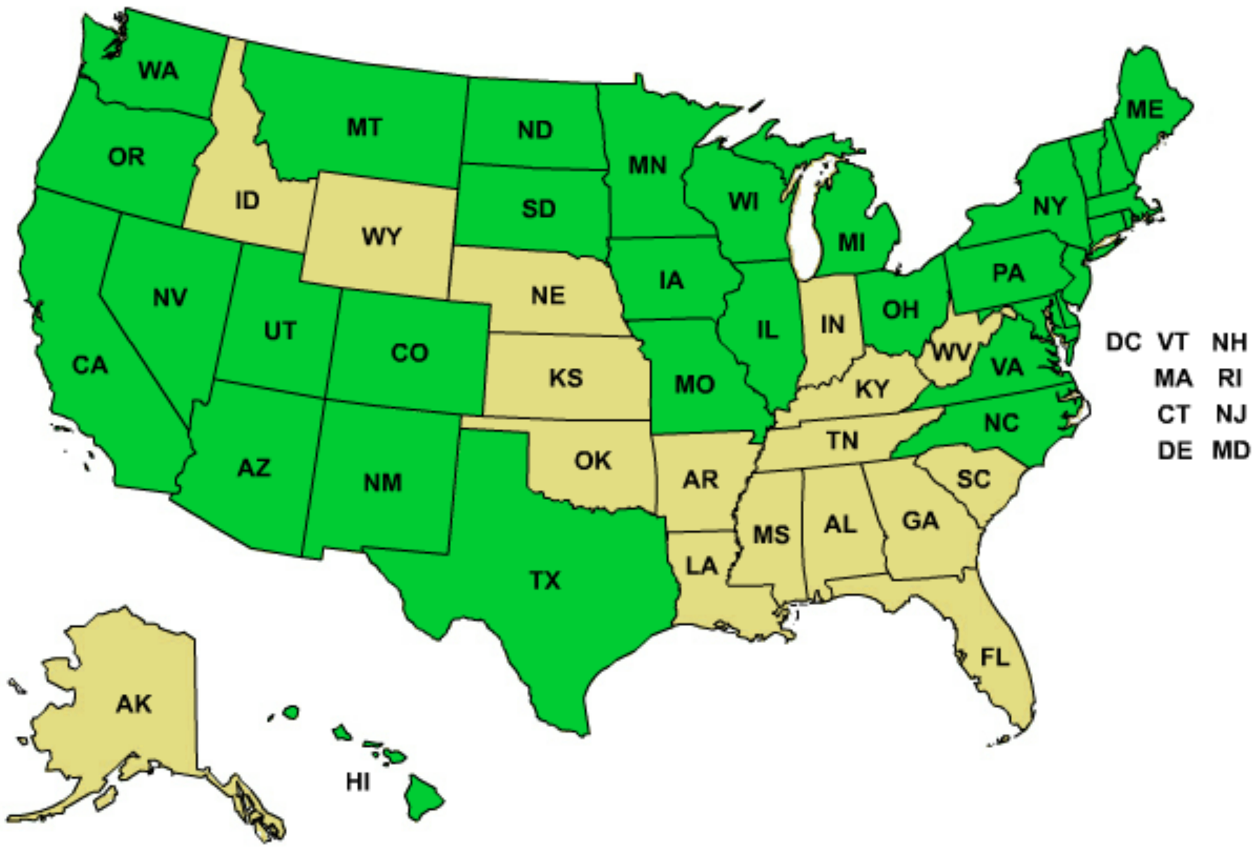
The RenewElec Project - Exploring Challenges and Opportunities for Integrating Variable and Intermittent Renewable Resources.

Presented by Paulina Jaramillo, Executive Director

Eighth Annual Carnegie Mellon Conference On The Electricity Industry – March 13, 2012

33 States Currently Have RPS



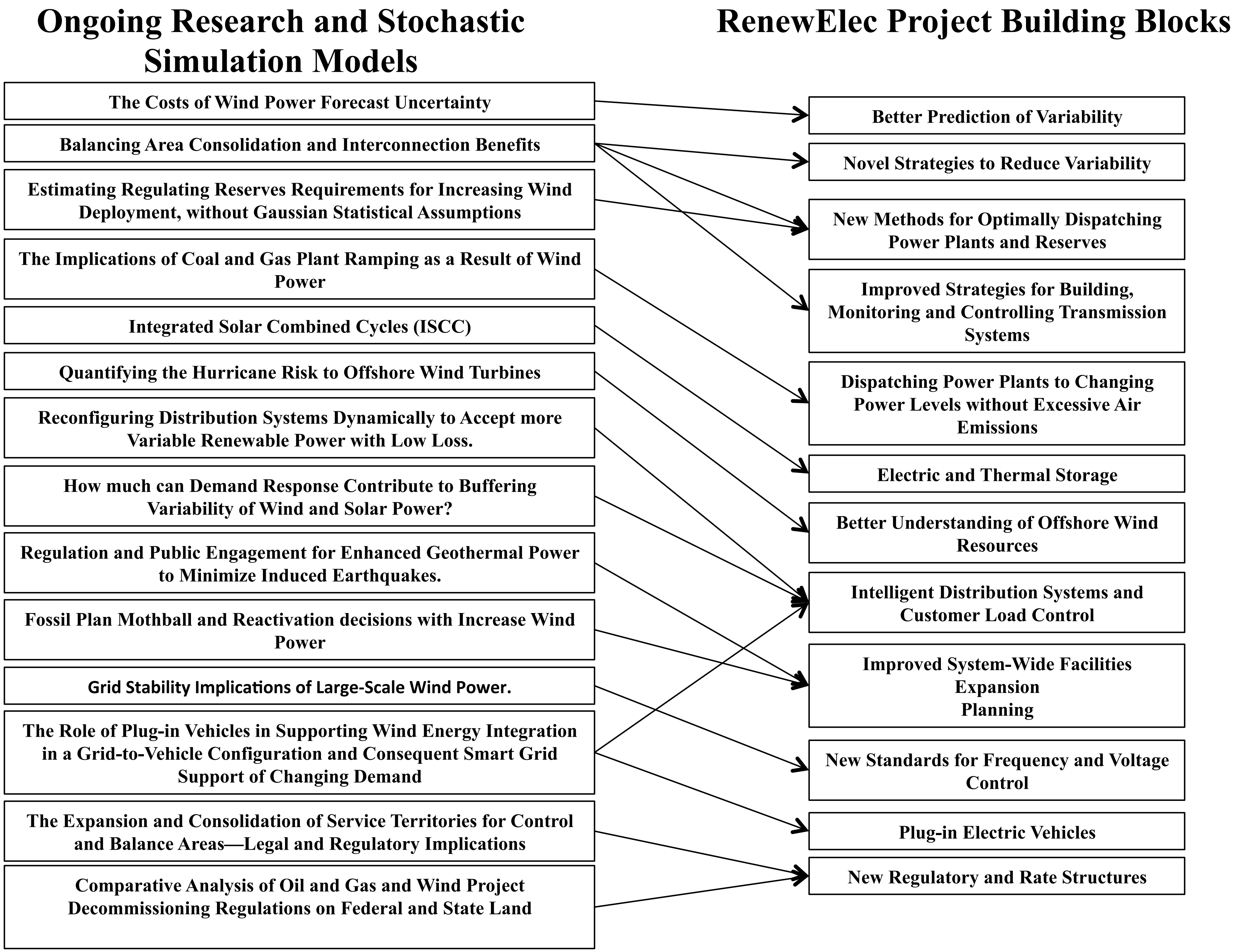
Carnegie Mellon

- Proponents of renewables argue that large amounts of variable and intermittent power can be easily accommodated in the present power system.

- Others argue that even levels as low as 10% of generation by variable and intermittent power can cause serious disruptions to power system operation.

At the RenewElec project,

We believe a *much-expanded* role for variable and intermittent renewables is possible but only if we adopt a systems approach that considers and anticipates the many changes in power system design and operation that may be needed, while doing so at an affordable price, and with acceptable levels of security and reliability.


Ongoing Research and Stochastic Simulation Models
RenewElec Project Building Blocks
The Costs of Wind Power Forecast Uncertainty
Balancing Area Consolidation and Interconnection Benefits
Estimating Regulating Reserves Requirements for Increasing Wind Deployment, without Gaussian Statistical Assumptions
The Implications of Coal and Gas Plant Ramping as a Result of Wind Power
Integrated Solar Combined Cycles (ISCC)
Quantifying the Hurricane Risk to Offshore Wind Turbines
Reconfiguring Distribution Systems Dynamically to Accept more Variable Renewable Power with Low Loss.
How much can Demand Response Contribute to Buffering Variability of Wind and Solar Power?
Regulation and Public Engagement for Enhanced Geothermal Power to Minimize Induced Earthquakes.
Fossil Plan Mothball and Reactivation decisions with Increase Wind Power
Grid Stability Implications of Large-Scale Wind Power.
The Role of Plug-in Vehicles in Supporting Wind Energy Integration in a Grid-to-Vehicle Configuration and Consequent Smart Grid Support of Changing Demand
The Expansion and Consolidation of Service Territories for Control and Balance Areas—Legal and Regulatory Implications
Comparative Analysis of Oil and Gas and Wind Project Decommissioning Regulations on Federal and State Land
Better Prediction of Variability
Novel Strategies to Reduce Variability
New Methods for Optimally Dispatching Power Plants and Reserves
Improved Strategies for Building, Monitoring and Controlling Transmission Systems
Dispatching Power Plants to Changing Power Levels without Excessive Air Emissions
Electric and Thermal Storage
Better Understanding of Offshore Wind Resources
Intelligent Distribution Systems and Customer Load Control
Improved System-Wide Facilities Expansion Planning
New Standards for Frequency and Voltage Control
Plug-in Electric Vehicles
New Regulatory and Rate Structures

Ongoing Research and Stochastic Simulation Models

- The Costs of Wind Power Forecast Uncertainty
- Balancing Area Consolidation and Interconnection Benefits
- Estimating Regulating Reserves Requirements for Increasing Wind Deployment, without Gaussian Statistical Assumptions
- The Implications of Coal and Gas Plant Ramping as a Result of Wind Power
- Integrated Solar Combined Cycles (ISCC)
- Quantifying the Hurricane Risk to Offshore Wind Turbines
- Reconfiguring Distribution Systems Dynamically to Accept more Variable Renewable Power with Low Loss.
- How much can Demand Response Contribute to Buffering Variability of Wind and Solar Power?
- Regulation and Public Engagement for Enhanced Geothermal Power to Minimize Induced Earthquakes.
- Fossil Plan Mothball and Reactivation decisions with Increased Wind Power
- Grid Stability Implications of Large-Scale Wind Power.
- The Role of Plug-in Vehicles in Supporting Wind Energy Integration in a Grid-to-Vehicle Configuration and Consequent Smart Grid Support of Changing Demand
- The Expansion and Consolidation of Service Territories for Control and Balance Areas—Legal and Regulatory Implications
- Comparative Analysis of Oil and Gas and Wind Project Decommissioning Regulations on Federal and State Land

RenewElec Project Building Blocks

- Better Prediction of Variability
- Novel Strategies to Reduce Variability
- New Methods for Optimally Dispatching Power Plants and Reserves
- Improved Strategies for Building, Monitoring and Controlling Transmission Systems
- Dispatching Power Plants to Changing Power Levels without Excessive Air Emissions
- Electric and Thermal Storage
- Better Understanding of Offshore Wind Resources
- Intelligent Distribution Systems and Customer Load Control
- Improved System-Wide Facilities Expansion Planning
- New Standards for Frequency and Voltage Control
- Plug-in Electric Vehicles
- New Regulatory and Rate Structures

Quantifying the Hurricane Risk to Offshore Wind Turbines

Quantifying the hurricane risk to offshore wind turbines

Stephen Rose[a], Paulina Jaramillo[a,1], Mitchell J. Small[a,b], Iris Grossmann[a], and Jay Apt[a,c]

[a]Department of Engineering and Public Policy; [b]Department of Civil and Environmental Engineering; and [c]Tepper School of Business, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213

Edited by William C. Clark, Harvard University, Cambridge, MA, and approved January 10, 2012 (received for review July 19, 2011)

The U.S. Department of Energy has estimated that if the United States is to generate 20% of its electricity from wind, over 50 GW will be required from shallow offshore turbines. Hurricanes are a potential risk to these turbines. Turbine tower buckling has been observed in typhoons, but no offshore wind turbines have yet been built in the United States. We present a probabilistic model to estimate the number of turbines that would be destroyed by hurricanes in an offshore wind farm. We apply this model to estimate the risk to offshore wind farms in four representative locations in the Atlantic and Gulf Coastal waters of the United States. In the most vulnerable areas now being actively considered by developers, nearly half the turbines in a farm are likely to be destroyed in a 20-y period. Reasonable mitigation measures—increasing the design reference wind load, ensuring that the nacelle can be turned into rapidly changing winds, and building most wind plants in the areas with lower risk—can greatly enhance the probability that offshore wind can help to meet the United States' electricity needs.

probabilistic analysis | wind energy | phase-type distribution | tropical cyclone

As a result of state renewable portfolio standards and federal tax incentives, there is growing interest and investment in renewable sources of electricity in the United States. Wind is the renewable resource with the largest installed-capacity growth in the last 5 y, with U.S. wind power capacity increasing from 8.7 GW in 2005 to 39.1 GW 2010 (1). All of this development has occurred onshore. U.S. offshore wind resources may also prove to be a significant contribution to increasing the supply of renewable, low-carbon electricity. The National Renewable Energy Laboratory (NREL) estimates that offshore wind resources can be as high as four times the U.S. electricity generating capacity in 2010 (2). Although this estimate does not take into account siting, stakeholder, and regulatory constraints, it indicates that U.S. offshore wind resources are significant. Though no offshore wind projects have been developed in the United States, there are 20 offshore wind projects in the planning process (with an estimated capacity of 2 GW) (2). The U.S. Department of Energy's 2008 report, *20% Wind by 2030* (3) envisions 54 GW of shallow offshore wind capacity to optimize delivered generation and transmission costs.

U.S. offshore resources are geographically distributed through the Atlantic, Pacific, and Great Lake coasts. The most accessible shallow resources are located in the Atlantic and Gulf Coasts. Resources at depths shallower than 60 m in the Atlantic coast, from Georgia to Maine, are estimated to be 920 GW; the estimate for these resources in the Gulf coast is 460 GW (2).

Offshore wind turbines in these areas will be at risk from Atlantic hurricanes. Between 1949 and 2006, 93 hurricanes struck the U.S. mainland according to the HURDAT (Hurricane Database) database of the National Hurricane Center (4). In this 58-y period, only 15 y did not incur insured hurricane-related losses (5). The Texas region was affected by 35 hurricane events, while the southeast region [including the coasts of Florida, where no offshore resources have been estimated (2)] had 32 events.

Hurricane risks are quite variable, both geographically and temporally. Pielke, et al. (6) note pronounced differences in the total hurricane damages (normalized to 2005) occurring each decade. Previous research has shown strong associations between North Atlantic hurricane activity and atmosphere-ocean variability on different time scales, including the multidecadal (7, 8). Atlantic hurricane data show that hurricane seasons with very high activity levels occur with some regularity; for instance, since 1950, there have been 25 y with three or more intense hurricanes (Saffir-Simpson Category 3 or higher). There were two 2-y periods with 13 intense hurricanes: 1950–1951 and 2004–2005. 2004 and 2005 hurricanes were particularly damaging to the Florida and Gulf Coast regions (six hurricanes made landfall in those areas in 2004 and seven the following year).

These hurricanes resulted in critical damages to energy infrastructure. Hurricane Katrina (2005), for example, was reported to have damaged 21 oil and gas producing platforms and completely destroyed 44 (9). Numerous drilling rigs and hydrocarbon pipelines were also damaged. Similarly, hurricanes have damaged powers systems. Liu, et al. (10) reported that in 2003 Dominion Power had over 58,000 instances of the activation of safety devices in the electrical system to isolate damages as a result of Hurricane Isabel. Although no offshore wind turbines have been built in the United States, there is no reason to believe that this infrastructure would be exempt from hurricane damages.

In order to successfully develop sustainable offshore resources, the risk from hurricanes to offshore wind turbines should be analyzed and understood. Here we present a probabilistic model to estimate the number of turbines that would be destroyed by hurricanes in an offshore wind farm. We apply this model to estimate the risk to offshore wind farms in four representative locations in the Atlantic and Gulf Coastal waters of the United States: Galveston County, TX; Dare County, NC; Atlantic County, NJ; and Dukes County, MA. Leases have been signed for wind farms off the coasts of Galveston (11) and Dukes County (12); projects off the coasts of New Jersey and North Carolina have been proposed (12).

Results

Wind Farm Risk from a Single Hurricane. Wind turbines are vulnerable to hurricanes because the maximum wind speeds in those storms can exceed the design limits of wind turbines. Failure modes can include loss of blades and buckling of the supporting tower. In 2003, a wind farm of seven turbines in Okinawa, Japan was destroyed by typhoon Maemi (13) and several turbines in China were damaged by typhoon Dujuan (14). Here we consider only tower buckling, because blades are relatively easy to replace

Author contributions: S.R., P.J., M.J.S., and J.A. designed research; S.R. performed research; I.G. contributed the meteorological component; S.R., P.J., M.J.S., and J.A. analyzed data; and S.R., P.J., I.G., and J.A. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

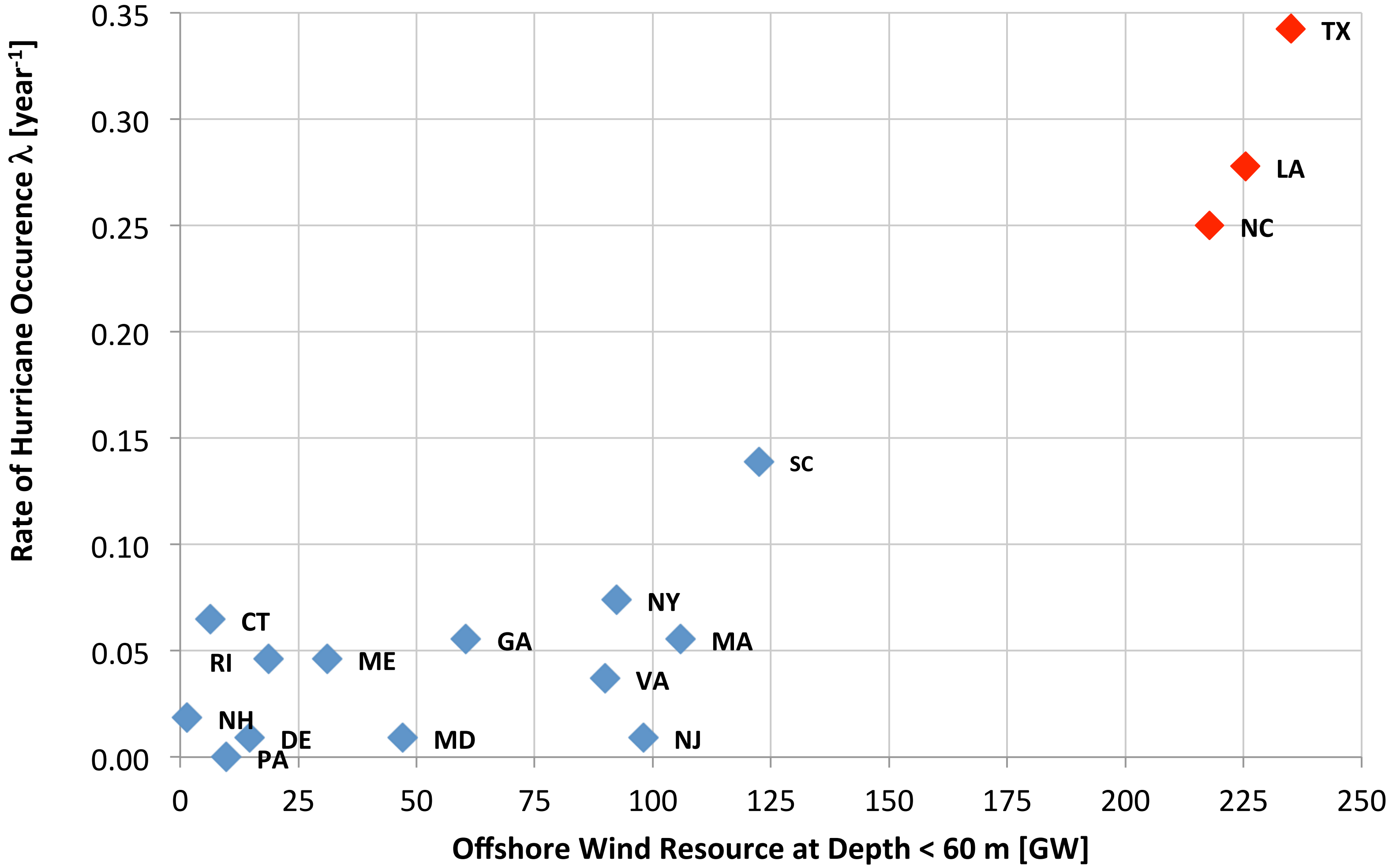
[1]To whom correspondence should be addressed. E-mail: paulina@cmu.edu.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1111769109/-/DCSupplemental.

SUSTAINABILITY SCIENCE

Stephen Rose,
Paulina Jaramillo,
Jay Apt,
Mitch Small,
Iris Grossmann

Offshore Wind Potential in Atlantic and Gulf Coasts



Wind Turbines are Vulnerable to Hurricanes

Typhoon Maemi, Okinawa, 2003

(a) WT No. 3

(b) WT No. 4

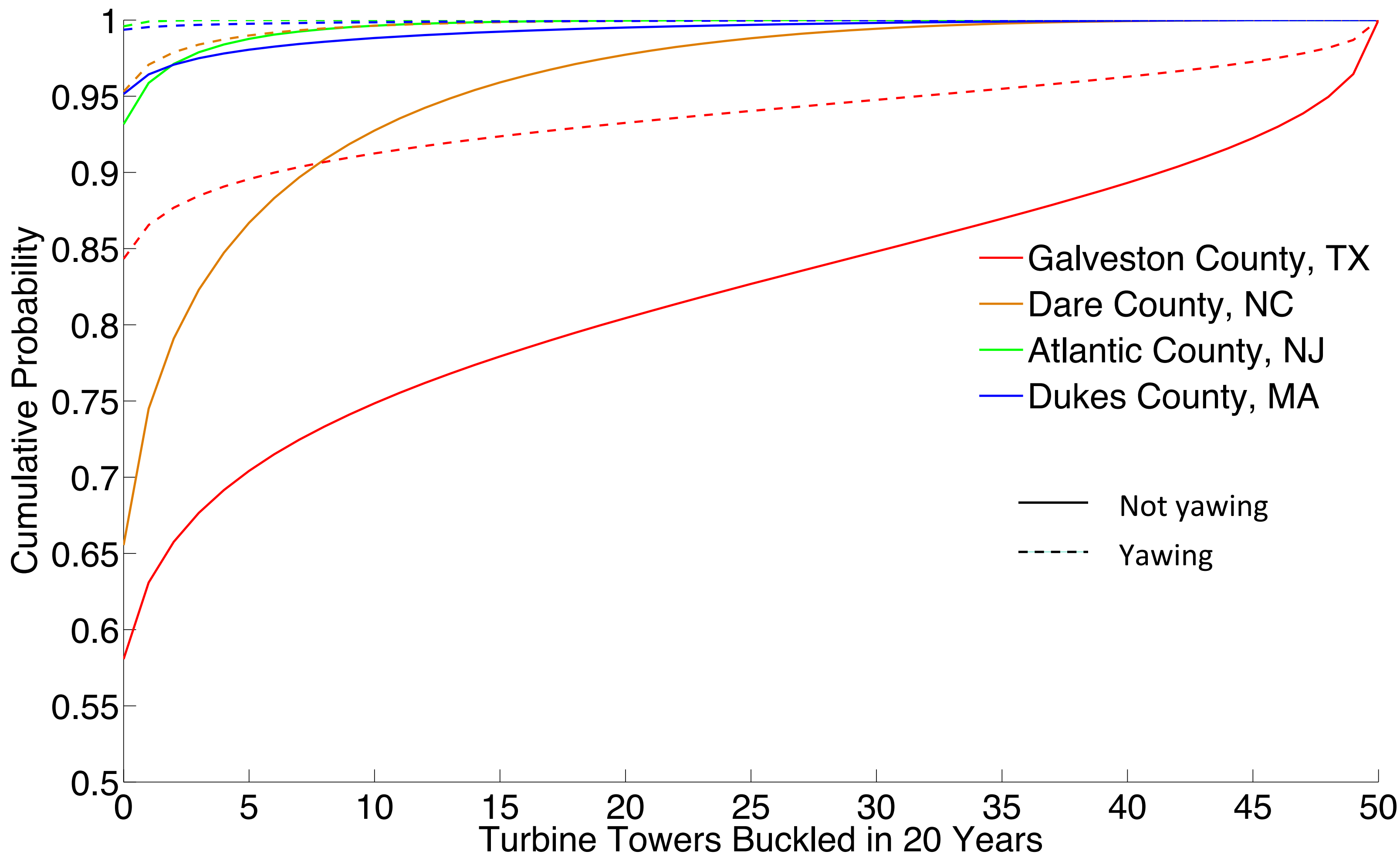
(c) WT No. 5

(d) WT No. 6

Takahara, et al (2004)

Turbines Destroyed in 20 Years

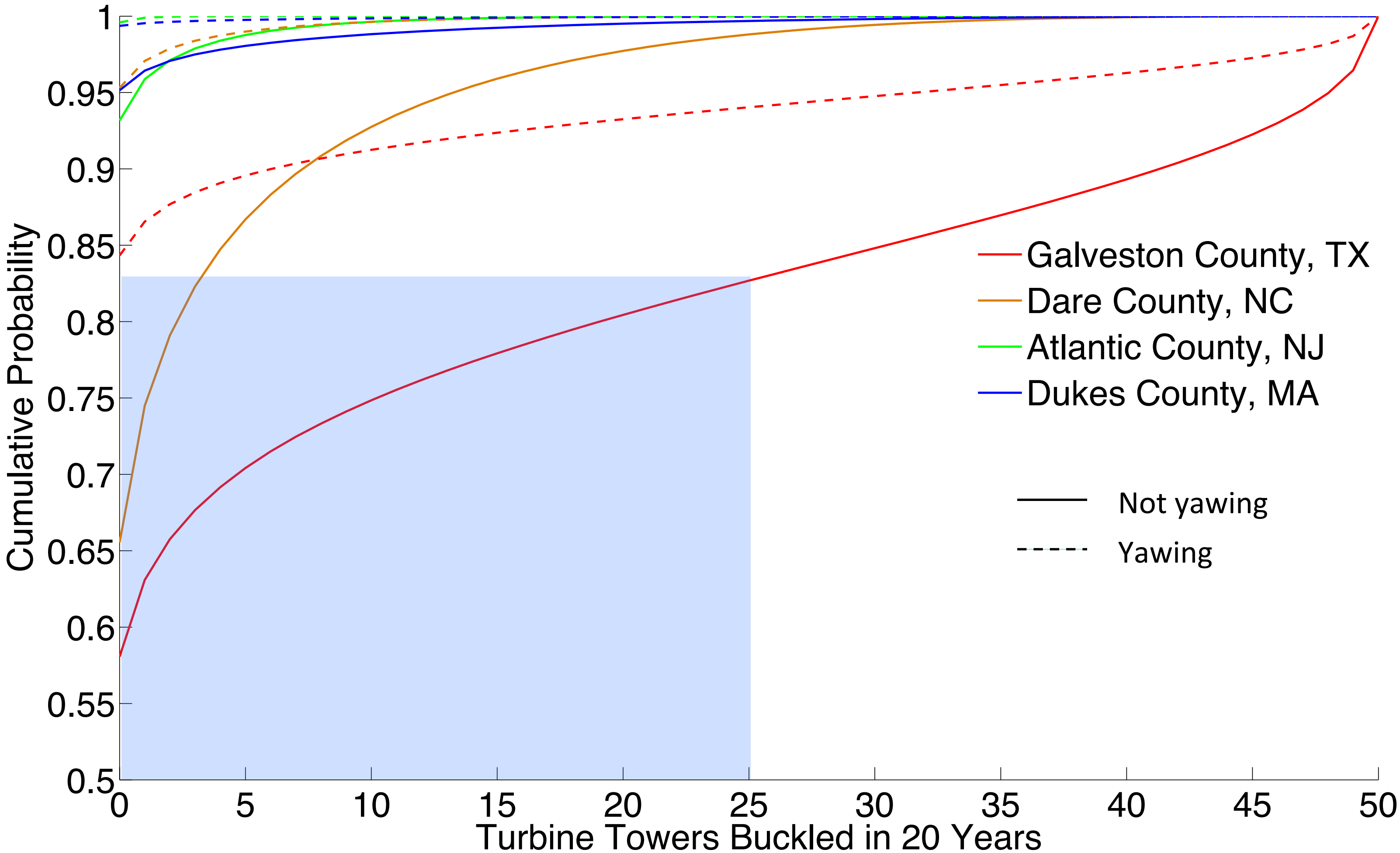
50-turbine wind farm



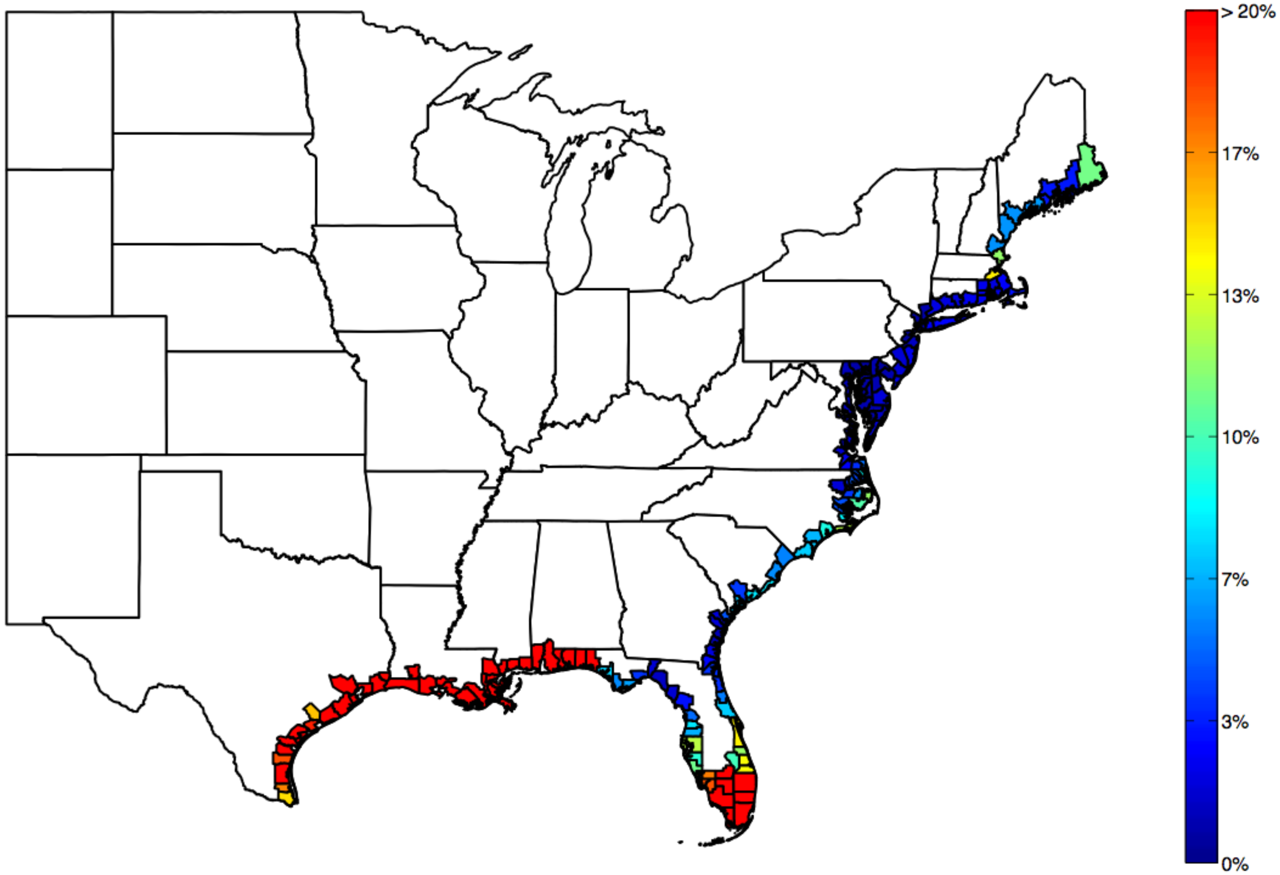
Carnegie Mellon

Turbines Destroyed in 20 Years

50-turbine wind farm



Probability That At Least 10% Of Turbines In A Wind Farm Will Be Destroyed By Hurricanes In 20 Years - No Yaw Scenario

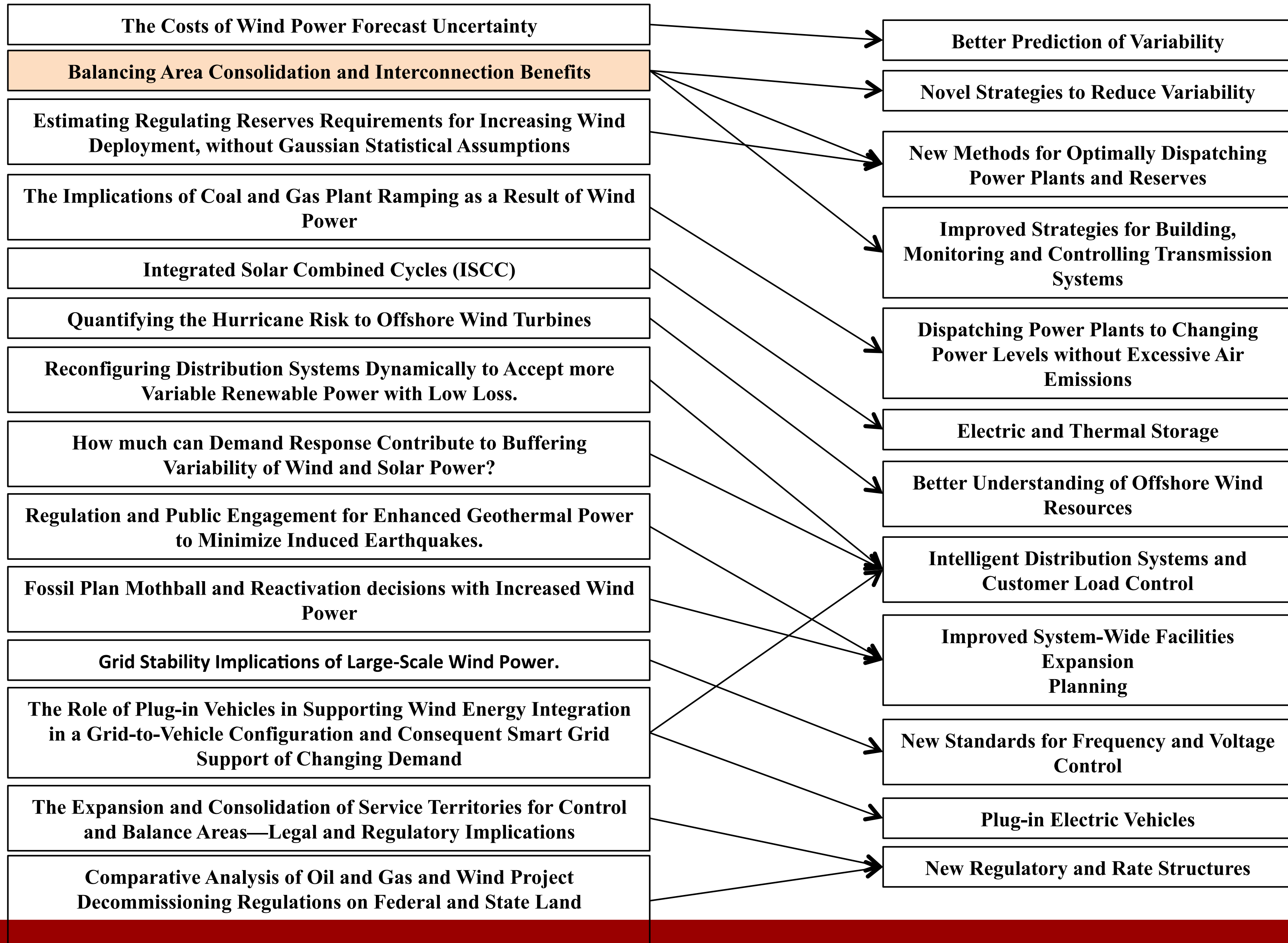


Engineering Changes Can Reduce Risk

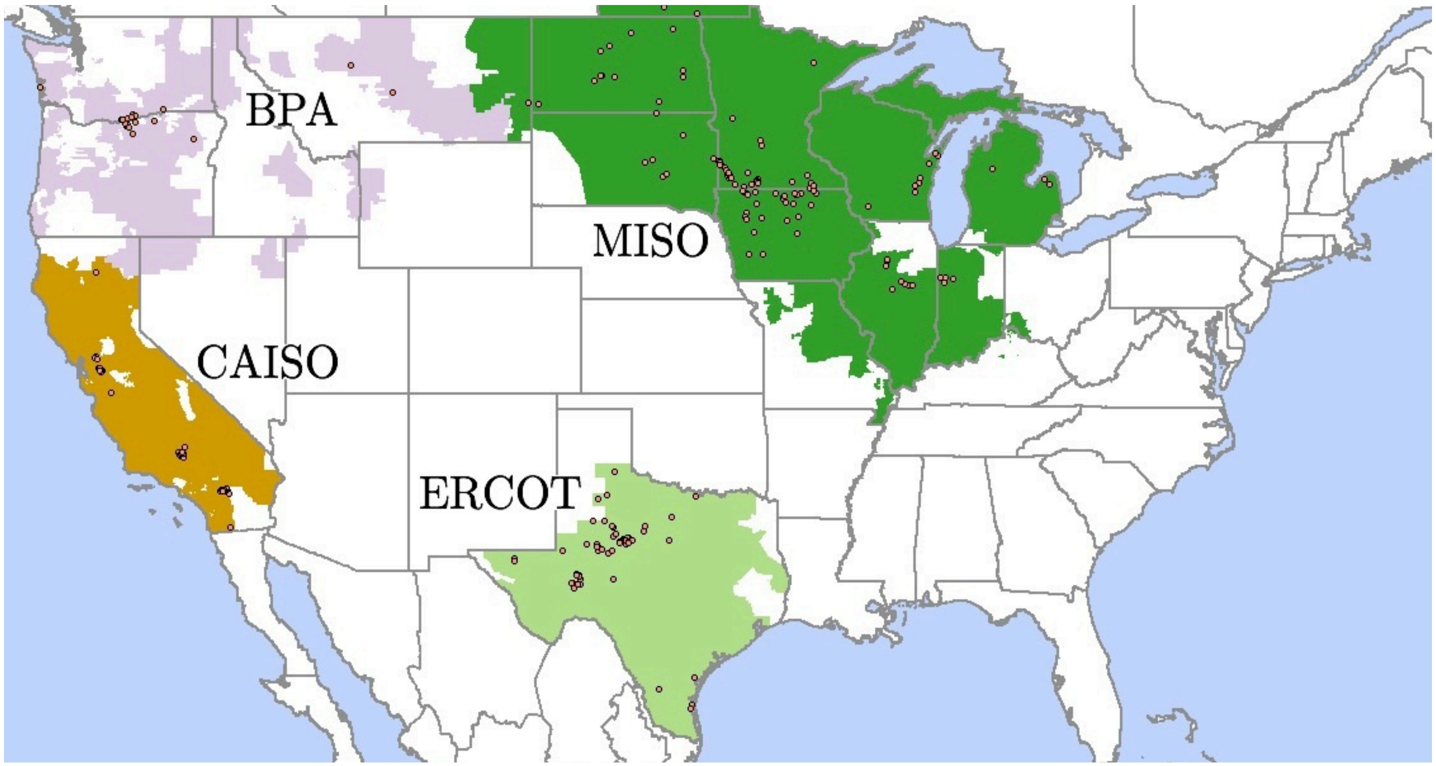
- Backup power for yaw system
  - Survival depends on active system
  - Wind vane must survive
  - Turbine must yaw quickly
- Stronger towers and blades
  - More steel in tower
  - More fiberglass in blades
  - 20 – 30% cost increase

Ongoing Research and Stochastic Simulation Models

RenewElec Project Building Blocks



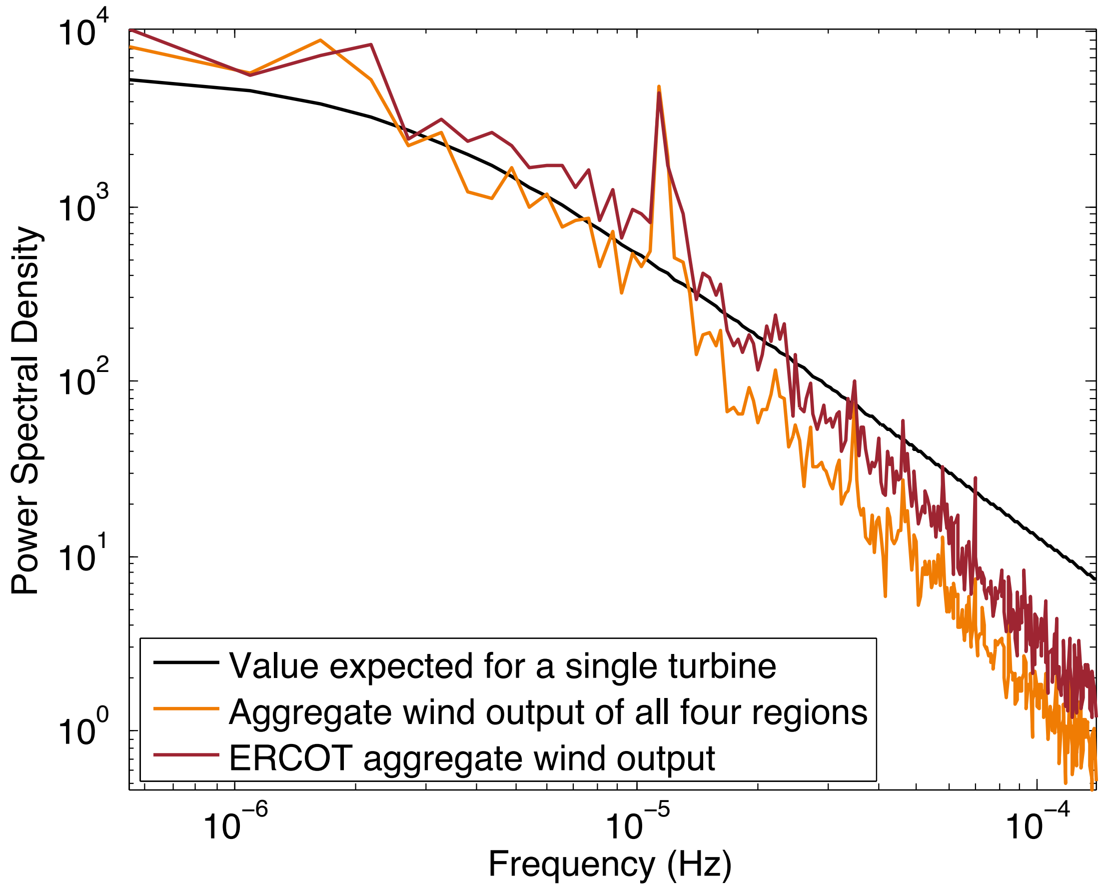
The Effect Of Long-distance Interconnection On Wind Power Variability



Emily Fertig, Warren Katzenstein, Jay Apt, Paulina Jaramillo

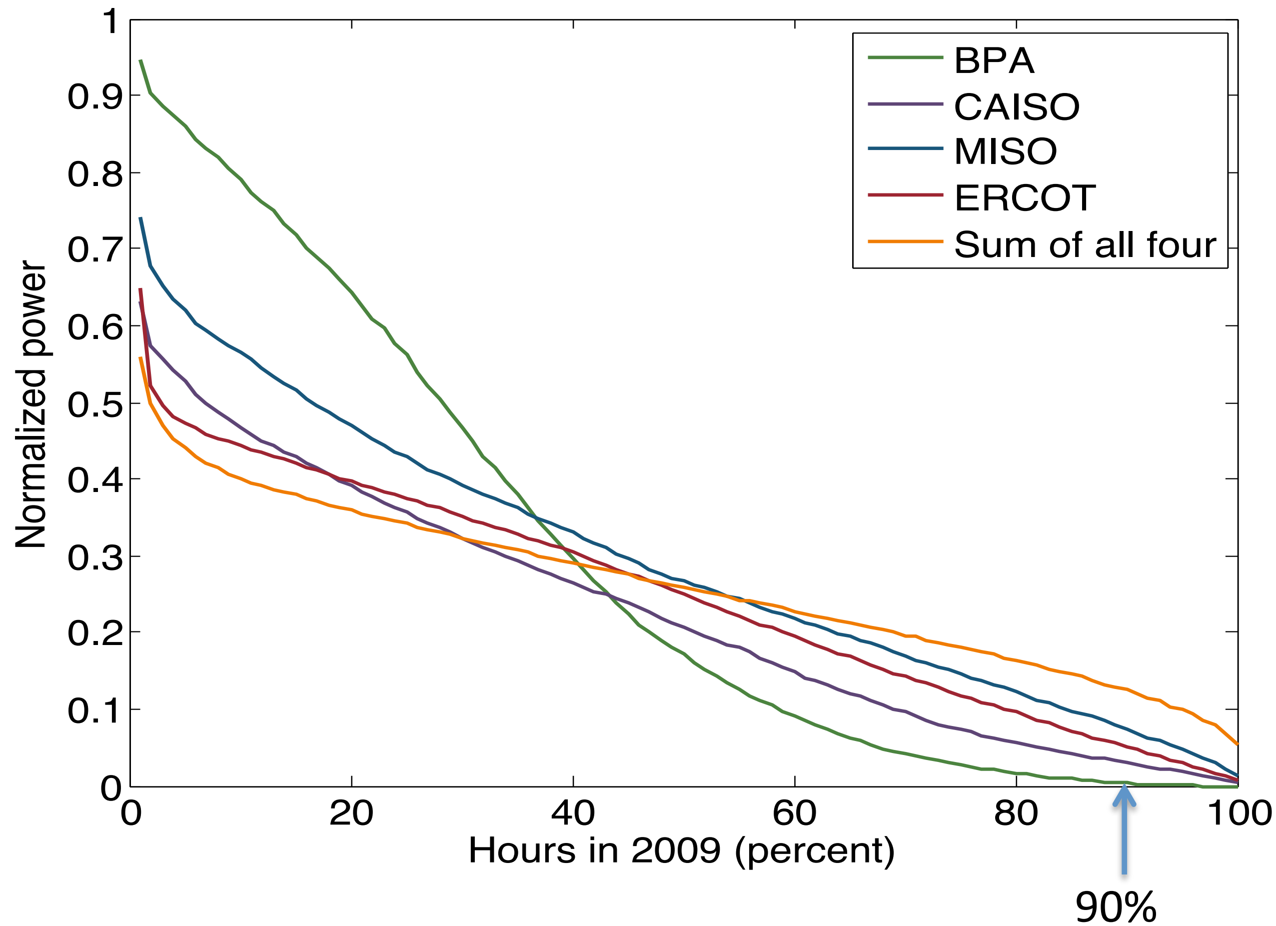
Carnegie Mellon

Connecting wind plants within a region reduces high-frequency fluctuations compared to a single wind plant.



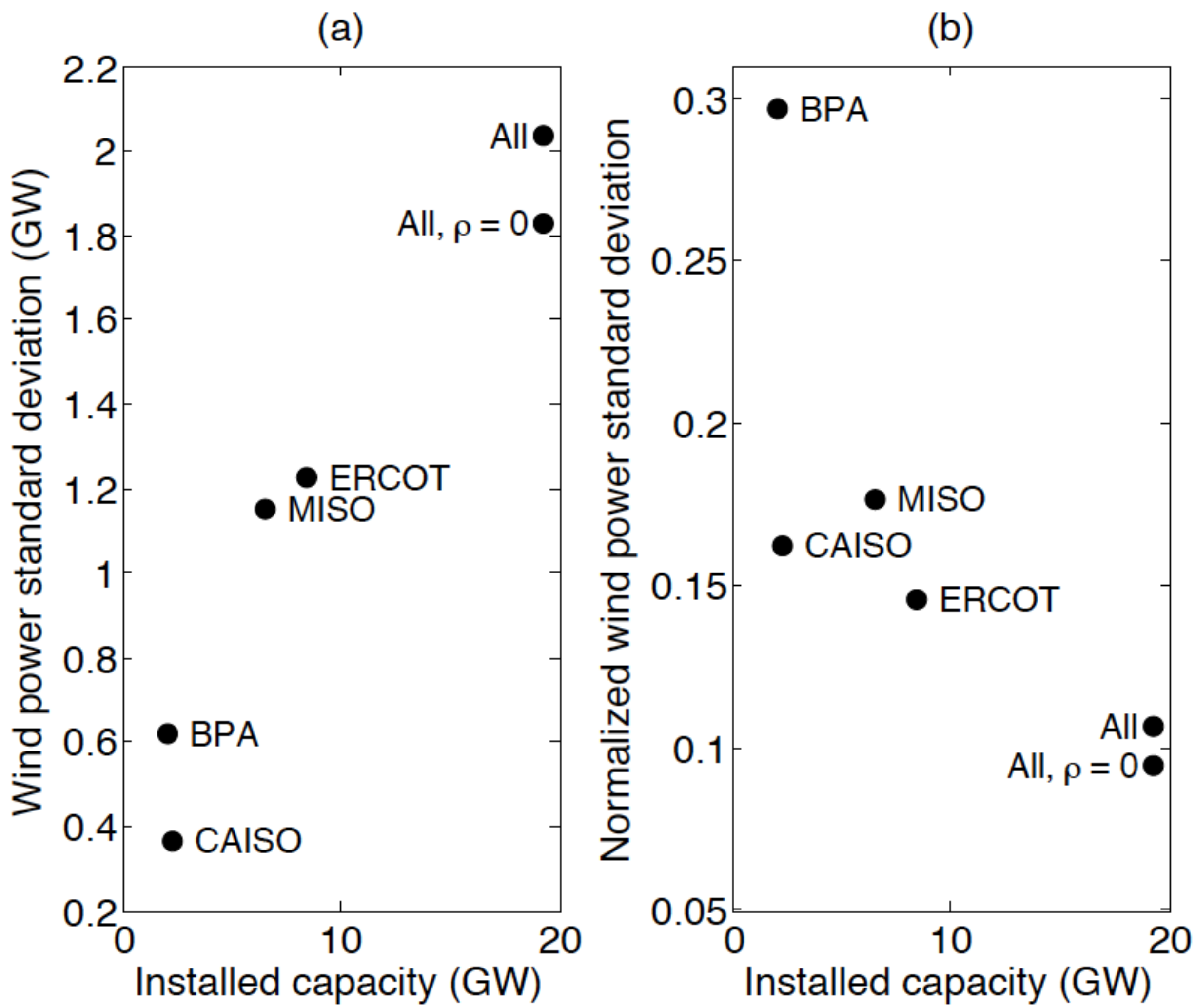
This reduces the need for quick-ramping resources such as batteries and peaker gas plants. Connecting all four regions provides negligible additional benefit compared with a single region (note log scale).

Interconnection substantially increases the percentage of firm wind capacity



12% of aggregate wind capacity of all four regions is available 90% of the time; only 1% to 6% of wind capacity of a single region is available 90% of the time

Interconnection also reduces the per-unit standard deviation



Next Step: Benefit-Cost Analysis

Ongoing Research and Stochastic Simulation Models

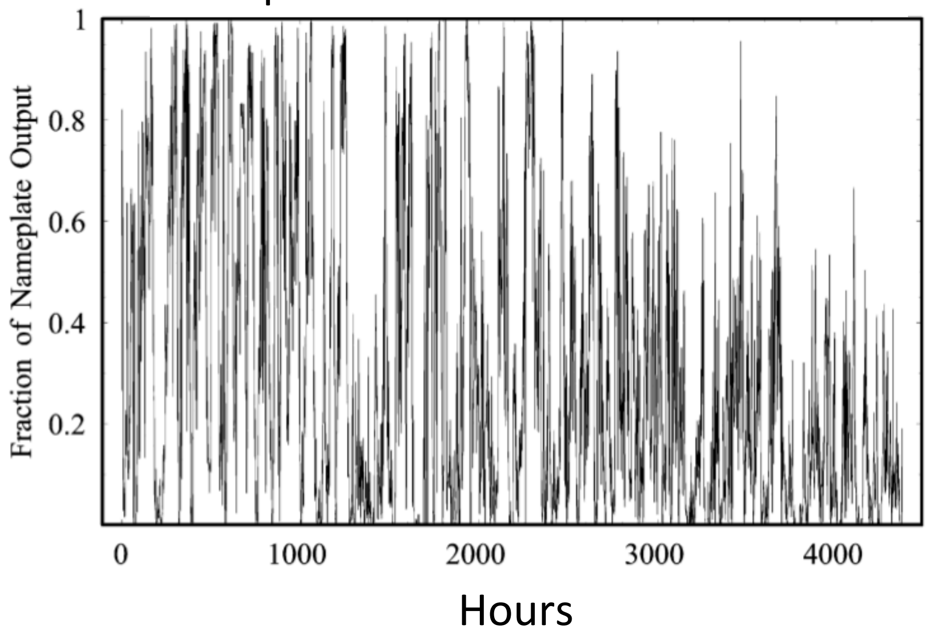
- The Costs of Wind Power Forecast Uncertainty
- Balancing Area Consolidation and Interconnection Benefits
- Estimating Regulating Reserves Requirements for Increasing Wind Deployment, without Gaussian Statistical Assumptions
- The Implications of Coal and Gas Plant Ramping as a Result of Wind Power
- Integrated Solar Combined Cycles (ISCC)
- Quantifying the Hurricane Risk to Offshore Wind Turbines
- Reconfiguring Distribution Systems Dynamically to Accept more Variable Renewable Power with Low Loss.
- How much can Demand Response Contribute to Buffering Variability of Wind and Solar Power?
- Regulation and Public Engagement for Enhanced Geothermal Power to Minimize Induced Earthquakes.
- Fossil Plan Mothball and Reactivation decisions with Increased Wind Power
- Grid Stability Implications of Large-Scale Wind Power.
- The Role of Plug-in Vehicles in Supporting Wind Energy Integration in a Grid-to-Vehicle Configuration and Consequent Smart Grid Support of Changing Demand
- The Expansion and Consolidation of Service Territories for Control and Balance Areas—Legal and Regulatory Implications
- Comparative Analysis of Oil and Gas and Wind Project Decommissioning Regulations on Federal and State Land

RenewElec Project Building Blocks

- Better Prediction of Variability
- Novel Strategies to Reduce Variability
- New Methods for Optimally Dispatching Power Plants and Reserves
- Improved Strategies for Building, Monitoring and Controlling Transmission Systems
- Dispatching Power Plants to Changing Power Levels without Excessive Air Emissions
- Electric and Thermal Storage
- Better Understanding of Offshore Wind Resources
- Intelligent Distribution Systems and Customer Load Control
- Improved System-Wide Facilities Expansion Planning
- New Standards for Frequency and Voltage Control
- Plug-in Electric Vehicles
- New Regulatory and Rate Structures

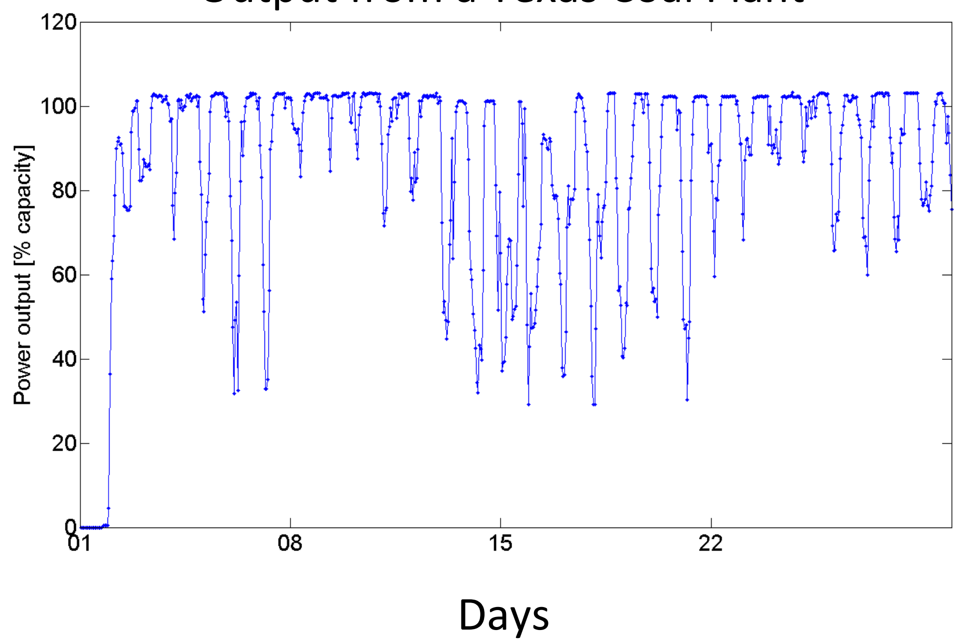
Impacts of Large Scale Penetration of Wind on the Operations of Coal Power Plants

Output from 6 Texas wind turbines



Source: (J Apt 2007)

Output from a Texas Coal Plant



Source: CEMS 2008

David Luke Oates, Paulina Jaramillo

Model Overview

"What are the capacities of each unit and demand for electricity?"

System Data

- Unit capacity, etc.
- Hourly Demand
- Hourly Wind

"How much power does each unit produce every hour?"

UCED Model

- Optimization Model
- Determine Schedule

"How much CO_2 and NO_X are produced?"

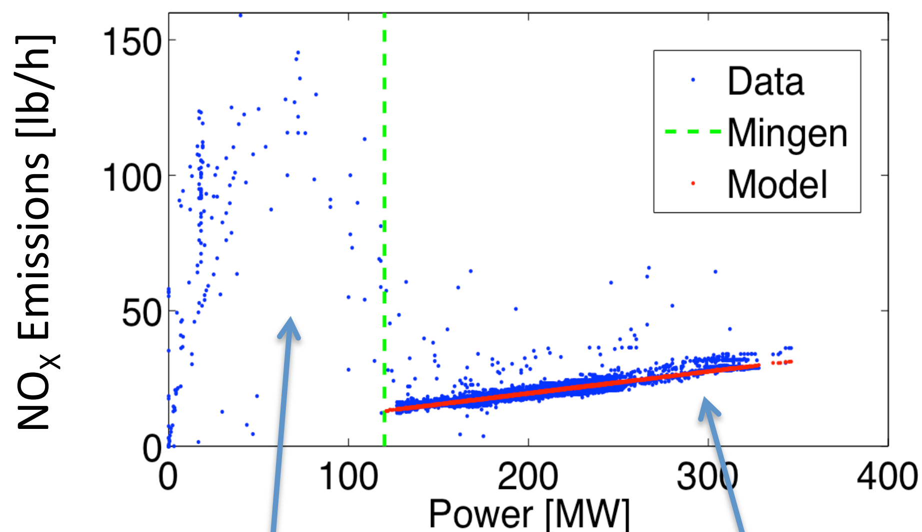
Emissions Model

- Many Regression Models
- Determine emissions

Emissions models capture changes in emissions rates during cycling

- Regressions models using CEMS data
- Emissions rates vary with power level and ramp-rate
- Capture emissions arising from cycling

PJM Combined Cycle Unit

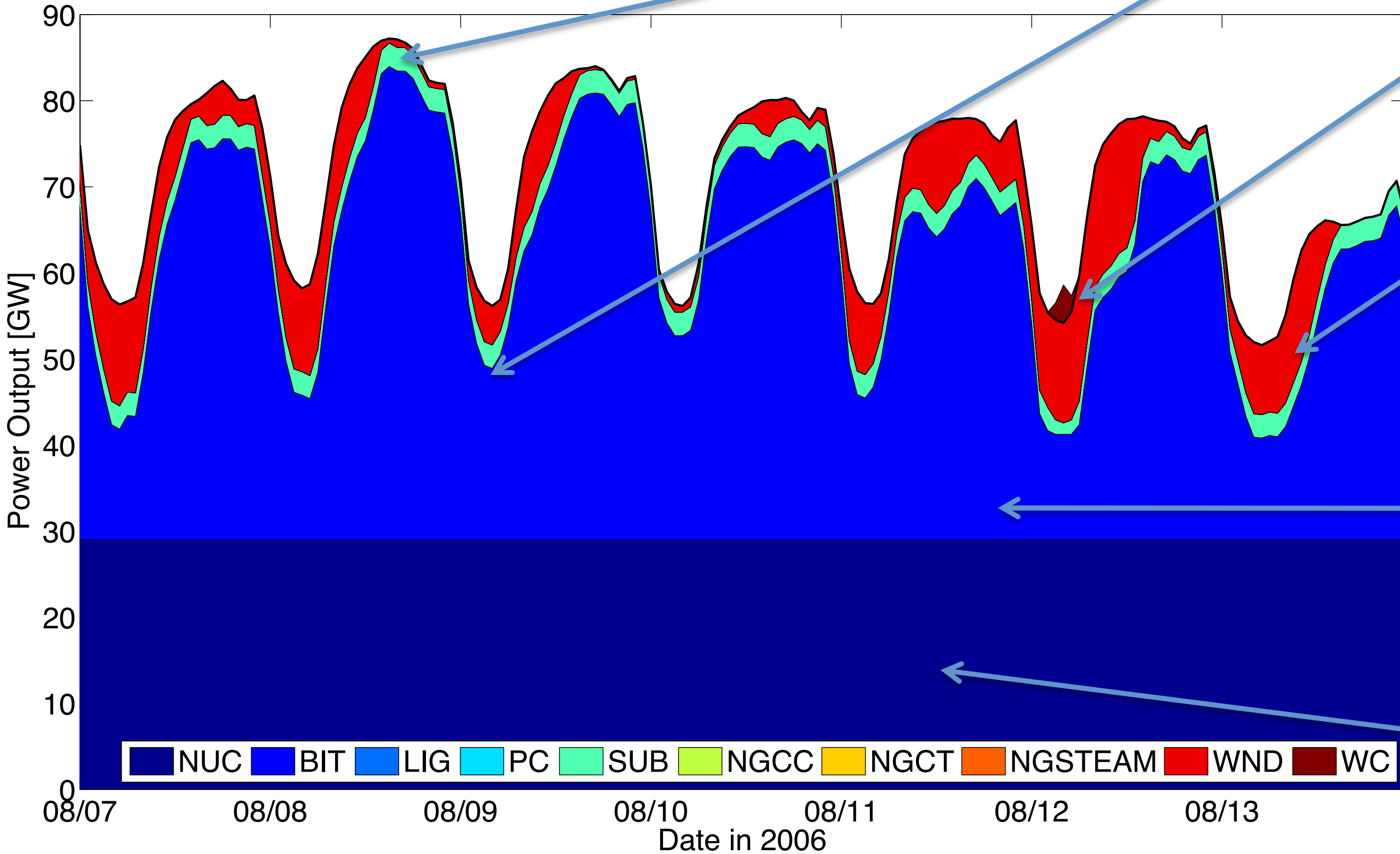


Model uses mean emissions produced during startup and shutdown

Model uses power and ramp rate as explanatory variables

Sample Model Output at 10% Wind

Energy Use Plot for Aug. 2006 in PJM – 10% Wind



Substantial coal cycling

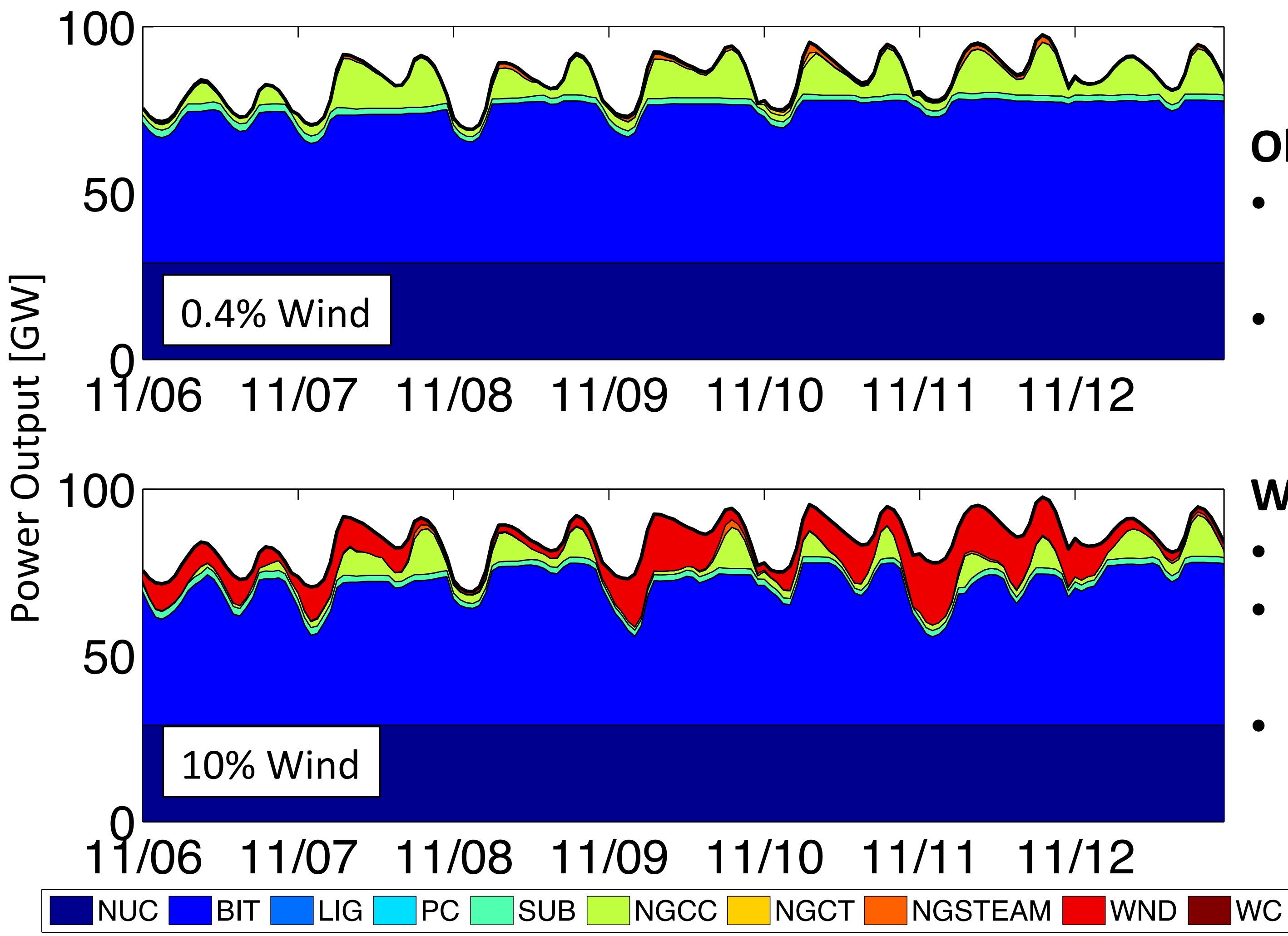
Wind curtailment

Effective wind penetration 7.3%

PJM uses a great deal of Bituminous coal

Nuclear is baseloaded

Transition from 0.4% to 10% wind



Observations

- Increase in Coal Cycling
- Wind offsets gas and coal

Work is ongoing to:

- Refine UCDM
- Refine Emissions Model
- Develop Scenarios

Thank you for your attention

Questions?

Visit us at www.renewelec.org