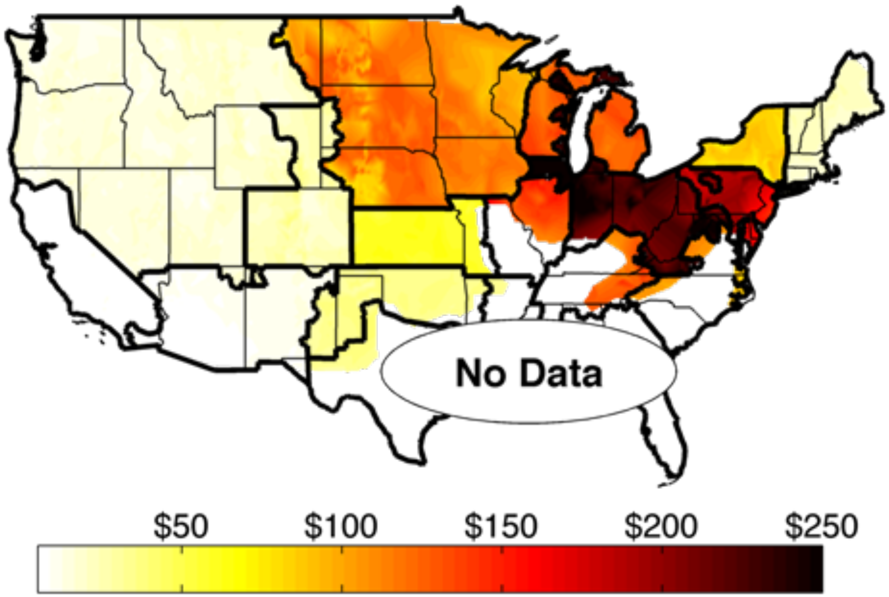
- Hurricanes pose surmountable risks to offshore wind turbines.
  - Small changes, such as having emergency power to turn the nacelle into the wind, can dramatically improve the survivability.
  - We quantified the riskier and safer areas to build



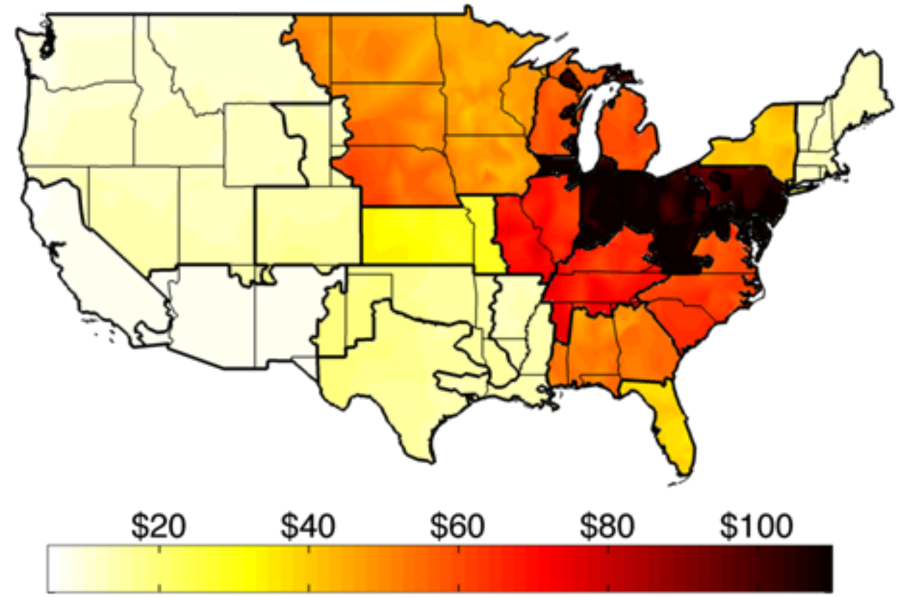


Where are Greatest Benefits from Wind & Solar?

If the goal is reducing pollution, it is MUCH better to locate wind and solar in the mid-Atlantic states than in the southwest.



Wind: Annual Health & Environmental Benefits From Displaced SO_2, NO_x, and $PM_{2.5}$ ($ per kW installed)



Solar: Annual Health & Environmental Benefits From Displaced SO_2, NO_x, and $PM_{2.5}$ ($ per kW installed)

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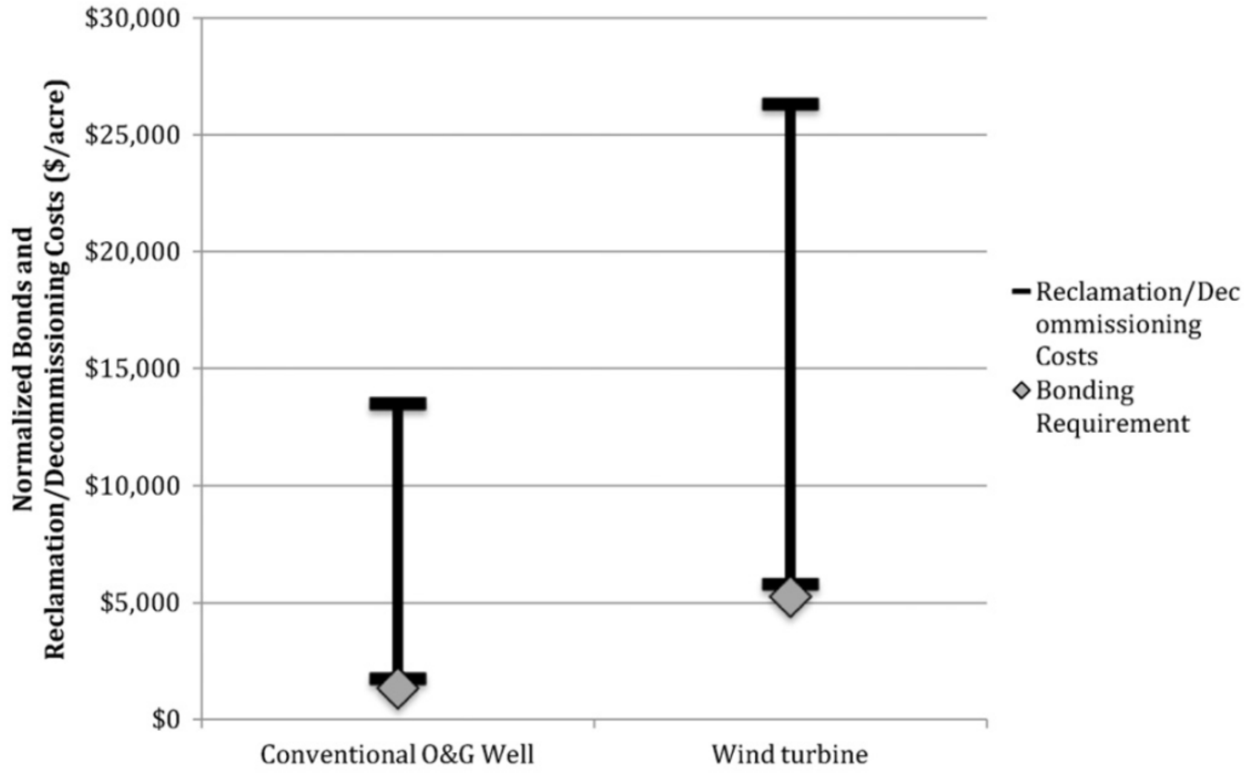
Decommissioning

Study comparing the decommissioning regulations of oil and gas wells and wind turbines at the federal, state, and county level revealed:

- Oil and gas bond requirements for permit to drill set in 1951 and 1960
  - Have not since been adjusted for inflation or to reflect true costs of decommissioning
- Wind turbine bonding requirements set in 2010
- State bonding requirements for oil and gas wells and wind turbines are generally greater than federal requirements
  - Bonds are still insufficient to meet the actual costs of decommissioning; oil and gas more deficient than wind

Decommissioning

- The bonding requirements for wind plants are generally at the very low end of projected decommissioning costs, as for oil and gas wells.



Short-Term Strategies

- Forecasters & grid operators: correct biased forecasts.
- Grid operators: incorporate forecast uncertainty in day-ahead reserve generation procurements.
- Legislators and regulators: provide incentives to site renewables where they will reduce pollution the most.
- Local, state, & federal governments: establish appropriate decommissioning requirements for gas well, as well as wind & solar power plants.
- Regulators and insurers: provide incentives to develop in areas with lower risks of hurricane hazards.

Long-Term Strategies

- ISO/RTOs and planners: large-scale geographic area connection by huge transmission lines is not required to mitigate the variability of wind.
- ISO/RTOs: develop market and non-market strategies to compensate energy storage operators for the benefits they can provide to customers.

Future Scott Institute Activities

- Next Policymaker Guide: Energy Storage

For More Information

Carnegie Mellon University

Scott Institute for Energy Innovation

www.cmu.edu/energy

Deborah D. Stine, PhD

Associate Director for Policy Outreach, Scott Institute

Professor of the Practice, Engineering and Public Policy

dstine@andrew.cmu.edu

Development and Dissemination of Scott Institute Policymaker Guides are Made Possible Through the Generosity of the Jesanis Family.