Climate Change, Cap-and-Trade, Renewable Electricity & Efficiency Mandates: How Do They Fit together?

Jay Apt and Lester B. Lave

June 12, 2009

The Carnegie Mellon Electricity Industry Center

www.cmu.edu/electricity

Carnegie Mellon Electricity Industry Center (CEIC)

- We are in our 8th year
  - Created jointly with A.P. Sloan Foundation and EPRI in August 2001 Close partnership with industry principals and field-intensive research.
- We define ‘Electricity Industry’ broadly to include the companies that supply the equipment, all the organizations that build and operate the nation’s electric power system, agencies that shape and regulate the system as well as customers who use the power.
- Support
  - Initial funding: $1.75 Million over 3 years from Sloan and EPRI.
  - Renewed twice.
  - Co-funding for specific projects from industry and government.
- Co-Directors: Professor Lester Lave and Professor Granger Morgan.
- Executive Director: Professor Jay Apt.
- 19 Faculty, 23 Ph.D. Students, and 4 post-doctoral fellows.
- 20 PhDs granted.

Current Research Areas

- Markets and Investment
- Security, Reliability, and Distributed Energy Resources
- Environmental Issues
- Advanced Generation, Transmission, Sensing, and Control
- Demand Side Issues
- Human Resources and Management Issues

Supported by:

The Alfred P. Sloan Foundation
Electric Power Research Institute
U.S. National Science Foundation
U.S. Environmental Protection Agency
U.S. Department of Energy
Tennessee Valley Authority
U.S. Office of Naval Research
McDermott Technology
American Public Power Association
Florida Power and Light
ELCON
Siemens Energy
National Rural Electrical Coop Assn.
ABB
Alliant Energy
Commonwealth of Pennsylvania
Customized Energy Solutions Ltd.
Duke Energy
RK Mellon Foundation
Carnegie Bosch Institute
The Pew Climate Change Center
The Southern Company
The Allegheny Conference
JP Morgan

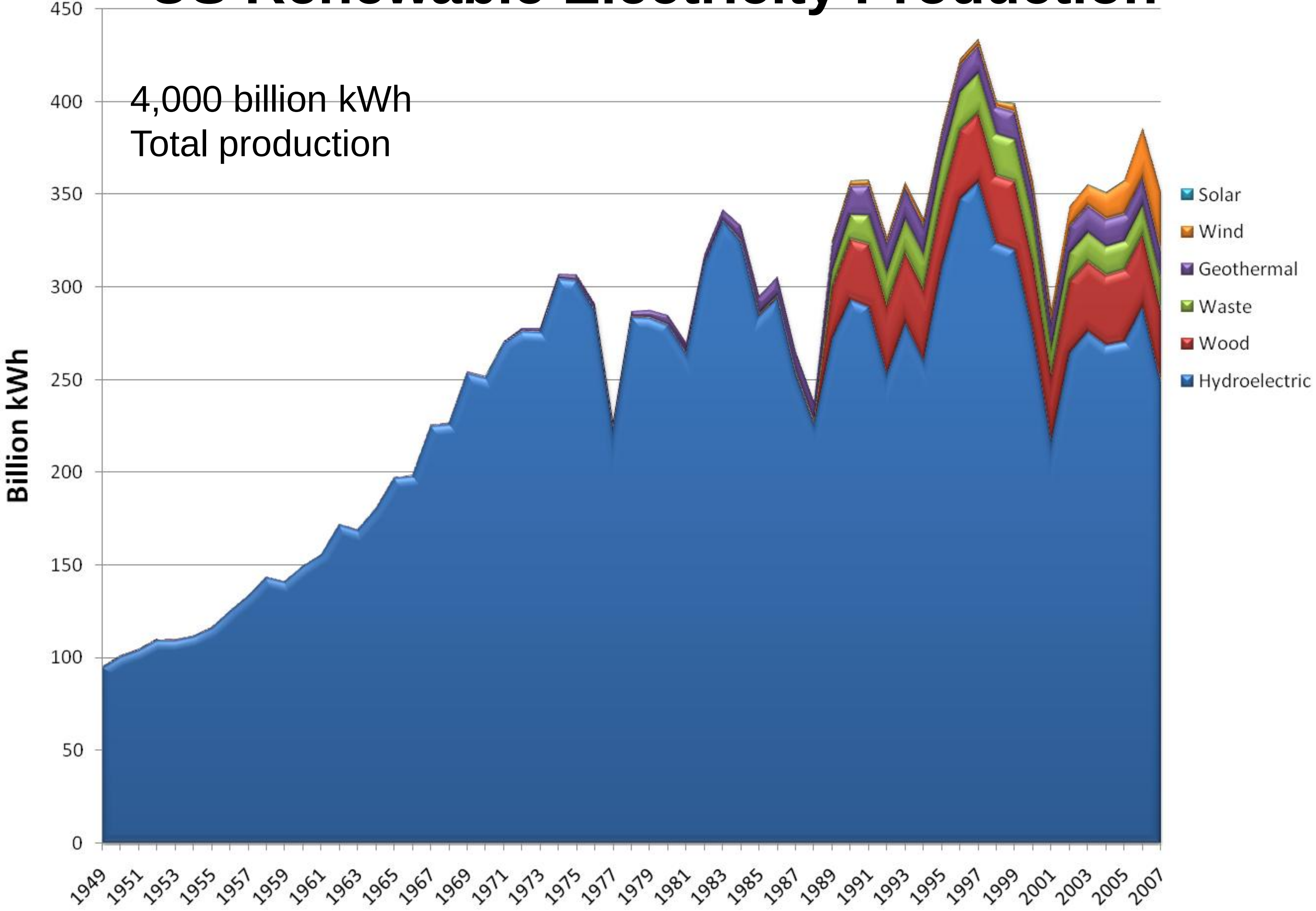
National Academy of Sciences, National Academy of Engineering

America's Energy Future

A review of energy technologies

Real Prospects for Energy Efficiency in the US

US Renewable Electricity Production



Principal Points

- **Our goals: Reliable, quality power at affordable prices that meets environmental & sustainability goals**
- We love renewables & see a large role on the time scale envisioned by Waxman-Markey
- Integrating wind & solar, particularly beyond 15%, poses large costs & technical problems
- Wind/solar with natural gas backup lowers CO_2 emissions less than assumed
- Large amounts of transmission are needed for wind/solar
- Handling variability with remote sites is expensive
- For wind/solar to make a large contribution, need cheap storage or possibly demand response

- We share the same goals but perhaps not the same priorities
- What are the tradeoffs among: Reliability, Cost, Sustainability, Environmental Quality & Global Climate Change?

- Putting a price on CO_2 gives tradeoffs

- CAFÉ & RPS often used to hide the costs & finesse the tough political question
- Who would argue against fuel economy?
  Renewables?

CAFÉ & RPS often used to hide the costs & finesse the tough political question

Who would argue against fuel economy?

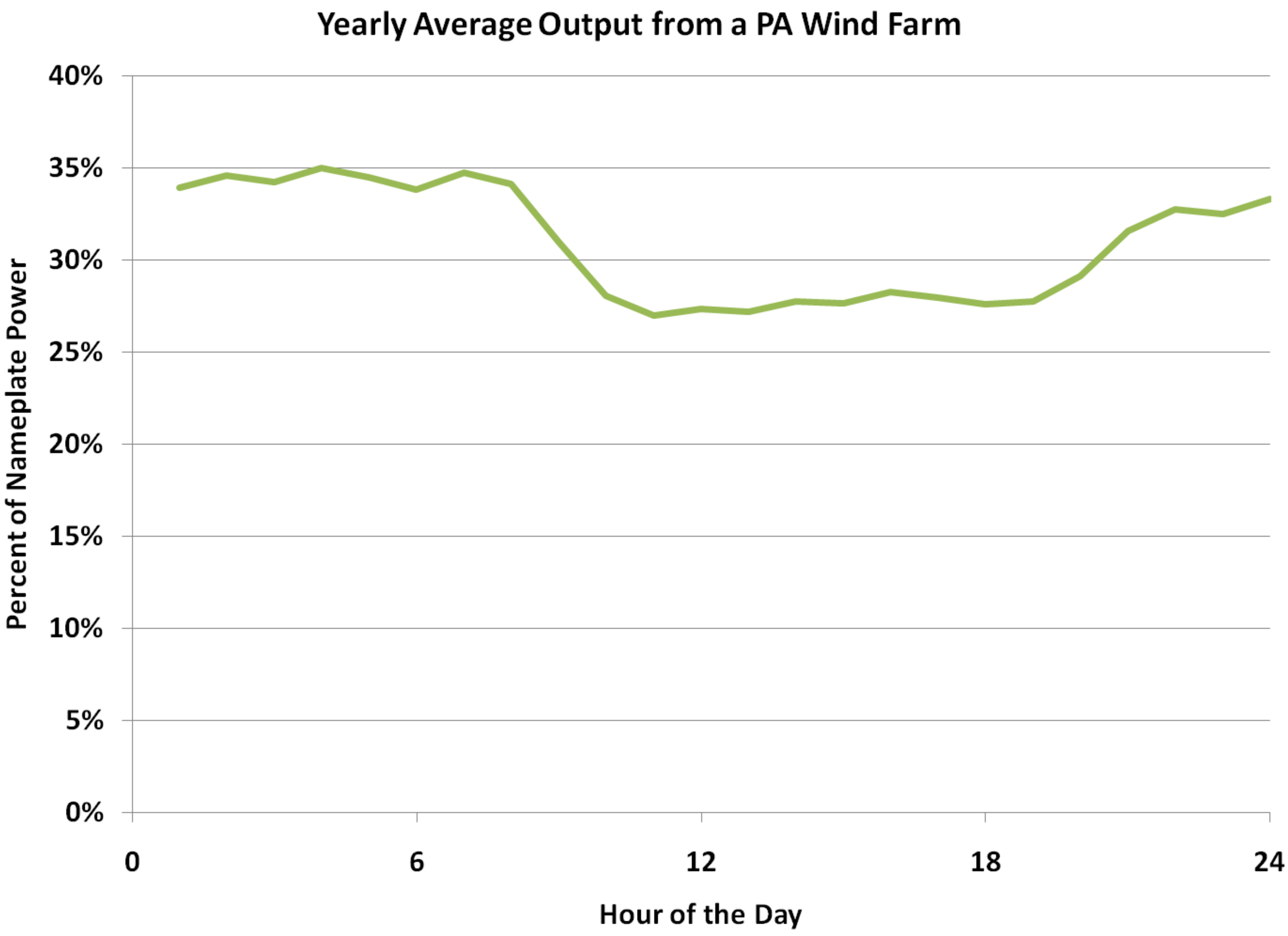
Renewables?

But

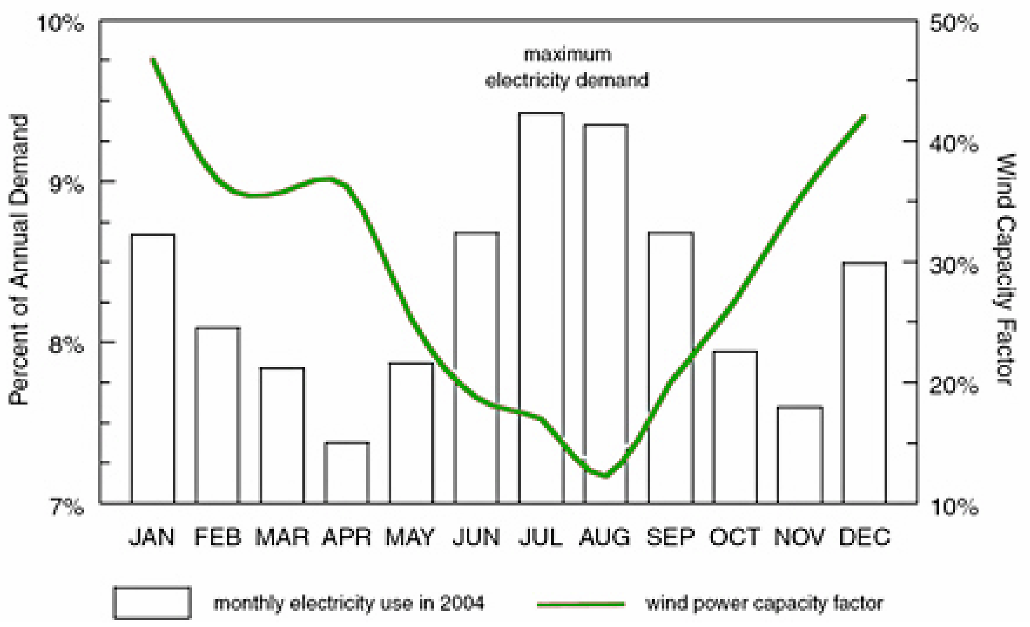
- Do we want to pay three times as much for electricity? (solar PV)
- To pay equivalent of $5/gal gasoline?

CHARACTERISTICS OF WIND AND SOLAR

Daily wind output does not match load well

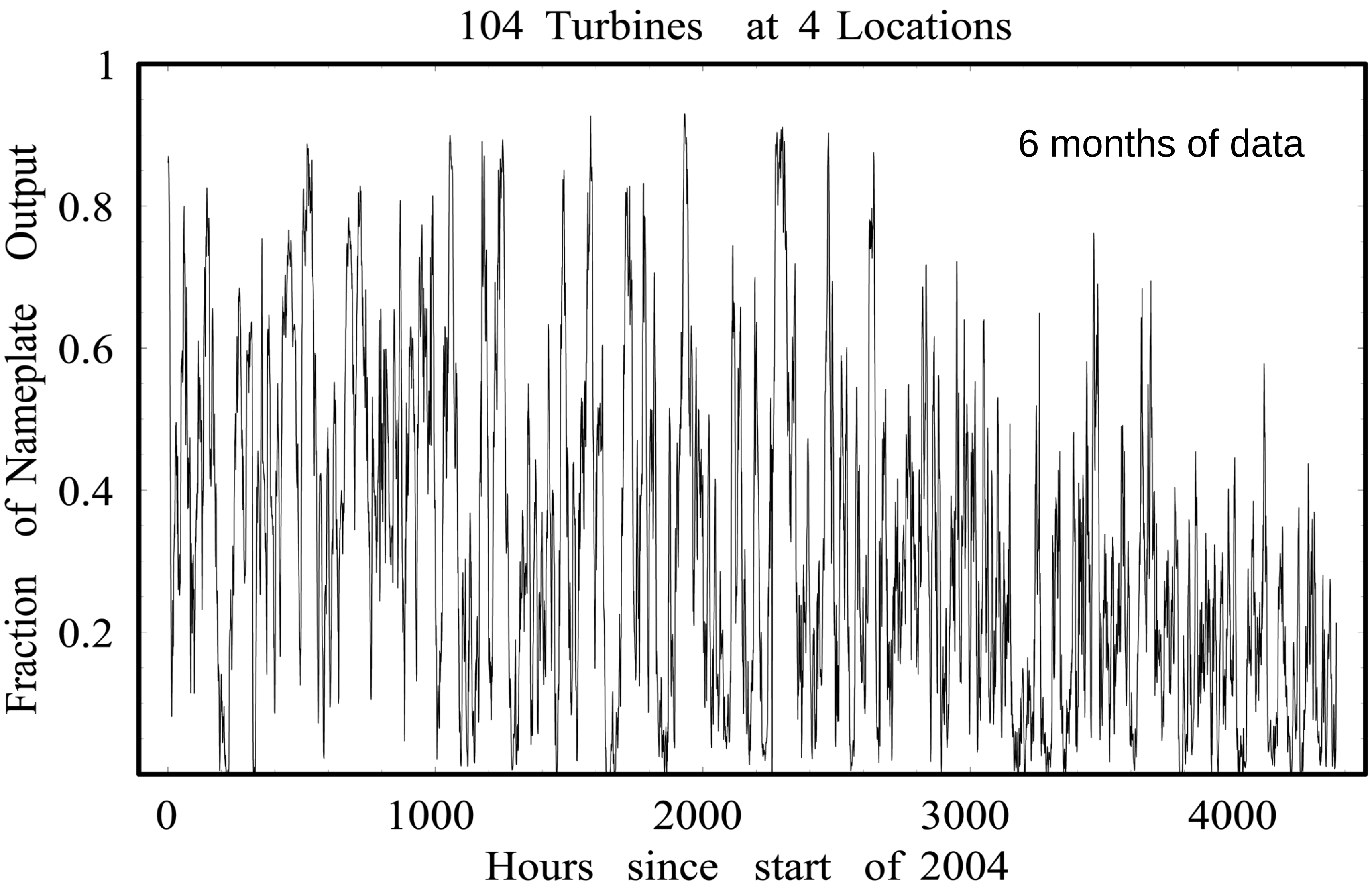


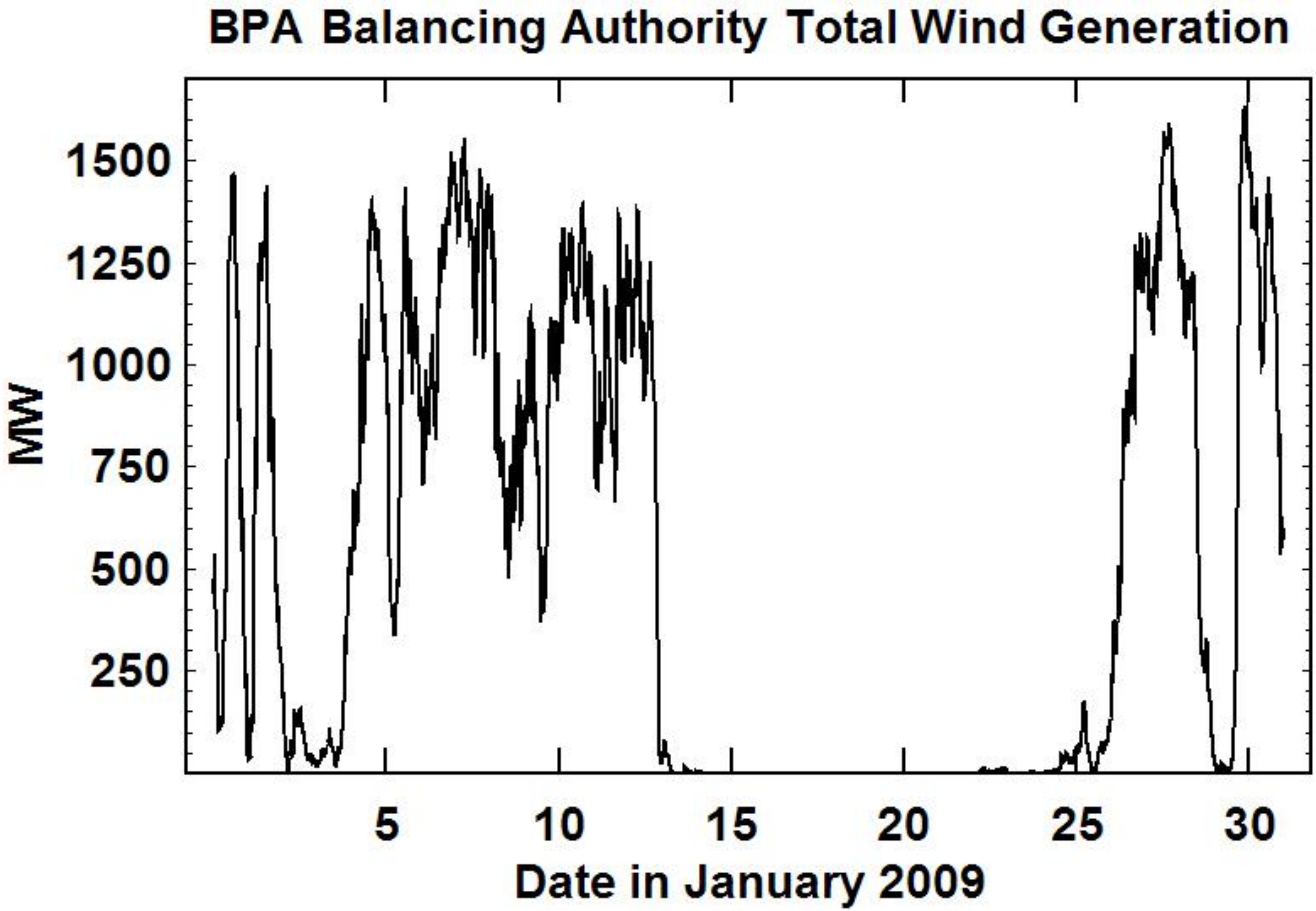
Seasonal wind output does not match load well

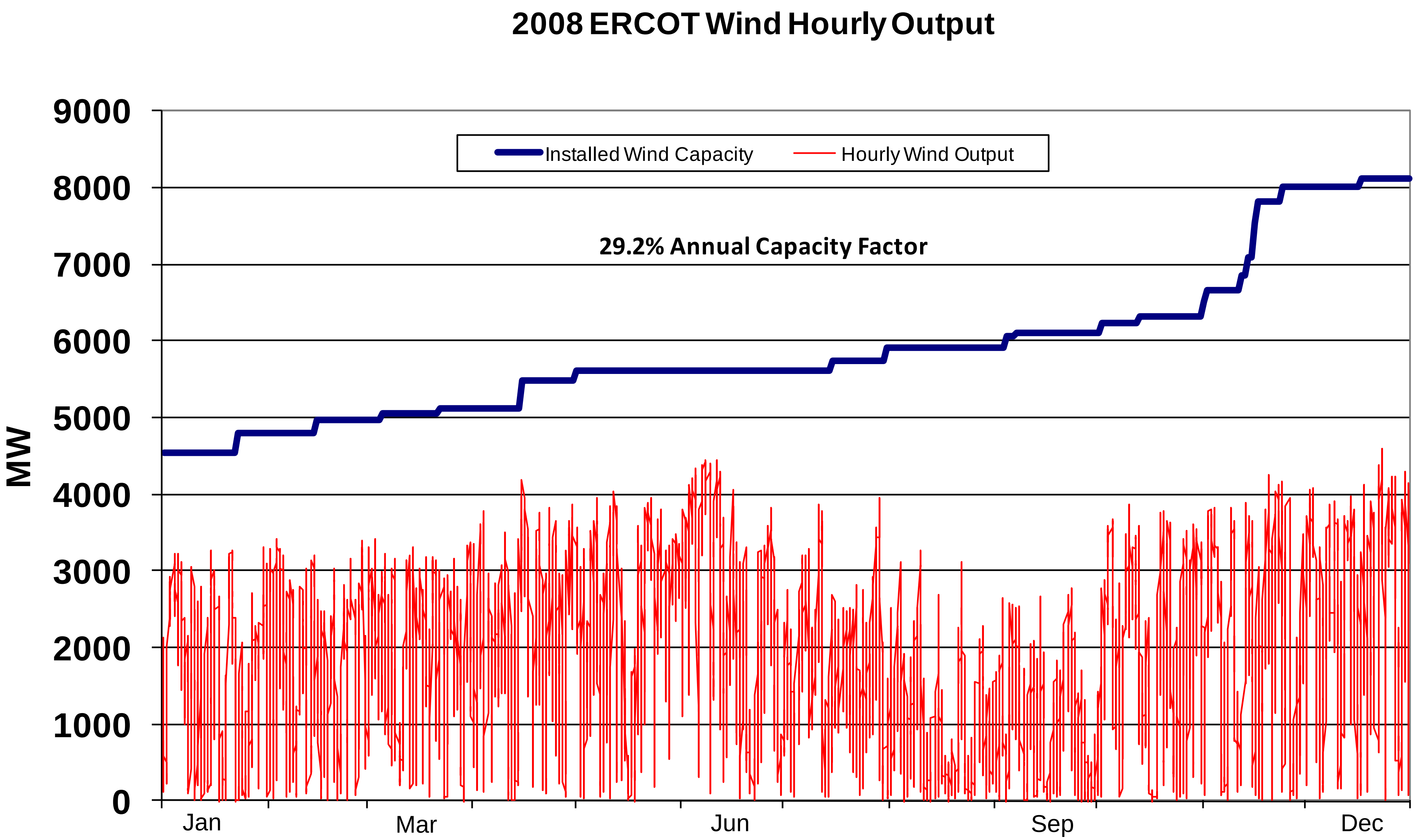


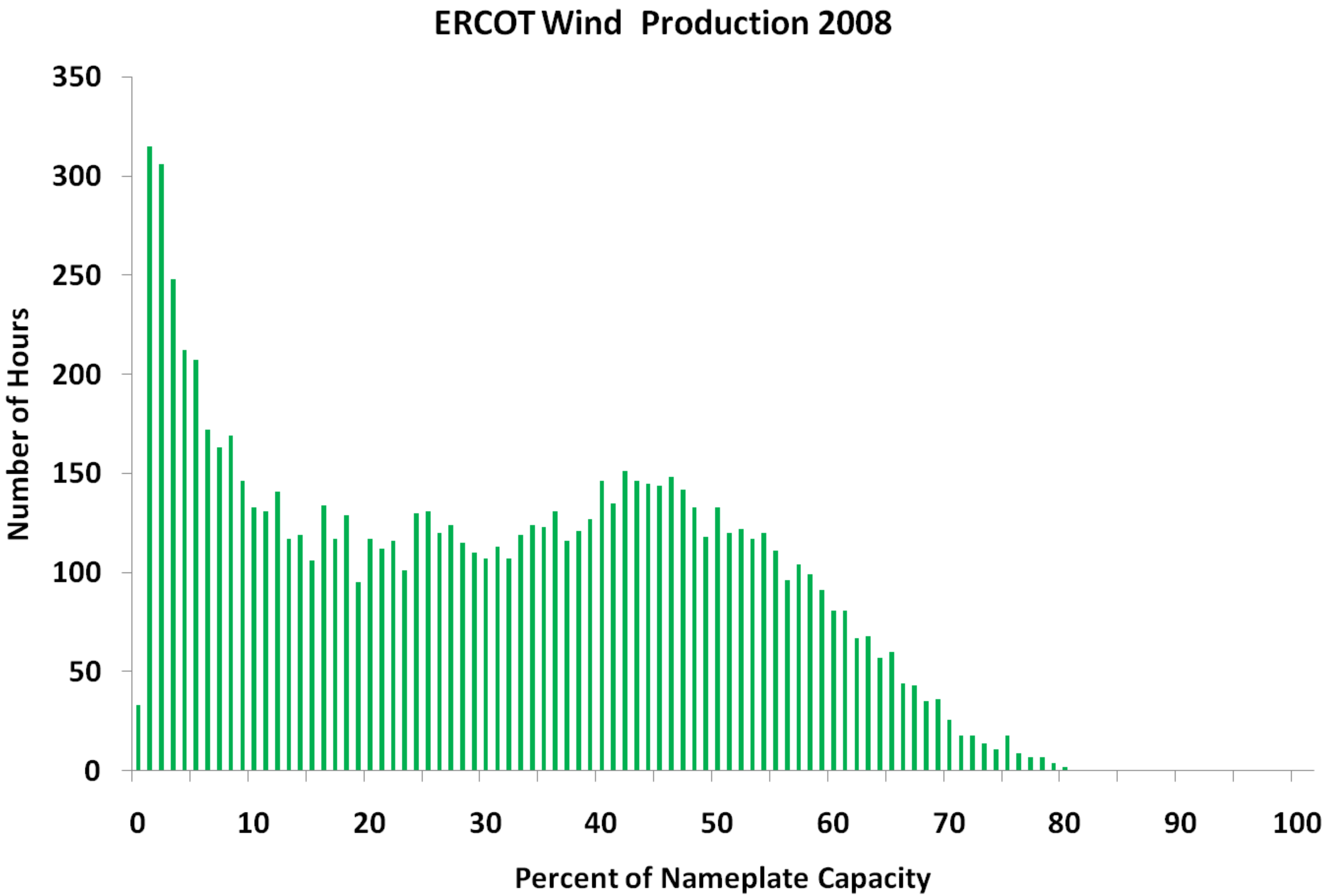
Monthly electricity demand and wind generation capacity factors in the Mid-Atlantic Highlands.
Source: National Research Council

Wind doesn't blow all the time



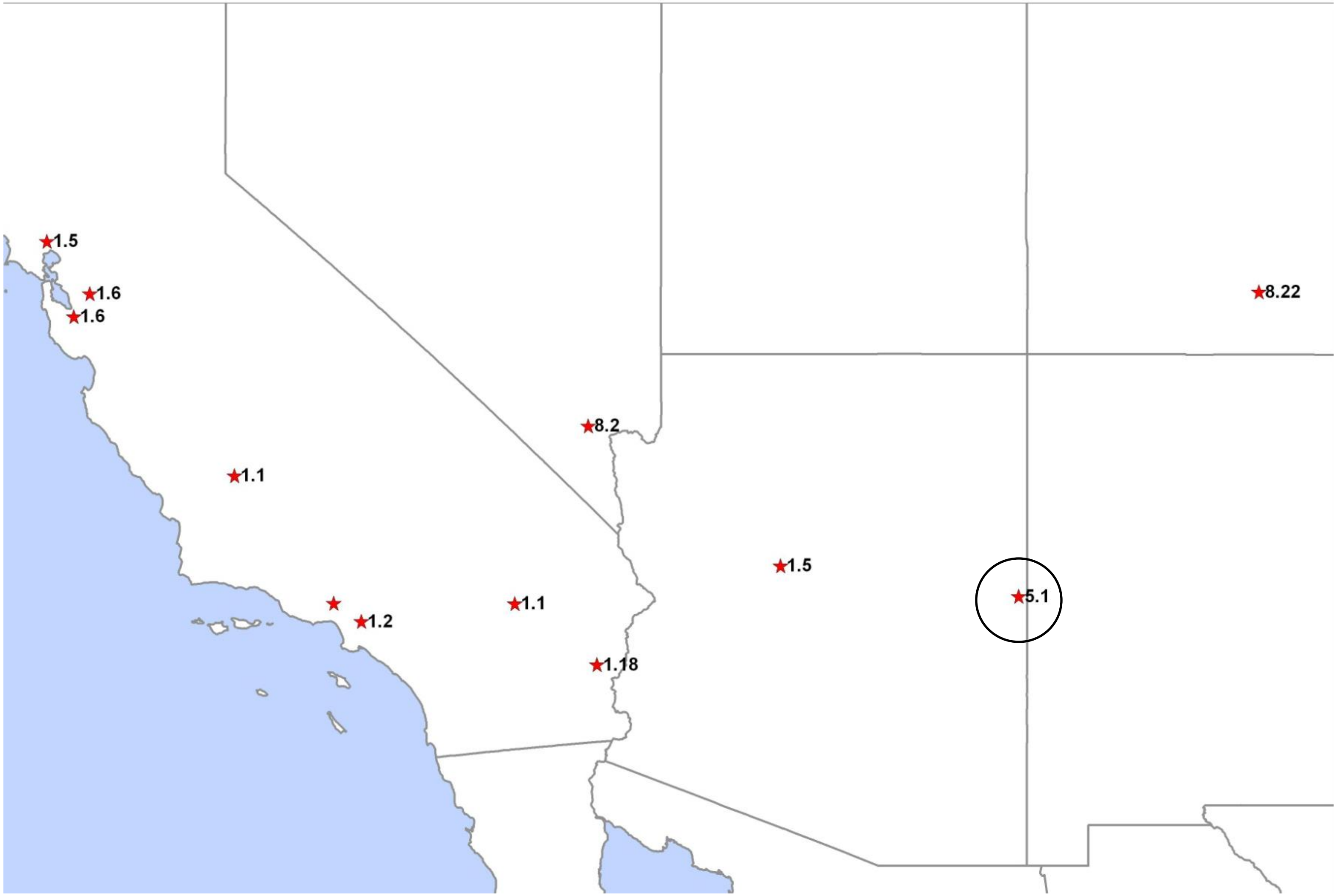

BPA Balancing Authority Total Wind Generation
MW
1500
1250
1000
750
500
250
5
10
15
20
25
30
Date in January 2009


2008 ERCOT Wind Hourly Output
Installed Wind Capacity
Hourly Wind Output
29.2% Annual Capacity Factor
MW
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan
Mar
Jun
Sep
Dec

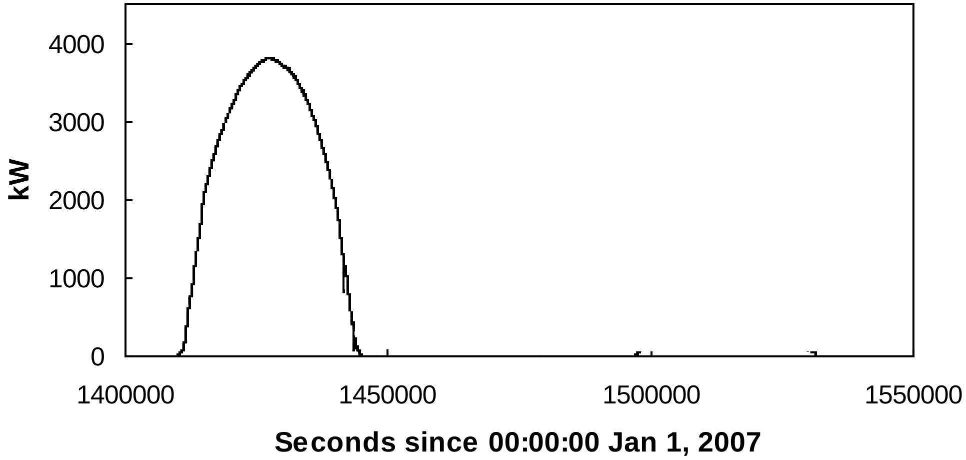


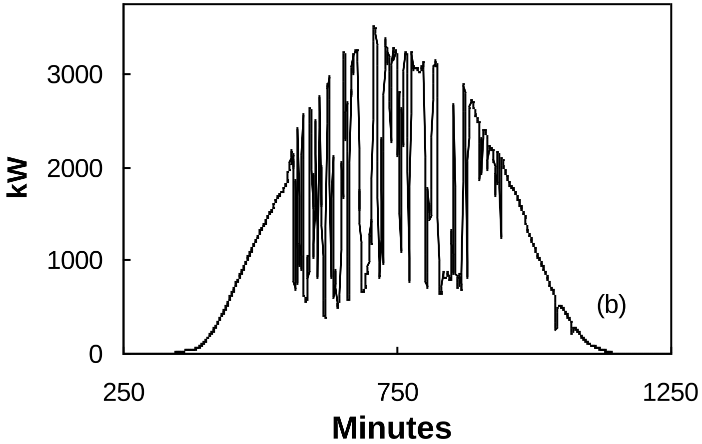
ERCOT Wind Production 2008
Number of Hours
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
Percent of Nameplate Capacity

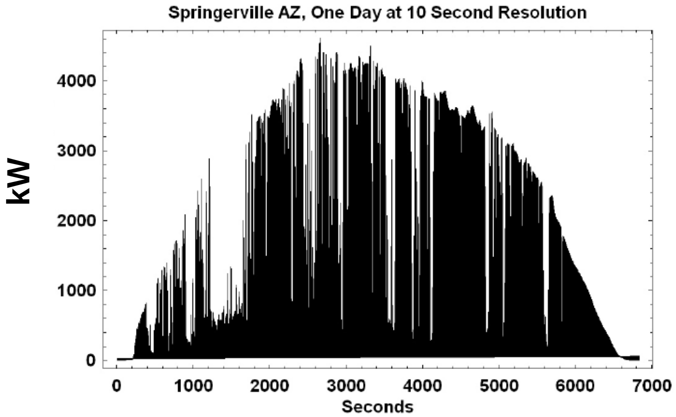
Solar



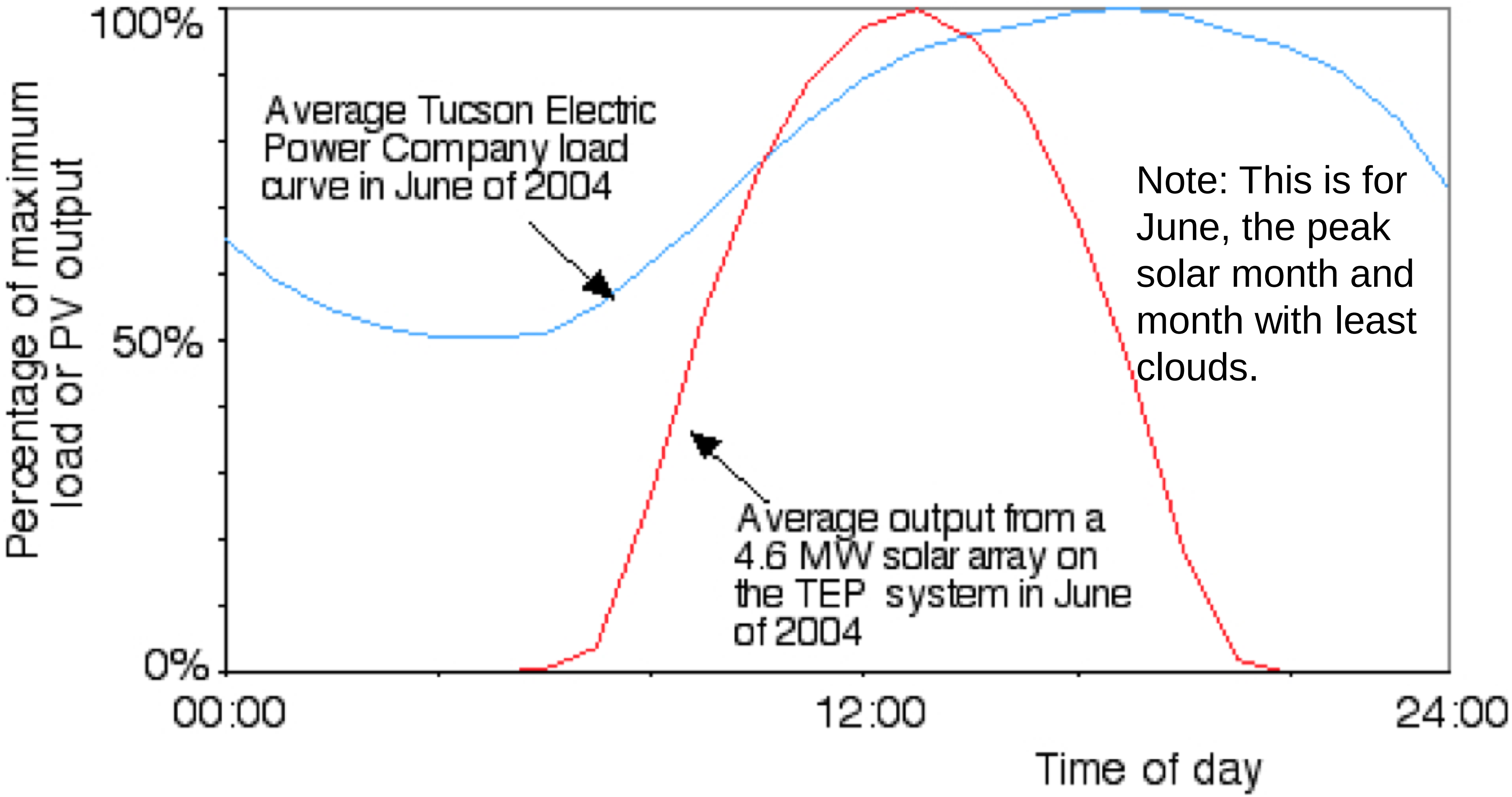
Comparison of Wind with Solar PV
4.6 MW TEP Solar Array (Arizona)







Solar PV and Load



Note: This is for June, the peak solar month and month with least clouds.

Solar thermal

While there are several solar thermal power plants now operating, and more in development, it is not yet clear how economical they will prove to be. But it appears that they can produce power for about the same cost as CdTe PV, 2/3 the cost of Si PV. And, they can fairly easily be coupled with phase change storage.

Source: Acconia

Experience Base

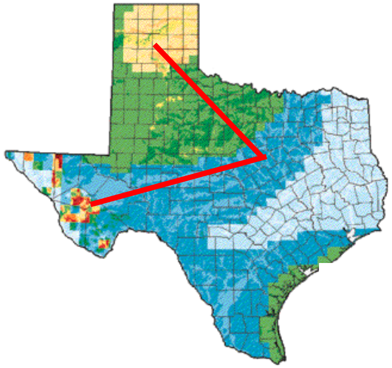
- Spain
  - By energy: 9.5% wind, 10% hydro, 24% gas, 26% coal, 20% nuclear
  - 86 GW of capacity for 45 GW of peak load; 15 GW of wind capacity
- Ireland
  - 1.4 GW of wind capacity; produces 8% of electric power
- Denmark
  - 20% wind by energy, but Denmark does not exist electrically (very large transmission lines to German fossil and Scandinavian hydro)
- Hawaii
  - 15 % wind on the Big Island (HELCO)
  - At night, they must accept looser frequency regulation (59.8 – 60.2); several occasions of 59.68 Hz. (ref: EPRI reports 1018715, 1018716)
  - Must allocate reserves among several units (not by lowest cost);
    (ref: *ibid.)*

Transmission

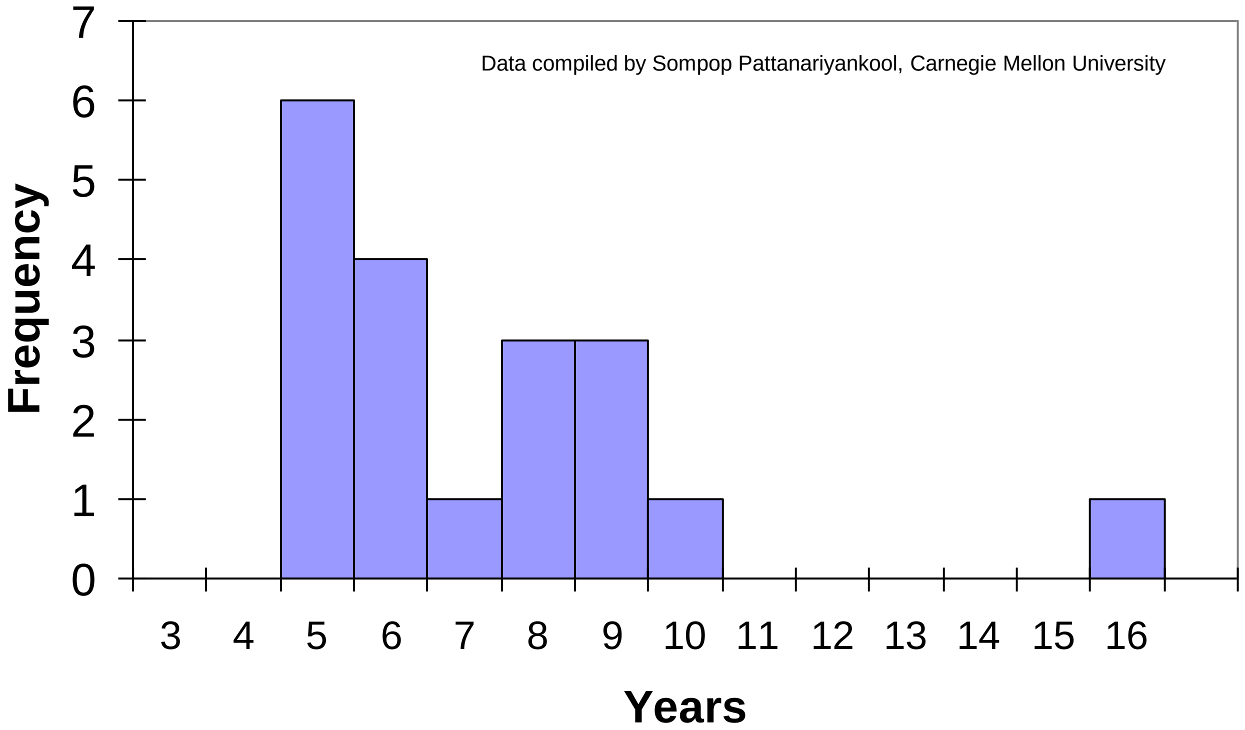
- The best wind sites are distant from load.
- American Electric Power did a 2008 study for AWEA.
- Forecasts that an investment of $60 billion of transmission projects is required to support a 20% wind RPS.
  - *Interstate Vision for wind Integration*, 2008. American Electric Power and the American Wind Energy Association. Available at http://www.aep.com/about/i765project/docs/WindTransmissionVisionWhitePaper.pdf.

But – that figure does not include the sub-transmission lines and substations (both at the wind end and the load) that may equal the transmission line cost.

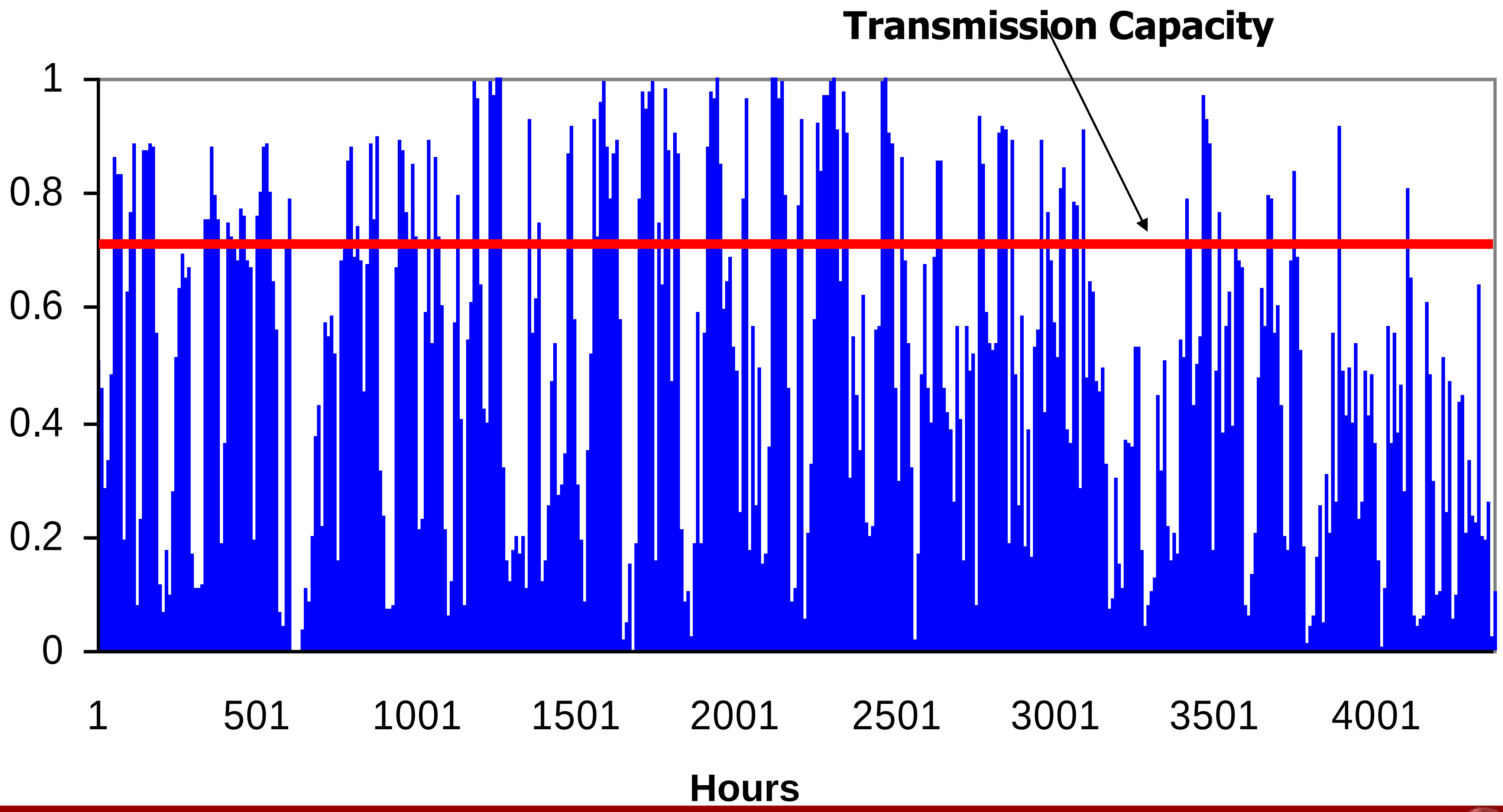
Texas Wind to Dallas: >300 km ($1 b)



Time from seeking approval to operational line
(Note that many lines were never approved)



Do you build transmission for the nameplate wind capacity?



ELSEVIER

Energy Policy 35 (2007) 650–671

ENERGY POLICY

www.elsevier.com/locate/enpol

Quantifying siting difficulty: A case study of US transmission line siting

Shalini P. Vajjhala[a,*], Paul S. Fischbeck[b]

[a] *Resources for the Future, 1616 P Street NW, Washington, DC 20036, USA*
[b] *Departments of Social and Decision Sciences and Engineering and Public Policy, Carnegie Mellon University, 208F Porter Hall, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA*

Available online 3 March 2006

Abstract

The worldwide demand for new energy infrastructures has been paralleled in recent years by the increasing difficulty of siting major facilities. Siting difficulty is the subject of widespread discussion, but because of the complexity of the problem, potential solutions are not obvious or well understood. This paper presents a two-step policy-level framework that first develops an empirical measure of siting difficulty and then quantitatively assesses its major causes. The approach is based on the creation and aggregation of four siting indicators that are independent of the common causes and localized effects of siting problems. The proposed framework is demonstrated for the case of US transmission line siting. Results of the analyses reveal significant variations in state siting difficulty and industry experts' perceptions of its dominant causes, with implications for the long-term success of Regional Transmission Organizations (RTOs) and knowledge transfer among siting professionals in the deregulated industry.

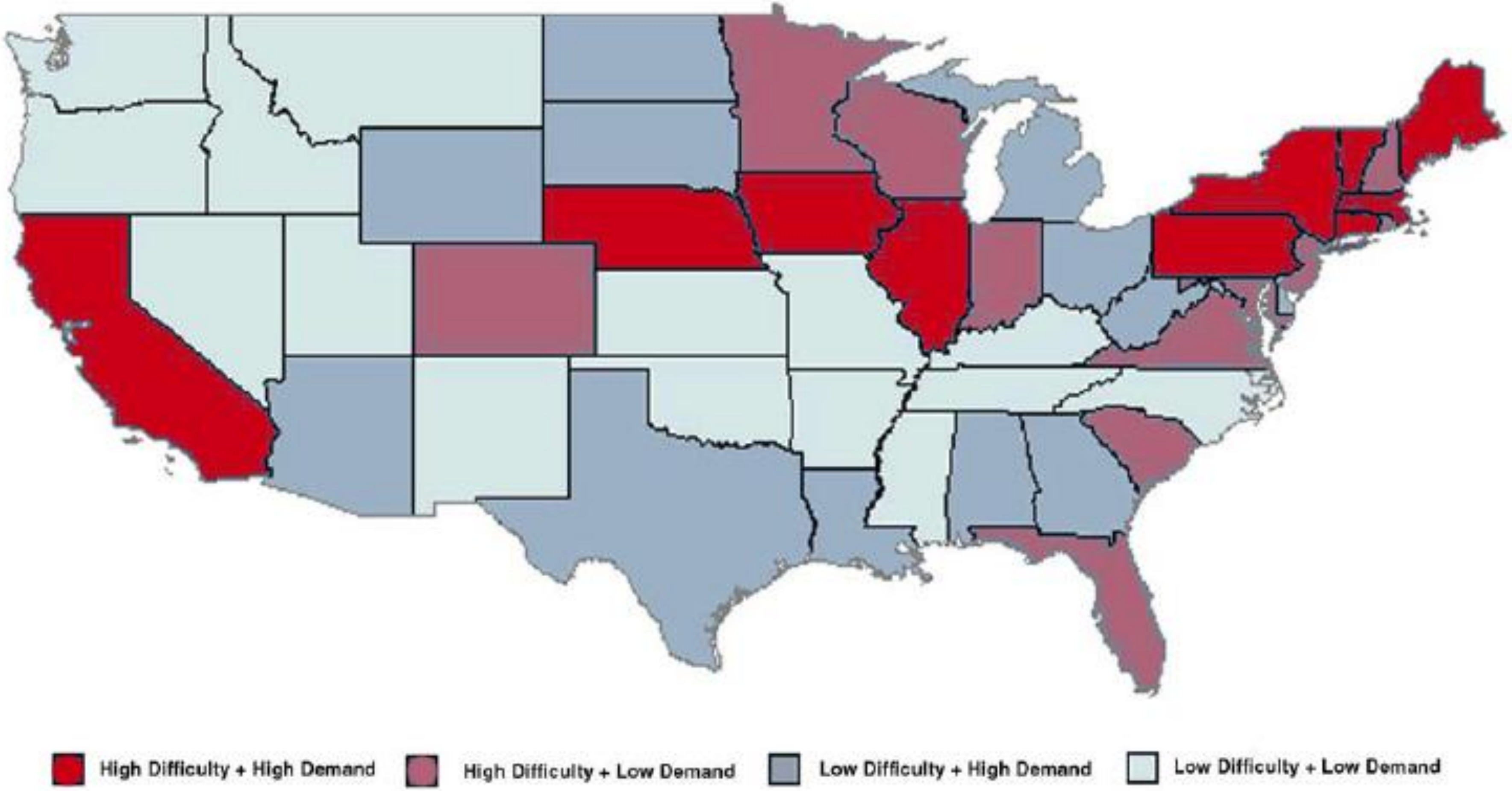
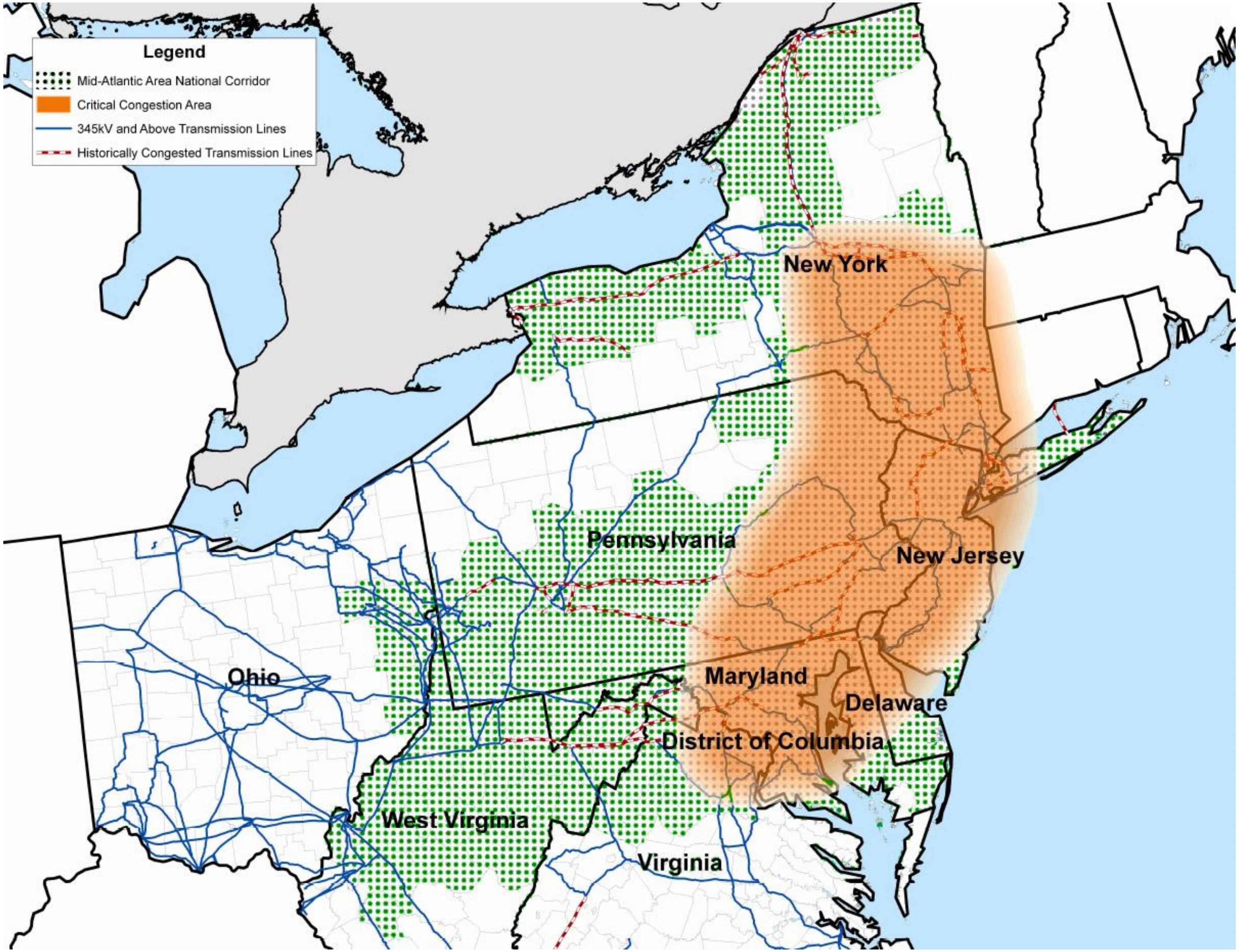


Fig. 4. National map of state siting difficulty and transmission demand.

NITCs



Legend
Mid-Atlantic Area National Corridor
Critical Congestion Area
345kV and Above Transmission Lines
Historically Congested Transmission Lines
New York
Pennsylvania
New Jersey
Ohio
Maryland
Delaware
District of Columbia
West Virginia
Virginia

Customer Response

- Real Time Pricing with an Electronic Energy Manager could move regulation & most spinning reserve to customer side of the meter, lowering cost, improving power quality, & easing the integration of renewables
- 2-way communication between customer & utility, real time to reflect market clearing price, congestion, & failures of generators & transmission lines
- An electronic energy manager, preprogrammed with the customer's instructions on how to react to price, could shed load quickly to correct variability & head off most cascading failures
- A priority for ARRA demonstrations

Environmental Issues: Wind & Solar

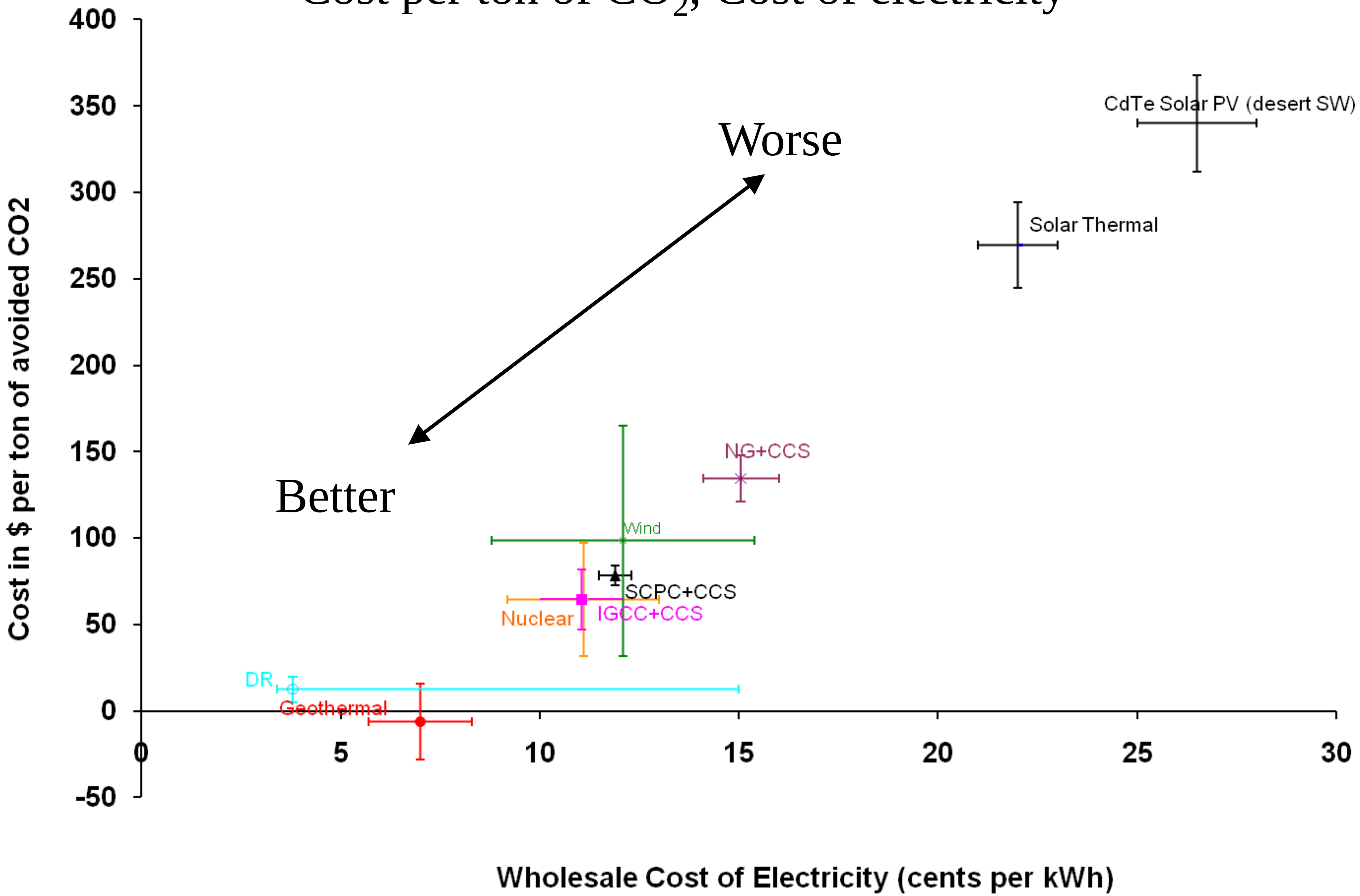
- Generating plants, nuclear, coal, gas turbines, like to run at full capacity.
- Coal & gas are less efficient, using more fuel, & emitting more CO_2 per MWh when operating below capacity.
- Smoothing variable wind & solar requires fast ramping generators

COSTS

Current capacity-weighted capital costs

	Capex/kW	Capacity Factor	Capacity-Weighed Capex
PV (CdTe)	$3,500	20%	$17,500
Solar Thermal	$3,500	24%	$14,583
Wind	$2,200	29%	$7,586
Nuclear	$6,500	90%	$7,222
Coal w/CCS	$5,075	80%	$6,344

Cost per ton of CO_2, Cost of electricity



Principal Points

- **Our goals: Reliable, quality power at affordable prices that meets environmental & sustainability goals**
- We love renewables & see a large role on the time scale envisioned by Waxman-Markey
- Integrating wind & solar, particularly beyond 15%, poses large costs & technical problems
- Wind/solar + natural gas lowers CO_2 emissions less than assumed
- Large amounts of transmission are needed for wind/solar
- Handling variability with remote sites is expensive
- For wind/solar to make a large contribution, need cheap storage or possibly demand response

Thank you.

Jay Apt
apt@cmu.edu

Lester B. Lave
Lave@cmu.edu