

Renewable energy consultants

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Regional Inter-annual Variability of Wind Production across the US

WINDPOWER 2011 Conference & Exhibition



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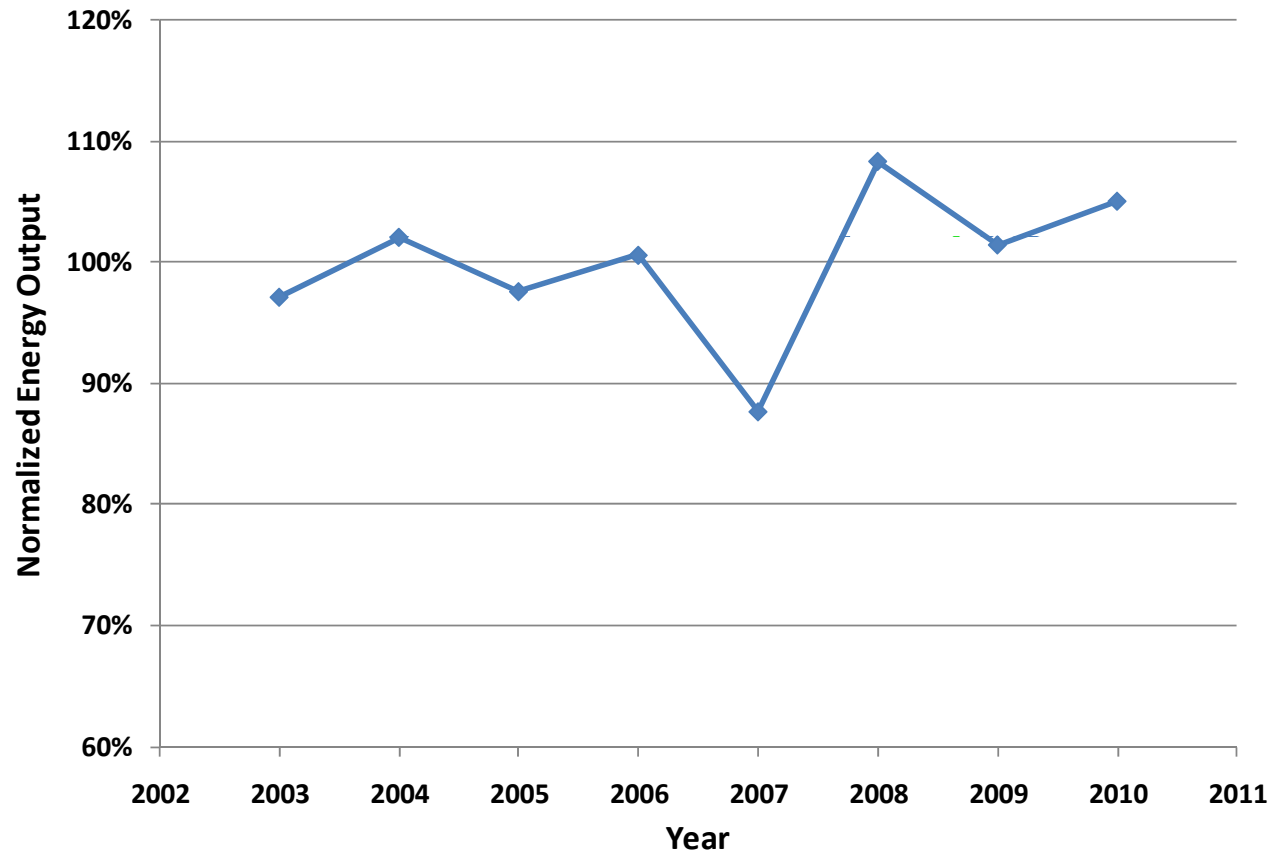


Overview

- **Introduction to inter-annual variability**
- **Purpose of the study**
- **Wind resource variability**
- **Other sources of inter-annual variation**
- **Observations from actual wind farm production variation**

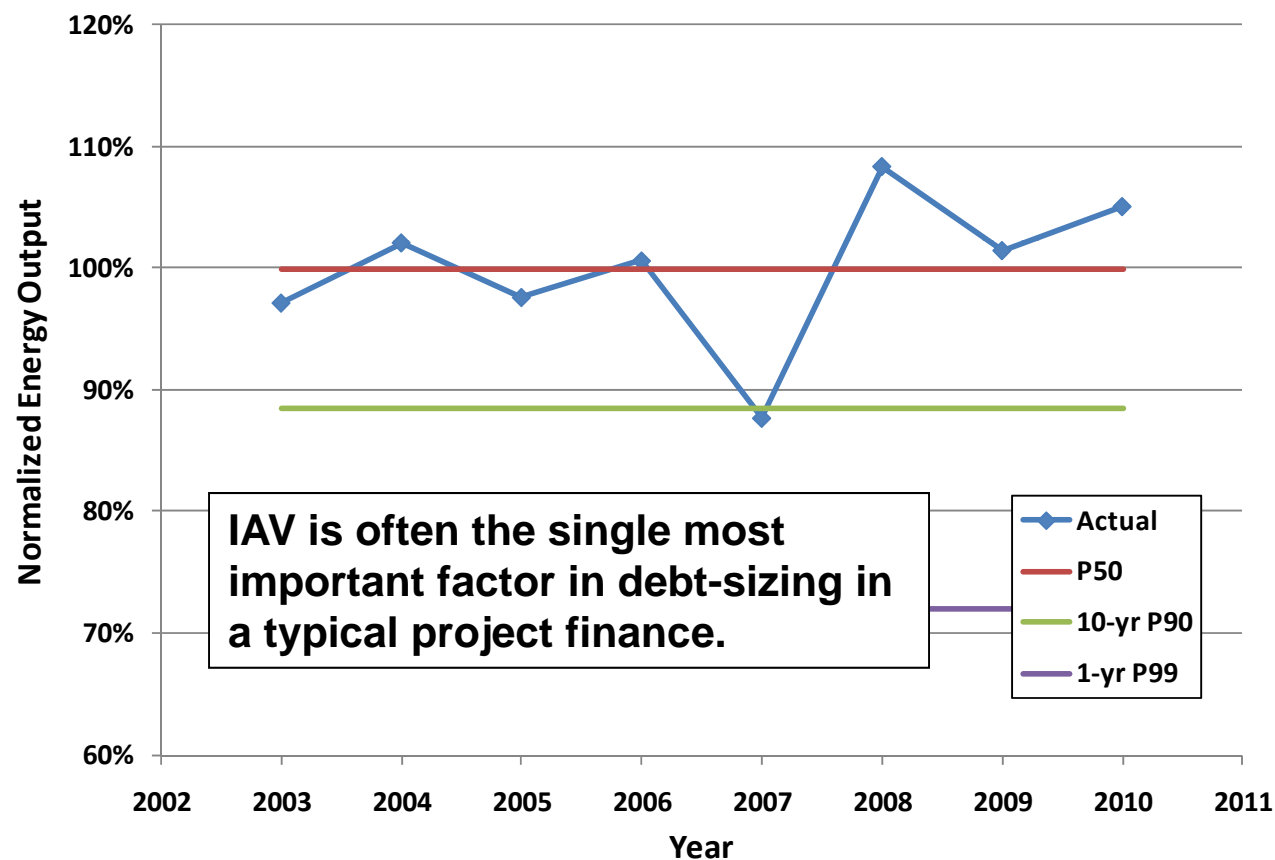
Inter-annual variability - a definition

Inter-annual variability is a measure of the variation in energy production from one year to the next; typically assumed to represent one standard deviation



Importance of inter-annual variability

Lenders consider downside production scenarios to evaluate revenue risk –
Focus on the 1-yr P99



Purpose of the study

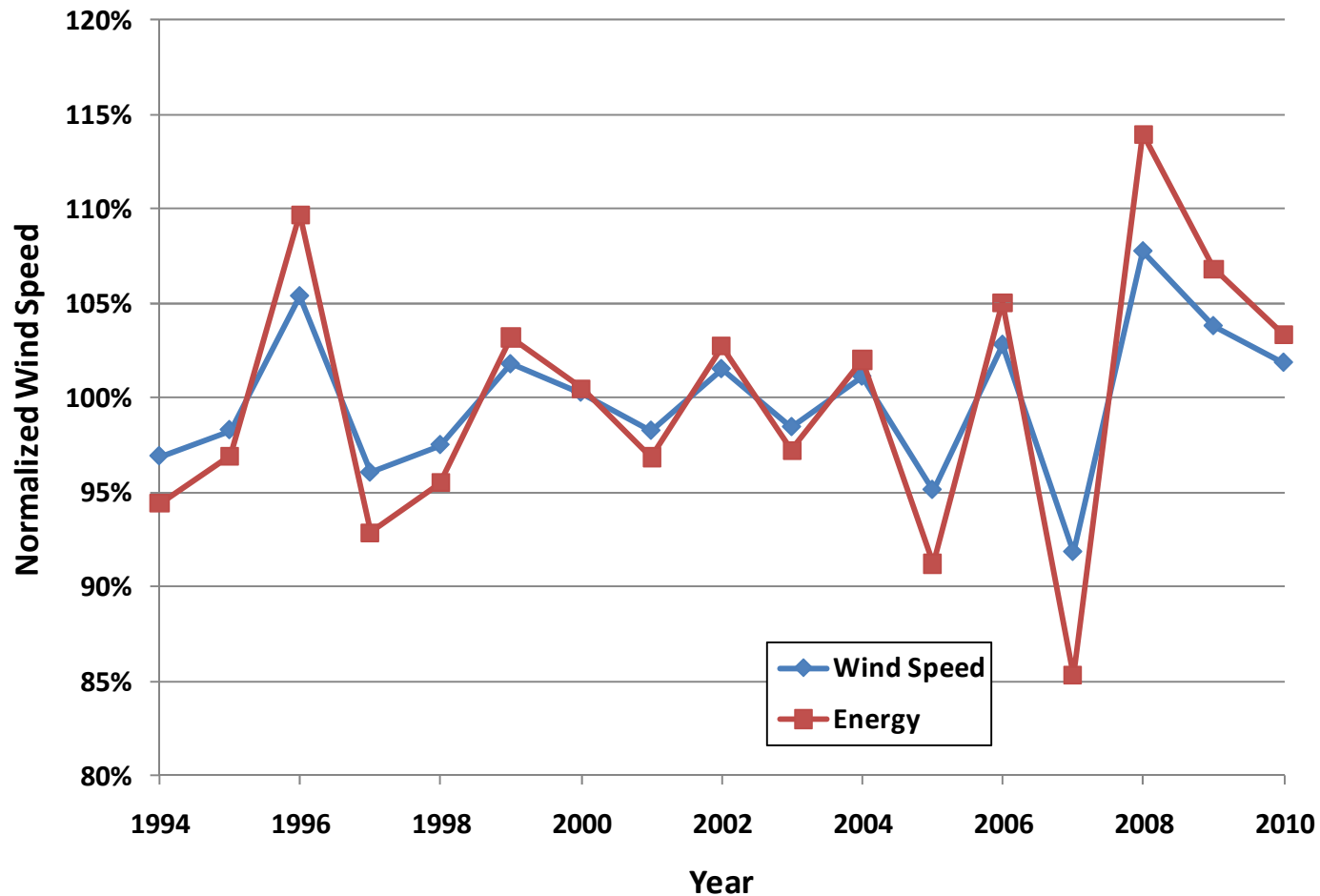
- **Re-examine current industry approach to determining inter-annual production variability**
- **Identify significant sources of inter-annual production variation**
- **Assess sources of IAV to determine:**
 - **Magnitude of various sources**
 - **Extent of geographic variation in IAV**
 - **Extent of project specific factors**
- **Compare estimates of IAV to actual production variability at operating wind farms**

Factors Influencing IAV

- **Wind Resource**
 - Annual mean wind speeds
 - Wind speed and direction frequency distribution
 - Shape of distribution
 - Wind rose
 - Wind shear and atmospheric stability
- **Availability**
- **Other Factors**
 - Environmental losses
 - Density
 - Curtailment

Wind Speed IAV – the biggest factor

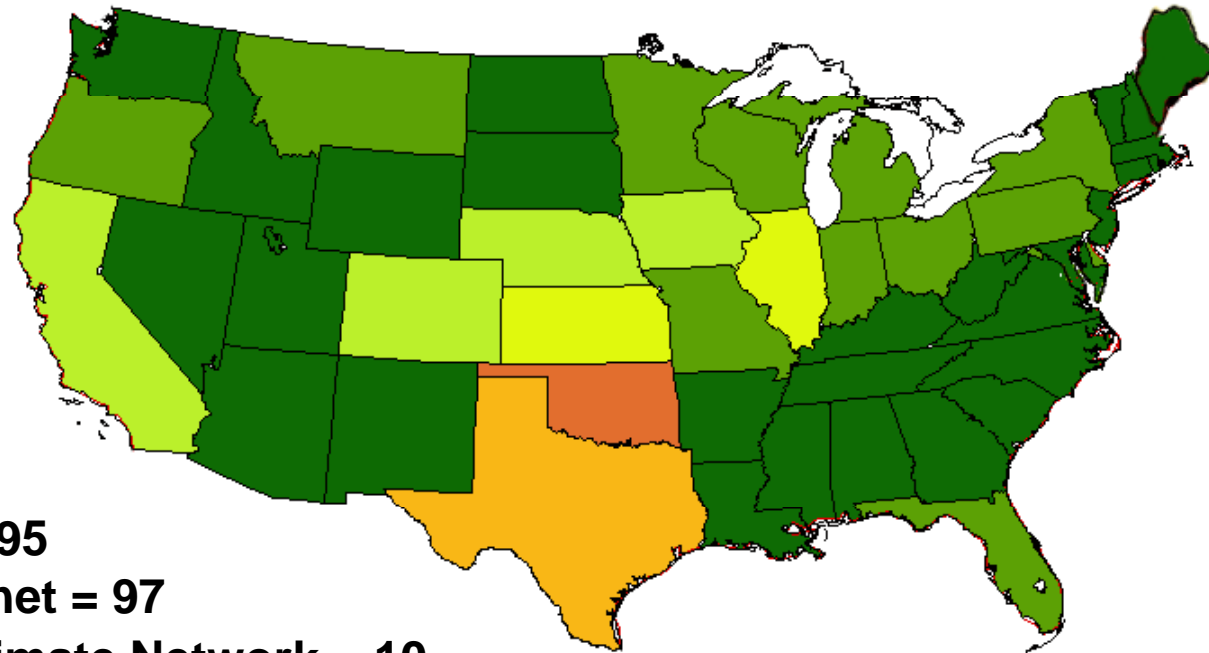
Example plot of inter-annual mean wind speed variability



Wind Speed IAV – how large?

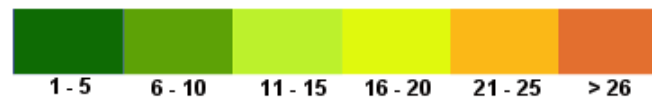
- **Observations from various long-term data sources**
 - NWS ASOS
 - Oklahoma Mesonet
 - Illinois Climate Network
- **Filters applied to control for data coverage and statistical outliers**
- **Range of typical observations:**
 - 3% - 7% on wind speed
 - 5% - 14% on energy
 - conversion of wind speed IAV to energy IAV is site specific and depends on wind speed frequency distribution and turbine power curve
- **Other data sources (e.g. Rawinsonde, Reanalysis-based) considered for comparison**

Distribution of long-term data sources

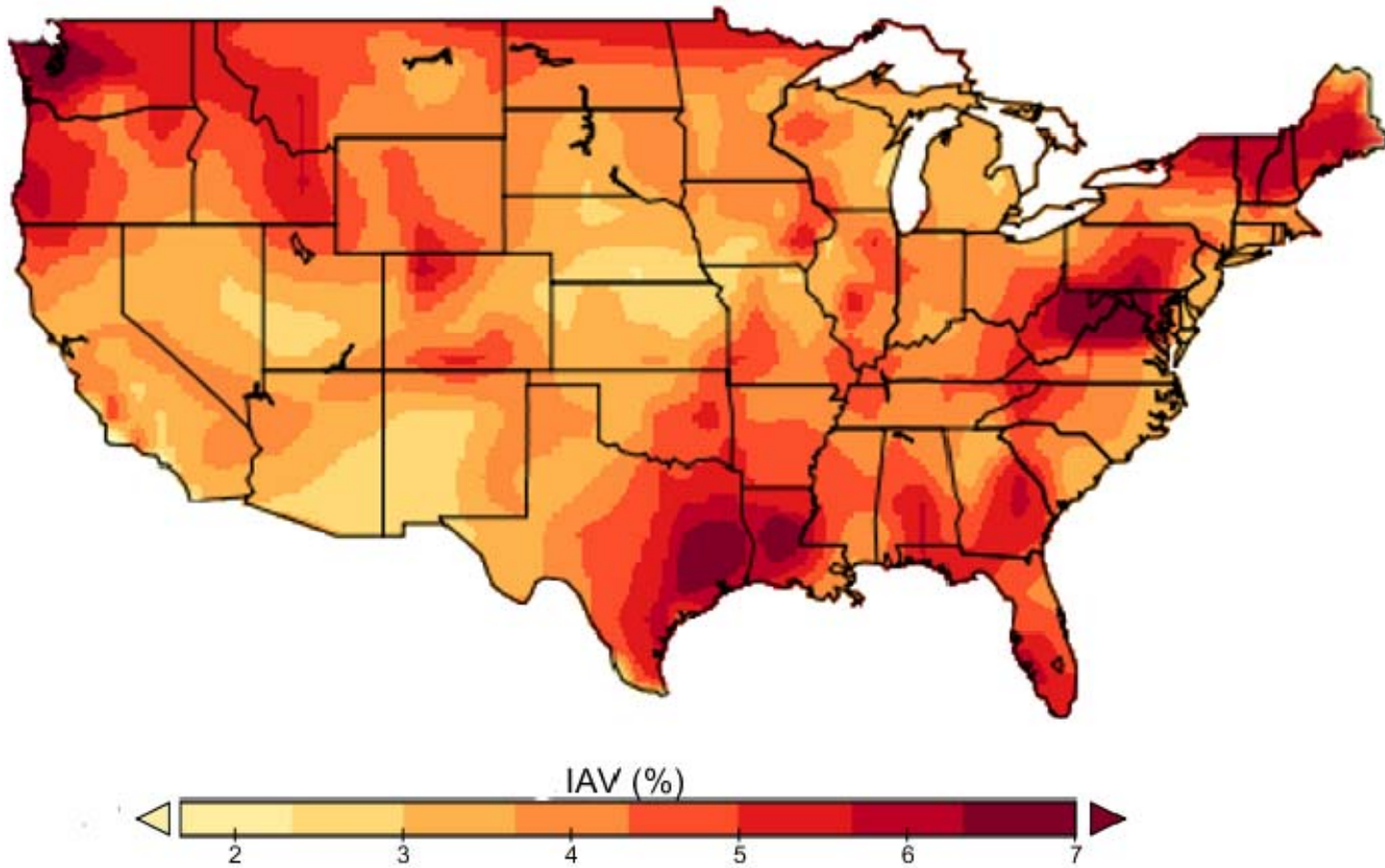


- ASOS = 295
- OK Mesonet = 97
- Illinois Climate Network = 10

Number of stations



Map of observed wind speed IAV



Wind Speed IAV – questions and issues

- **Length of measurements**
 - Only 15-17 years for ground-based sources
 - Central Limit Theorem suggests a longer period is required (~30 yrs)
 - Reanalysis-based data sets show materially lower levels of IAV compared to concurrent ground-based sources
- **Height of measurements**
 - Majority of surface data available at 10 m
- **Annual mean wind speeds assumed to be randomly distributed**
 - Past research indicates only weak auto-correlation between years
 - What about longer-term quasi-cycles (El Nino) and impacts of climate change?

Other inter-annual variations in wind resource

- **Shape of the wind speed frequency distribution**
 - The shape of the distribution may vary somewhat independently from the annual mean wind speed
 - Magnitude of IAV depends on turbine power curve
- **Wind shear and atmospheric stability**
 - Shape and magnitude of vertical profile may affect energy flux through the rotor
- **Wind rose**
 - Influences wake effects
 - May change relative pattern of windiness across the site



Availability and other factors

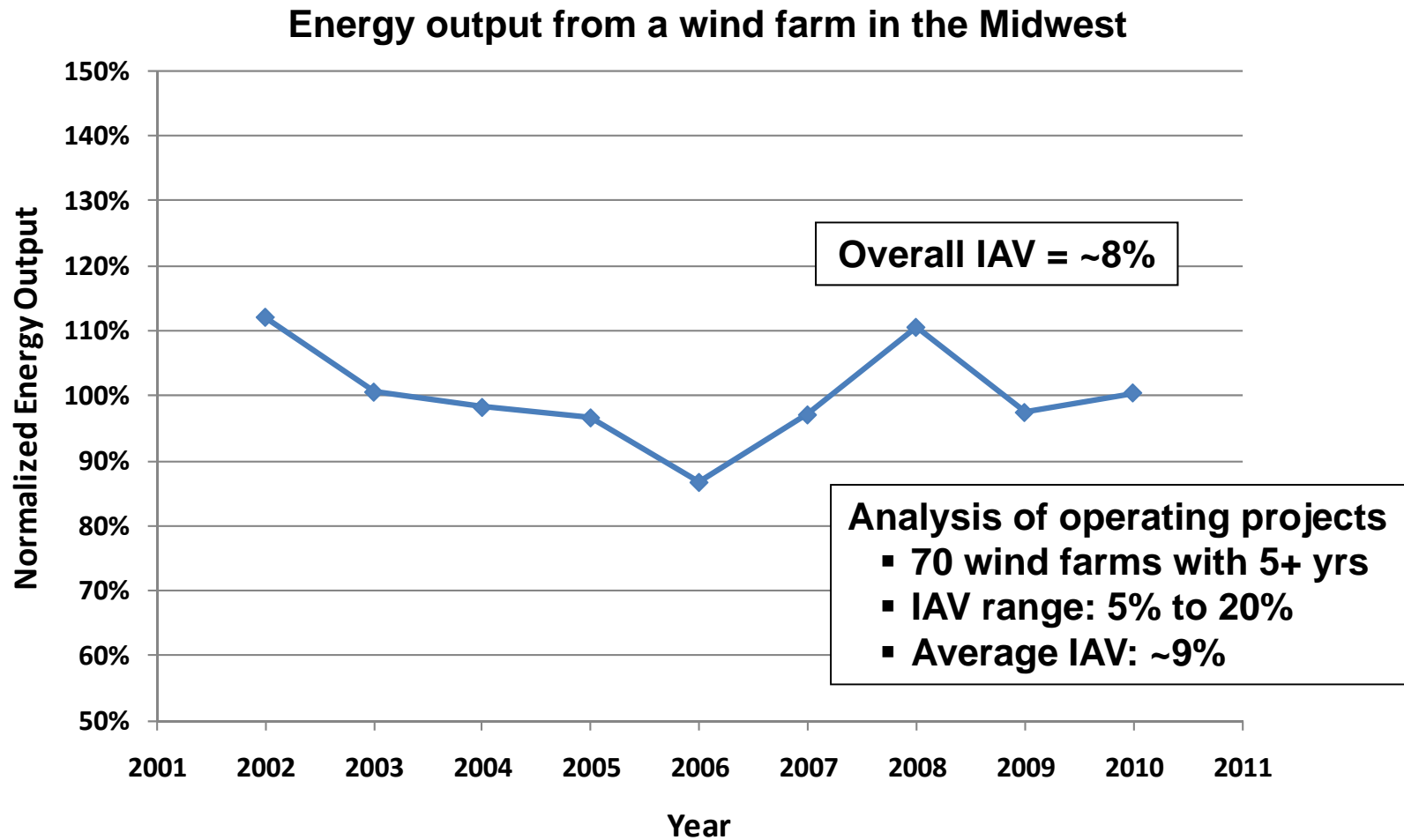
- **Availability IAV of US wind farms**
 - Significant database of wind farms with 6+ years of operation
 - Observed range: 1% to 4% on energy (for most wind farms)
 - Data suggest variation by turbine model and project specific factors
 - Independent of wind speed variability
- **Air Density**
 - Temperature may vary slightly from one year to next
 - Overall impact on IAV is small
- **Environmental losses**
 - Icing
 - Blade degradation
- **Curtailment**
 - Very site specific
 - Can become largest source of IAV

Overall inter-annual variation in production

- **Combine all sources on root sum square basis**
- **Typical overall figures:**

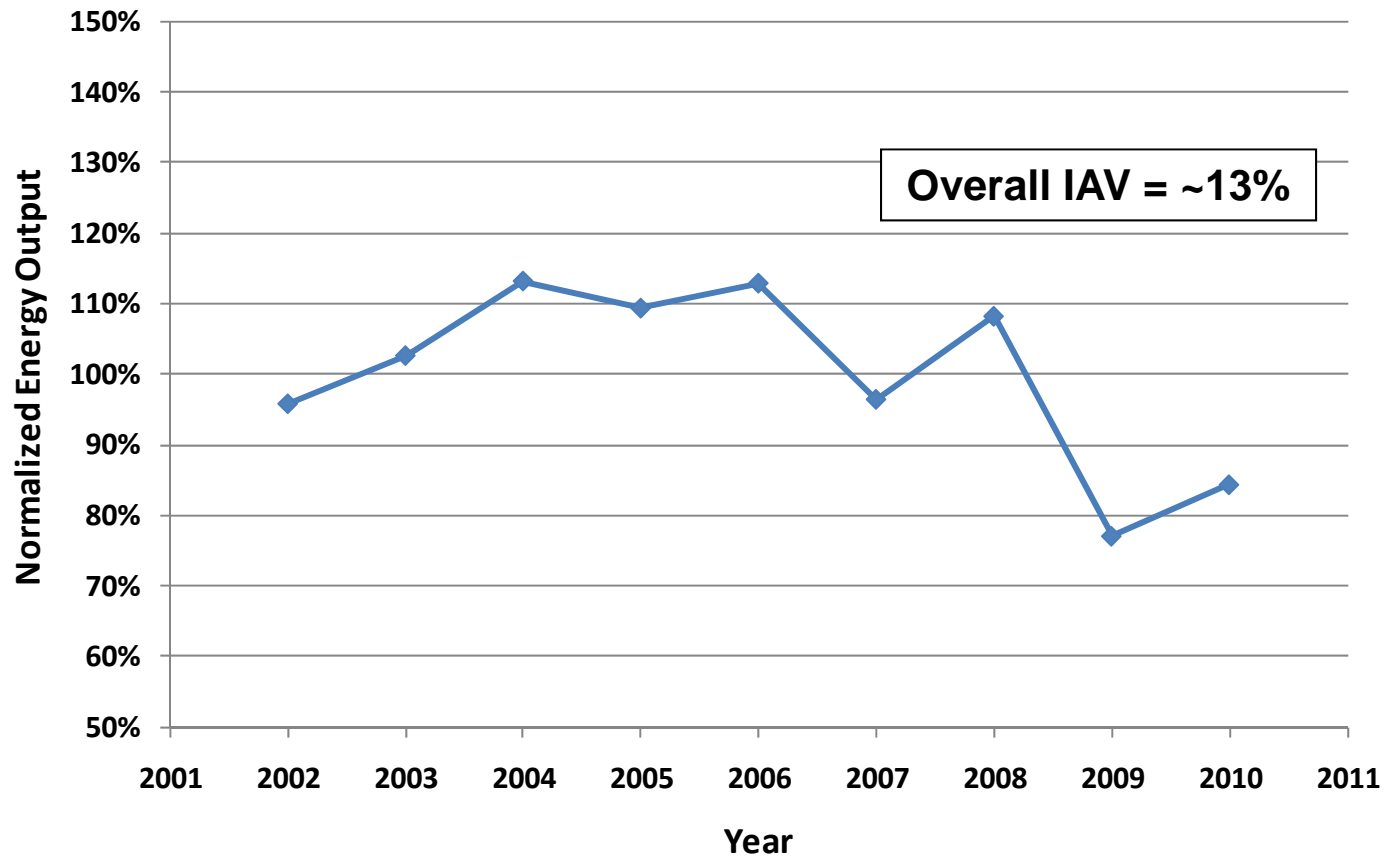
Source of IAV	Wind Speed	Energy
Mean Wind Speed	4.5%	7.9%
Wind Speed Frequency Distribution		1.5%
Availability		2.0%
Environmental losses		0.5%
Air density		0.25%
Curtailement		0%
Overall Energy IAV		8.3%

Observed variation in real wind farm production



Observed production variation – with curtailment

Energy output from a wind farm in the Texas –
curtailment can dominate other sources of inter-annual variation



Conclusions

- **Inter-annual variability is a primary driver for debt sizing for typical project financing**
- **Wind speed variability is the dominant factor affecting IAV but other factors should be considered**
- **Overall wind farm production IAV is site specific**
 - **Regional patterns of wind resource IAV**
 - **Availability IAV influenced by turbine model, project specific details**
 - **Curtailement can dominate overall IAV**

Thank you

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