

# Demand Dispatch and Probabilistic Wind Power Forecasting in Unit Commitment and Economic Dispatch: A Case Study of Illinois

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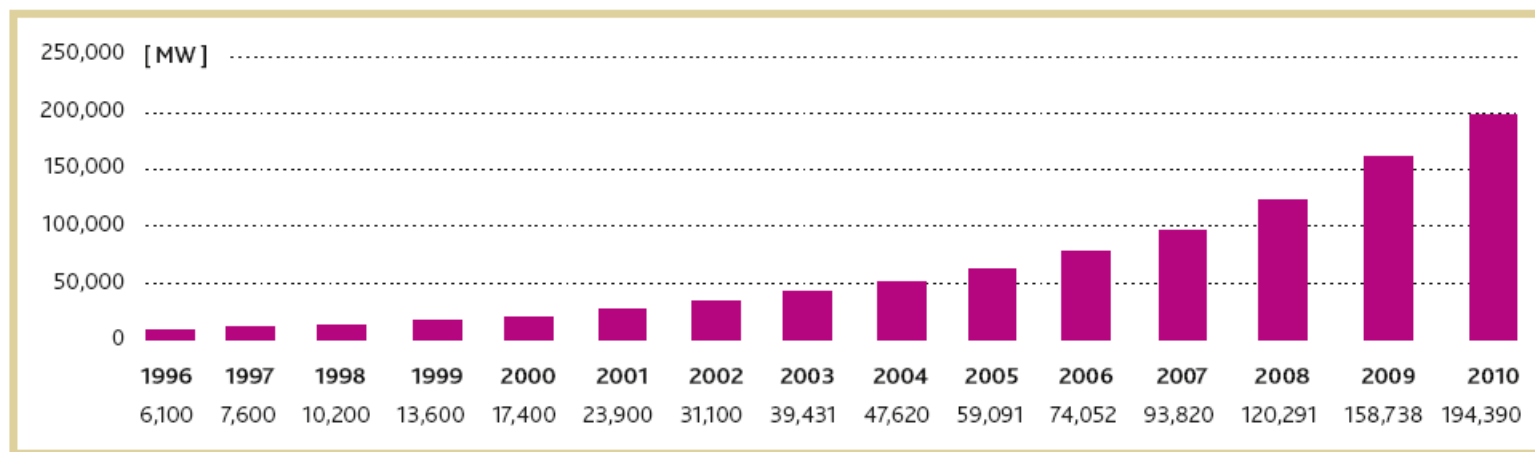
# Outline

- **Background and Motivation**
- **Market Operation Model**
  - Wind Power Forecasting
  - Demand Dispatch (DD)
  - Market Operation
- **Test Case**
  - IL Power System
  - System Operation Analysis
- **Conclusions**

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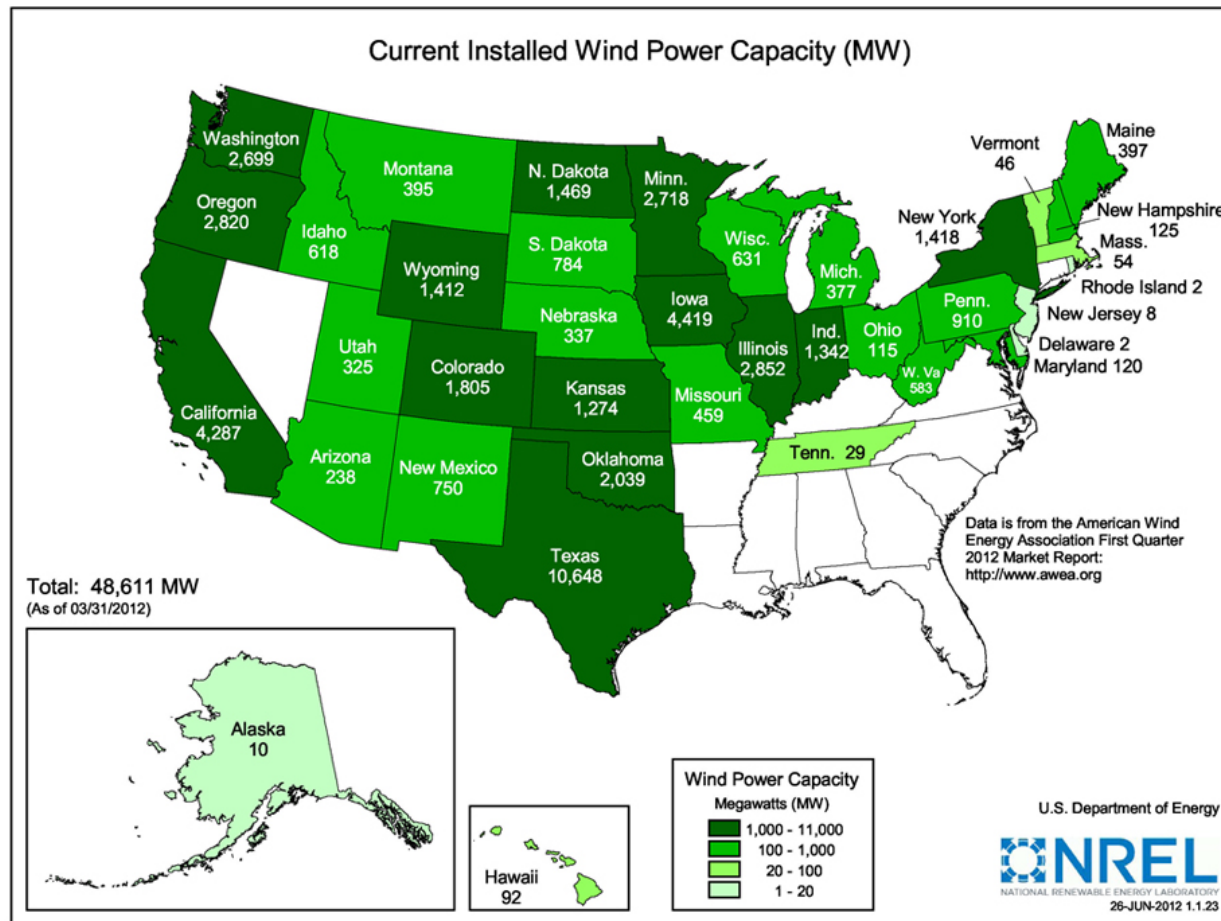
# Motivation - Global Installed Wind Power Capacity



Country	(end of 2010)	MW	%
China		42,287	21.8
USA		40,180	20.7
Germany		27,214	14.0
Spain		20,676	10.6
India		13,065	6.7
Italy		5,797	3.0
France		5,660	2.9
UK		5,204	2.7
Canada		4,009	2.1
Denmark		3,752	1.9
Rest of the world		26,546	13.7

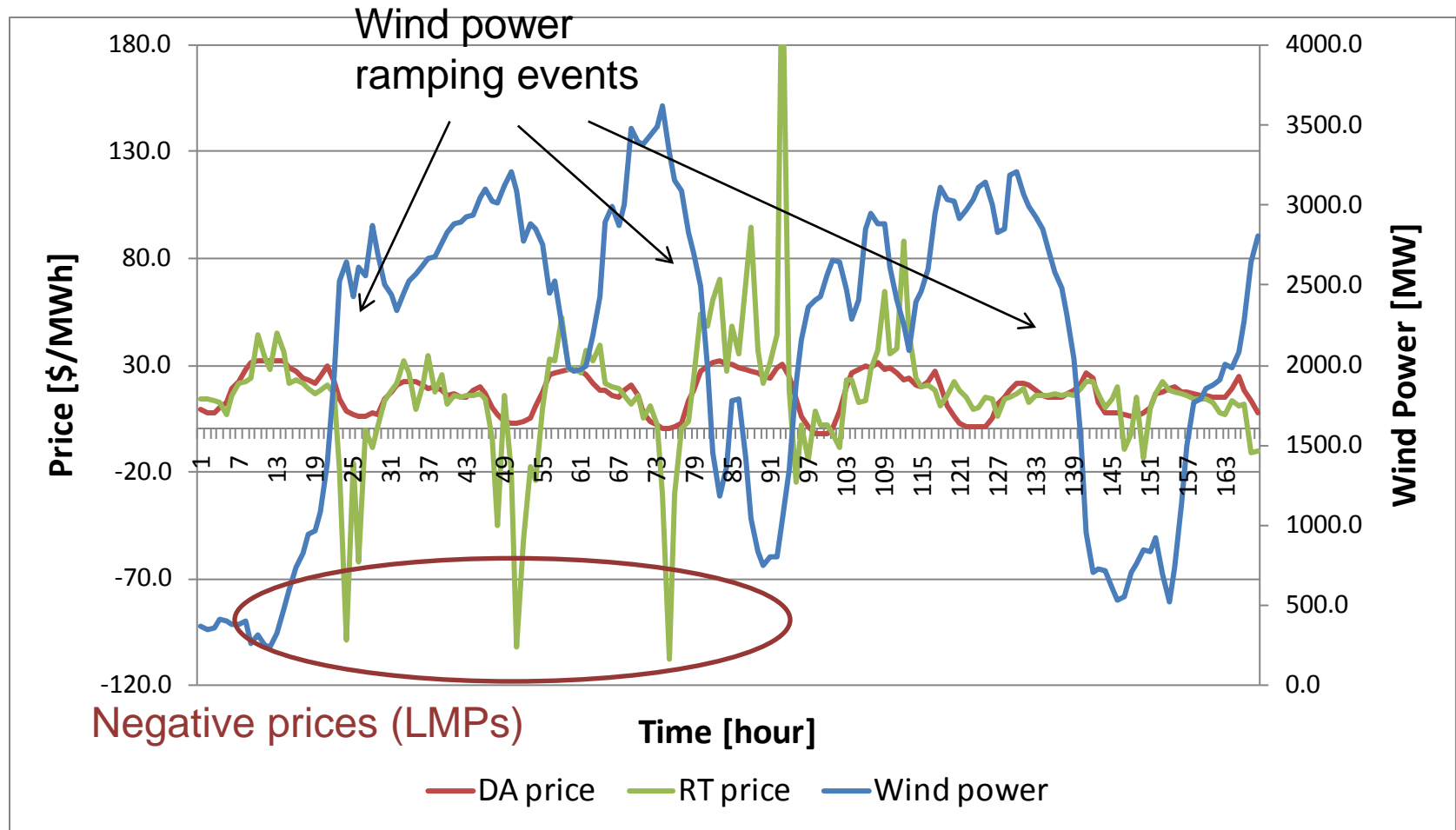
# Motivation – U.S. Wind Power Capacity

- Wind power has been rapidly integrated into the current power systems



# Motivation - Influence on Electricity Markets Today

Midwest ISO Wind Power and Iowa\* LMPs, May 11-17, 2009:

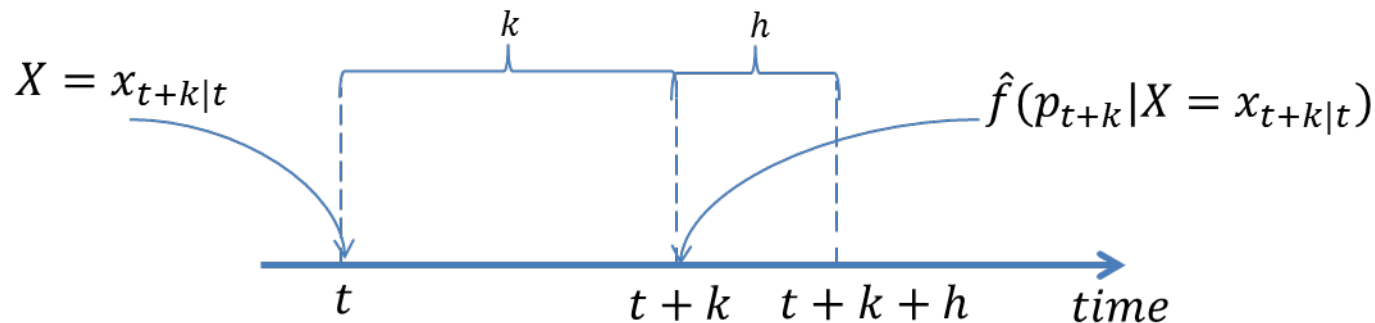


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# Wind Power Probabilistic Forecasting

- Basic problem
  - Given a sequence of independent identically distributed random variables  $X_1, X_2, \dots, X_t, \dots$  with common probability density function  $f(x)$ , how can one estimate  $f(x)$ ?
- Problem description under wind power forecasting



$h$ : forecasting horizon  
 $k$ : look ahead time step

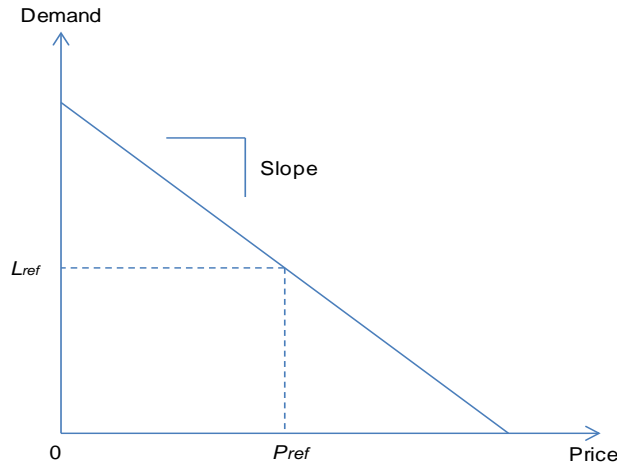
- Formulation based on kernel density estimation

$$\hat{f}(y|X = x) = \frac{1}{N \cdot h_y} \cdot \sum_{i=1}^N K_y \left( \frac{y - Y_i}{h_y} \right) \cdot \frac{1}{N} \cdot \sum_{i=1}^N K_u \left( \frac{F_X^e(u) - F_X^e(U_i)}{h_u} \right) \cdot K_v \left( \frac{F_X^e(v) - F_X^e(V_i)}{h_v} \right)$$

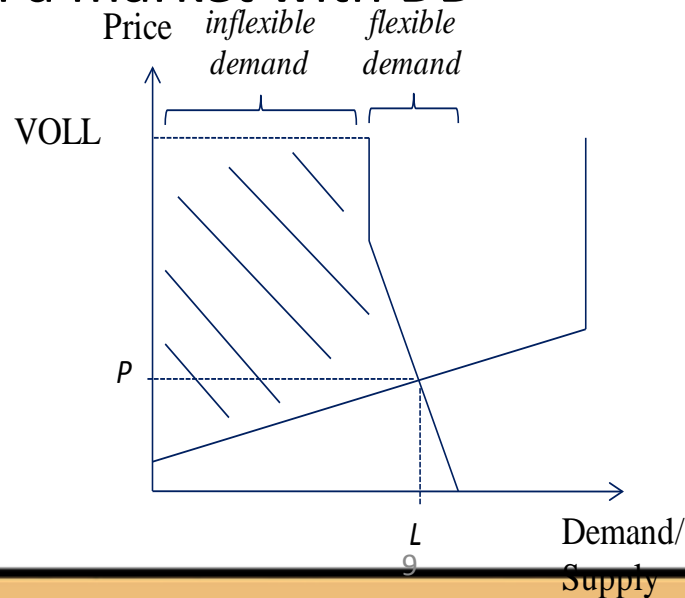


# Demand Dispatch Modeling

- A simplified linear demand dispatch curve

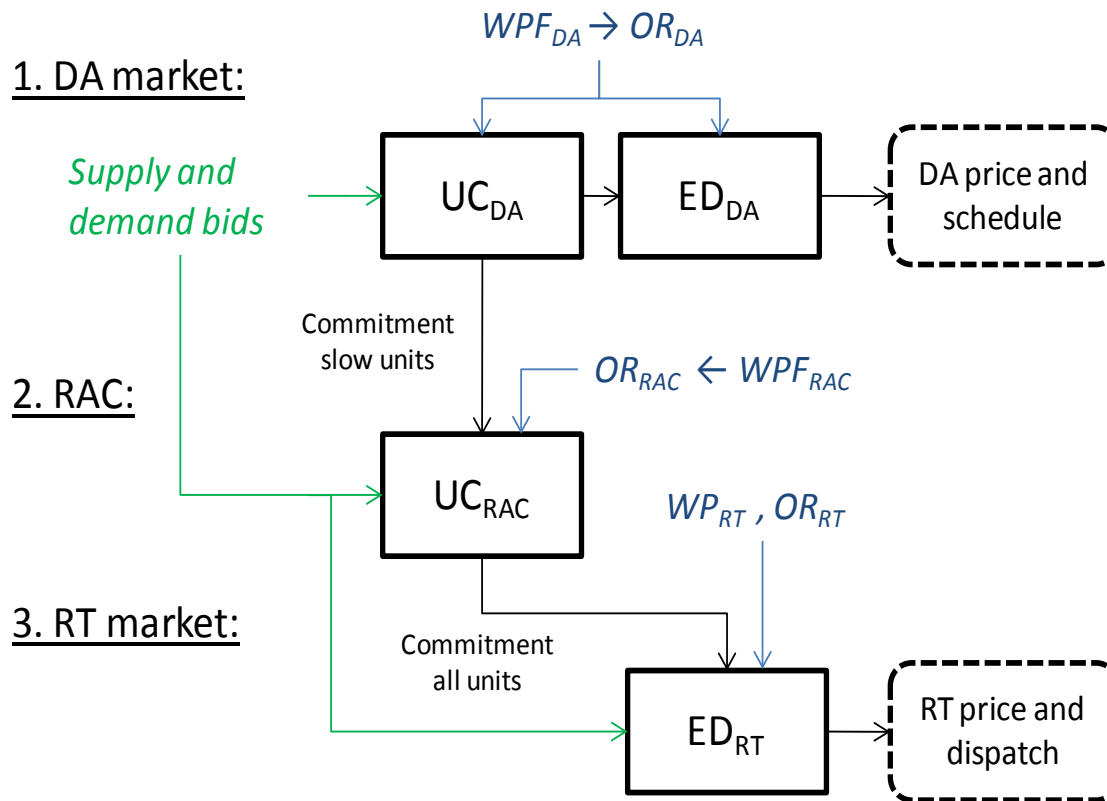


- Market clearing in a market with DD



# Market Operation

- Two-settlement market clearing

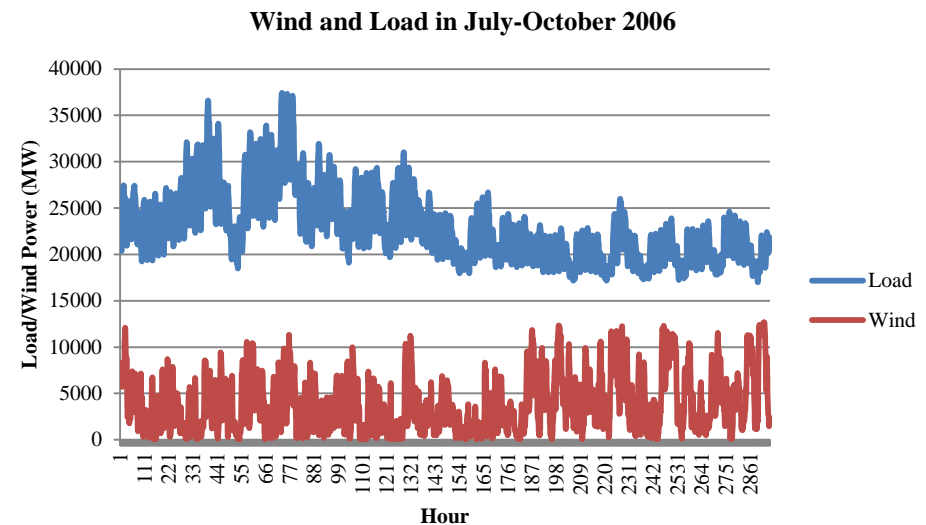
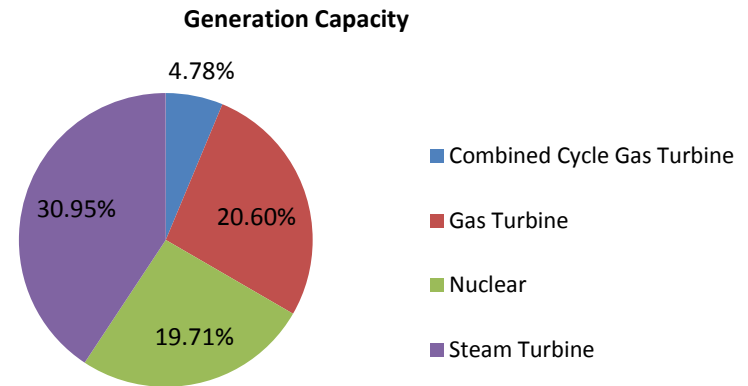


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# Case Study Assumptions

- 210 thermal units: 41,380 MW
  - Base, intermediate, peak units
- Peak load: 37,419 MW
  - 2006 load series from Illinois
- Wind power: 14,000 MW
  - 2006 wind series from 15 sites in Illinois (NREL EWITS dataset)
  - 20% of load
- No transmission congestion
- 120 days simulation period (July 1<sup>st</sup> to October 31<sup>st</sup>, 2006)
  - Day-ahead unit commitment w/wind power point forecast
  - Real-time RAC w/ wind power scenarios



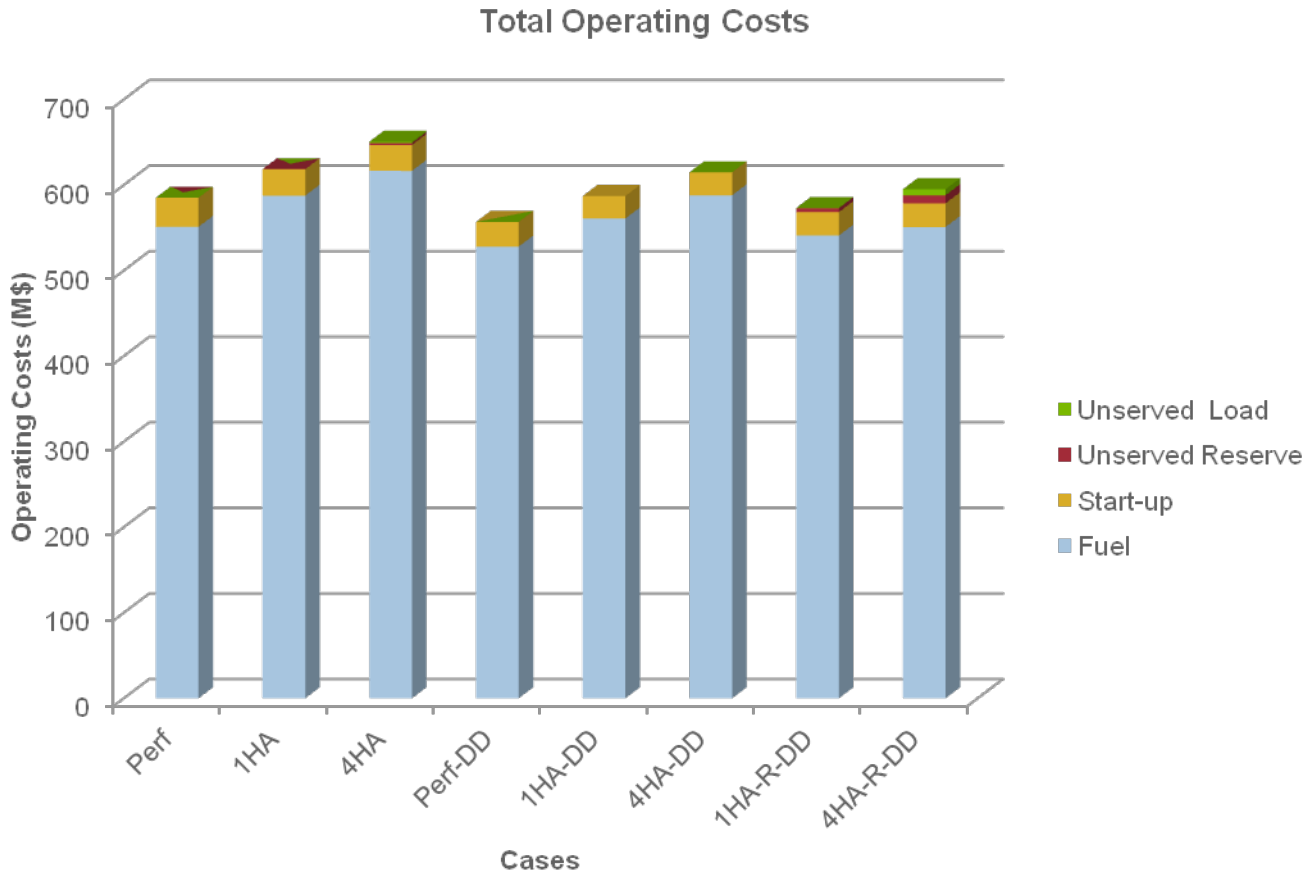
A. Botterud, et. al. "Demand Dispatch and Probabilistic Wind Power Forecasting in Unit Commitment and Economic Dispatch: A Case Study of Illinois," *IEEE Transactions on Sustainable Energy*.

# Test Cases

<i>Case</i>	<i>WPF in DA</i>	<i>WPF in RAC</i>	<i>Wind reserves*</i>	<i>Demand dispatch</i>
<b>Perf</b>	Perfect	Perfect	None	No
<b>1HA</b>	DA	1HA	Dynamic	No
<b>4HA</b>	DA	4HA	Dynamic	No
<b>Perf-DD</b>	Perfect	Perfect	None	Yes
<b>1HA-DD</b>	DA	1HA	Dynamic	Yes
<b>4HA-DD</b>	DA	4HA	Dynamic	Yes
<b>1HA-R-DD</b>	DA	1HA	Reduced	Yes
<b>4HA-R-DD</b>	DA	4HA	Reduced	Yes

\* This additional reserve is applied at the RAC stage only to handle wind power uncertainty. All cases use a regular reserve,  $OR_{reg,t}$ , equal to the largest contingency ( 1146 MW).

# Summary of Total Operating Cost



# Summary of Curtailments

Case	Load		Spinning Reserve		Wind	
	MWh	hours	MWh	hours	MWh	hours
Perf	0	0	31.7	4	5206	17
1HA	0	0	2.5	1	14913	30
4HA	432.5	2	1962	5	45334	62
Perf-DD	0	0	0	0	3375	14
1HA-DD	0	0	0	0	9950	24
4HA-DD	0	0	0	0	38134	53
1HA-R-DD	49.2	1	4238	23	7048	21
4HA-R-DD	1998	4	8514	48	17462	25

# Summary of Dispatch by Technology

Case	Nuclear	Steam	Comb. Cycle	Combustion	Wind	Total
Perf	30.44	25.37	0.45	0.56	11.33	68.33
1HA	30.12	25.24	0.48	1.00	11.32	68.33
4HA	29.89	25.09	0.44	1.45	11.29	68.33
Perf-DD	30.48	25.27	0.26	0.39	11.33	67.90
1HA-DD	30.18	25.41	0.31	0.72	11.33	68.12
4HA-DD	29.96	25.29	0.29	1.13	11.30	68.14
1HA-R-DD	30.27	25.32	0.32	0.48	11.33	67.90
4HA-R-DD	30.20	25.27	0.32	0.62	11.32	67.91



# Summary of Start-ups for Thermal Units

Case	Nuclear	Steam	Comb. Cycle	Combustion	Total
Perf	0	2446	188	1061	3695
1HA	0	2208	220	4035	6463
4HA	0	2191	207	4999	7397
Perf-DD	0	2299	101	685	3085
1HA-DD	0	2082	119	2840	5041
4HA-DD	0	2077	118	3756	5951
1HA-R-DD	0	2195	143	1614	3952
4HA-R-DD	0	2180	141	2269	4590

# Summary of Energy and Reserve Prices

Case	Energy		Spinning Reserve		Non-Spin Reserve	
	DA	RT	DA	RT	DA	RT
<b>Perf</b>	21.2	21.2	3.5	3.5	0.0	0.0
<b>1HA</b>	22.5	16.3	6.9	0.4	0.0	0.0
<b>4HA</b>	22.7	19.2	7.5	1.9	0.0	0.0
<b>Perf-DD</b>	19.7	19.7	2.9	2.9	0.0	0.0
<b>1HA-DD</b>	20.6	15.9	6.1	0.3	0.0	0.0
<b>4HA-DD</b>	20.6	15.6	6.1	0.2	0.0	0.0
<b>1HA-R-DD</b>	20.8	29.2	4.5	11.6	0.0	0.0
<b>4HA-R-DD</b>	20.7	40.6	4.4	20.8	0.0	0.0

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# Conclusions

- **Demand Dispatch**

- It reduces wind power curtailment.
- Total operational costs are significantly reduced as well.
- A modest amount of DD improves reliability in terms of reserve and load curtailment.

- **Probabilistic Wind Power Forecasting**

- More accurate forecasts help reduce wind curtailment when making re-commitment decision
- Lower operating costs, committed fewer thermal resources

- **Framework**

- Relatively modest changes from current operational practices
- Proposed market framework with dynamic reserves

# Comments and Questions

*Thank You*

## *References:*

1. A. Botterud, Z. Zhou, *et. al.* "Demand Dispatch and Probabilistic Wind Power Forecasting in Unit Commitment and Economic Dispatch: A Case Study of Illinois," *IEEE Transactions on Sustainable Energy*.
2. Z. Zhou, A. Botterud, *et. al.*, "Application of Probabilistic Wind Power Forecasting in Electricity Markets," *Wind Energy*
3. R. Bessa, *et. al.* "Time-adaptive quantile-copula for wind power probabilistic forecasting", *Renewable Energy*.