Future Wind Energy Development and Wildlife Interactions

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The U.S. Energy Picture
by source - 1850-1999

The US History and Future Planned Additions of Coal Generated Electricity

Source: Black & Veatch Analysis of data from Global Energy Decisions Energy Velocity database
Growth of Wind Energy Capacity Worldwide

Jan 2008 Cumulative MW = 90,521

- Rest of World = 16,795
- North America = 18,612
  - U.S = 16,842 MW
  - Canada = 1,770 MW
- Europe = 55,114

Sources: BTM Consult Aps, March 2007
Windpower Monthly, January 2008
*NREL Estimate for 2008
Total: 16,904 MW (5,329 MW added in 2007)

Installed capacity data are from the AWEA project database. Locations are based on matching the database with Platts POWERmap data, the physical description in the database, and other available data sources.

Wind Power Capacity
Megawatts (MW)
- 1,000 - 4,500
- 100 - 1,000
- 20 - 100
- 1 - 20

Wind Projects >= 1 MW
- Online Prior to 2007
- Added in 2007

Source: Platts, powermap.platts.com, 6/2007, a Division of the McGraw-Hill Companies

U.S. Department of Energy
National Renewable Energy Laboratory

ONRCL
A New Vision  
For Wind Energy in the U.S.

State of the Union Address

“...We will invest more in ... revolutionary and solar wind technologies”

Advanced Energy Initiative

“Areas with good wind resources have the potential to supply up to 20% of the electricity consumption of the United States.”

20% Wind by 2030 Report

www.eere.energy.gov/windandhydro
Wind Energy Supply Curve

Excludes PTC, includes transmission costs to access 10% existing electric transmission capacity within 500 miles of wind resource.
What does 20% wind electricity look like?
Installed Wind Nameplate Capacity by State (2030)

Wind Capacity
Total Installed (2030) (GW)
- 0.0 - 0.1
- 0.1 - 1
- 1 - 5
- 5 - 10
- > 10

The black open square in the center of a state represents the land area needed for a single wind farm to produce the projected installed capacity in that state. The brown square represents the actual land area that would be dedicated to the wind turbines (2% of the black open square).
Wind Energy Technology

At it’s simplest, the wind turns the turbine’s blades, which spin a shaft connected to a generator that makes electricity. Large turbines can be grouped together to form a wind power plant, which feeds power to the electrical transmission system.
Stream Tube for Momentum Balance

For Maximum Power:

\[ V_i = \frac{1}{3} V_w \]

\[ P = \frac{16}{27} \left( \frac{1}{2} \rho A V_w^3 \right) \]

**The Betz Limit**
Wind Energy Production Terms

- **Power in the Wind** = \( \frac{1}{2} \rho A V^3 \)
- **Power Coefficient** - \( C_p \)
- **Betz Limit** - 59% Max
- **Efficiency** – about 80%
- **Rated Power** – Maximum power generator can produce
- **Capacity factor** - Annual energy capture / Generator max output \( \times 8760 \)
- **Cut-in** wind speed where energy production begins
- **Cut-out** wind speed where energy production ends

Modern Turbine Power Curve
Wind Energy Increases with Height

Best areas 6.5-7 m/s
Capacity factors 30-35%

Best areas 7-7.5 m/s
Capacity factors 35-40%

Best areas 7.5-8.2 m/s
Capacity factors 40-45%
Considerations for Siting a Wind Farm

• Income = Energy Output ~ (Wind Speed)^3
• Transmission Access
• Power Purchase Agreement with Utility
• Land with landowner willing to lease
• Permits: Minimal Wildlife & NIMBY
• Turbines at a Competitive Price
• Financing

Rotor Blades 37m:
• Shown Feathered
• 37m length

A Utility Scale 1.5 MW Wind Turbine

National Renewable Energy Laboratory
Land Based Technology Improvement Options

Advanced Rotor Technology
- Extended rotor architectures through **load control**
- Incorporate advanced materials for hybrid blades
- Cyclic & independent blade pitch control for load mitigation
- Sweep and flap twist coupled architectures
- Light weight, high TSR with attenuated aeroacoustics

Power Train Enhancements
- Permanent Magnet DD Architectures
- Split load path multi-stage generation topologies
- Reduced stage (1-2) integrated gearbox designs
- Convoloid gearing for load distribution
NREL Tests Innovative Wind Industry Blades Designs

Ultimate Strength Testing of a new Blade Design

Structural Test of Knight and Carver Blade
Test preparation of a swept blade providing twist-flap coupling for gust load reduction
Energetic flowfield
Globally separated
Steep gradients
Dynamically active

Responsive structure
Light and flexible
Advanced materials
Aeroelastic load control

Basic R&D Needs:
Aeroelasticity
Nonlinear & coupled
Multiple physics
Multiple Scales

Powerful winds
U_∞, direction vary
Coherent turbulence
Turbine wakes

Complex wake
Trailed vortices
Shed vortices
Persistent
Land Based Technology Improvement Options

Power Conversion
- High temperature silicon carbide device; improved reliability & reduce hardware volume
- Novel circuit topologies for high voltage & power quality improvement
- Medium voltage designs for multi-megawatt architectures

Tower Support Structures
- Tall tower & complex terrain deployment
- Advanced structures & foundations
- New materials and processes
- Self erecting designs
Land Based Technology Improvement Options

Manufacturing and Learning Curve

- Larger volume and steady markets drive toward more automated manufacturing
- Historical progress ratios (price reduction for each doubling in production) for wind turbines have been 90-95%
- Getting to 20% requires five doublings
- Reduced Capital Cost 4-6% per doubling; 20-30% total
- Improved Quality and Reliability

Experience curve for wind turbines installed in Spain 1984-2000
Progress ratio 91%
$r^2 = 0.85$

Experience curve: a tool for energy policy assessment (EXTOOL)
Analysis sponsored by European Union
http://www.iset.uni-kassel.de/extool/Extoolframe.htm
Offshore Wind: Why?

Land-based sites are not close to coastal load centers

Load centers are close to offshore wind sites

28 Coastal States Use 78% of Electricity
No exclusions assumed for resource estimates
Substructure Load-out and Installation

Photo Credit: Talisman Energy Offshore Demonstration
5 MW 126m Repower Turbine
45 m water depth, North Sea
Aberdeen, Scotland
The Siting and Permitting Challenge

To reach 20% wind energy by 2030 will require minimizing the barriers to siting and permitting by “understanding, minimizing and, mitigating environmental impacts to wildlife”. The issues that must be addressed through further research are:

- Understanding, minimize, avoiding, and mitigating specific species impacts:
  - Birds
  - Bats
  - Other species using the windfarm habitat
- Habitat modification and fragmentation effects
- Individual animal versus cumulative population impacts
- The influence of variables such as weather, lighting, turbine height, turbine rotation speed
- Effective mitigation measures and methods, both onsite and offsite
Evolution of U.S. Commercial Wind Technology

The 1980's
- Altamont Pass, CA Kenetech 56-100kW 17m Rotor
- 50kW
- 100kW

The 1990's
- Altamont Pass, CA Kenetech 33-300kW 33m Rotor
- Buffalo Ridge, MN Zond Z-750kW 46m Rotor
- 300kW
- 500kW
- 750kW

2000 & Beyond
- Arklow, Scotland GE 3.6MW 104m Rotor
- 1.5 MW
- 2.5 MW
- 3.6 MW
- 5 MW
- Offshore
- Land Based
- Medicine Bow, WY Clipper 2.5MW 93m Rotor

Timeline of Wind Energy-Avian Interactions Research

1980
- Orloff, S. and Flannery, A. "Wind turbine effects on avian activities, habitat use, and mortality in Altamont Pass..." (1992)

1985
- National Avian Wind Planning Meeting I 1994 (NAWPMI-1994)
- NAWPM II (1995)

1990
- NAWPM III (1998)

1995
- NAWPM IV (2000)
The Specific Wildlife Research Areas

Meeting Outcome - Five Major Research Areas:

1. Assess mortality attributable to wind turbines at existing sites (including control data from “no turbine” sites)
2. Predict mortality at planned wind power sites, based in part on previous bullet
3. Predict population consequences
4. Identify ways to reduce bird kills at wind plants
5. Set values for off-site mitigation
6. High Bat Fatalities in Mid-Atlantic Highlands (New Issue in 2004)
7. Habitat impacts (New Issue in 2006)

Current Status of Issues:

1. Mortality estimates made post construction
2. No pre-construction predictor of post-construction mortality, which slows permitting greatly
3. No population impact predictor
4. In process at Altamont Pass
5. No standard mitigation values set
6. Under study through Public-Partnership
7. Under study for Prairie Chickens and other Prairie Songbirds
Proportion of fatalities at sites reporting fatalities by species, summarized for all regions where studies have been conducted (Pacific Northwest, Mid-West, Rocky Mountains, and East).

Source: Strickland and Morrison
Visualization of Avian Interaction Zones

Windfarm Flight Zone

- Over-flight
- Strike Zone
- Fly-thru
- Fatality Risk

Rotor Zone
A Simple Stick Collision Model

Bird passage time through the rotor:

\[ t_p = \frac{L}{V} = \text{Length speed ratio (sec)} \]

Blocked Sector of Turbine Rotor:

\[ B = t_p \times w \ (\text{deg}) \]

Probability of collision:

\[ P_c = \frac{\text{Blocked Area}}{\text{Disk Area}} \]

\[ P_c = \frac{3B}{360 \text{deg}} \]

To account for avoidance:

\[ P_c = 3A \times \frac{L}{V} \times \frac{w(\text{deg/sec})}{360 \text{deg}} \]

where \( A = \begin{cases} <1 & \text{for avoidance} \\ 1 & \text{for no behavior} \\ >1 & \text{for attraction} \end{cases} \)
Avian Strike Probability Versus Turbine Size

Altamont Scale

15 Meter Diameter and 100 kW

Next Generation Scale

93 Meter Diameter and 2.5MW
Avoidance Behavior is Significant

Radar Tracks of Migrating Birds through Nysted Offshore Windfarm for Operation in 2003

Response distance:
- day = c. 3000m
- night = c. 1000m
Candidate Avian Risk Metrics

Hypothesis: “Mortality risk increases with flight time in the rotor zone (yellow zone), if the turbine is operating”

- A Candidate Post-construction Fatality Metric:
  
  Species Risk = Fatalities/(Swept Area x Turbine Operation Hours)

- A Candidate Preconstruction Relative Risk Metric:

  Species Relative Risk = (Flight Hours in Rotor Zone with Wind in Operating Range)/(Plant Swept Area x Hours with Wind in Operating Range)
A Collaborative Research Approach

In the past:
• Research was reactive to site-specific issues (i.e. Altamont Pass and Backbone Mountain)
• Typically did not engage all key stakeholders
• Underestimated the potential long term wildlife problems

Now the wind industry is taking a longer term view:
• Shifting to long term proactive collaborative research, such as forming and funding the American Wind and Wildlife Institute to sponsor research on wind-wildlife
• Entering collaborative public-private partnerships
• Leveraging resources
Current Collaborative Environmental Research Activities with NREL Involvement

1. Participation in NWCC Wildlife Work Group and its subgroups:
   - Core Group Member
   - Mitigation Toolbox workgroup
   - Grassland and Shrub Steppe Species Collaborative, co-funding and serving as the technical monitor for Kansas State U. Prairie Chicken Study
   - Nocturnal Methods & Metrics Update
   - Research Gaps Analysis
   - Risk Assessment Analysis
   - Habitat Work Group

2. The Greater Prairie Chicken Study:
   - Evaluating potential impacts of wind power development on demography and population genetics of the greater prairie-chicken
   - A 4 yr Before-After-Control-Impact (BACI) study.
   - A Multi-stakeholder funded study by KSU
Current NREL Environmental Research Activities (cont.)

3. Bats and Wind Energy Cooperative Studies:
   • Validating and refining the accuracy of methods and metrics to predict post-construction impacts based on pre-construction acoustic assessments, and
   • development and field testing of an acoustic deterrent to discourage bats from entering wind facilities (reduction of impacts).
   • PI: Bat Conservation International

Photo by Jason Horn, Boston University
Could the Tip Vortex Attract Bats and the Low Pressure Core Cause Trama?

- Near blade tips the flow is highly three-dimensional with flow from the higher pressure side of the blade to the suction side of the blade.
The Tip Vortex and the Wake

Biot Savart Law

\[ V_\theta = \frac{\Gamma}{2\pi r} \]

\( V_\theta \) = tangential velocity
\( \Gamma \) = vortex strength
\( r \) = distance from vortex center

Low Pressure Core
Video of Bat Investigating a Moving Blade
Fatalities decrease with increasing wind speed.

Source: Ed Arnett BWEC Presentation at “Toward Wildlife–Friendly Windpower Meeting” 27-29 June 2006
Current NREL Environmental Research Activities (cont.)

4. U.S. Fish and Wildlife Service Wind Turbine Guidelines Advisory Committee:
   • **Objective:** “The committee will provide advice and recommendations to the Secretary of the Interior on developing effective measures to avoid or minimize impacts to wildlife and their habitat related to land-based wind energy facilities”
   • 2003: USFWS published *Interim Guidelines to Avoid and Minimize Wildlife Impacts from Wind Turbines*
   • 2005: Began effort to update guidelines
   • 2007: FACA formed; 2yr timeframe
   • NREL provides advice, and technical support for to the DOE Committee Member and serves as an Alternate Member and subcommittee working group member.

5. NWCC Birds and Bats Fact Sheet Development
   • **Purpose:** A summary of research results on wind interactions with birds and bats and examines the remaining research questions
   • Used by permitting organizations and regulators to understand the issues and status of current research issues
   • Second edition published November 2004
   • NREL serving as the technical monitor
   • **Should be published in late 2008**
6. NWCC Avian Guidance Document

- **Objective:** Provides Guidelines methods and tools for assessing the suitability of a proposed wind farm site with regard to avian concerns. Supported and reviewed by the NWCC Wildlife Workgroup and endorsed as a product of the NWCC.
- **Originally published December 1999**
- **NREL is serving as the technical monitor**
- **Should be updated by early 2009**
Current NREL Environmental Research Activities (cont.)

7. Determining avian and bat migratory flyways using achieved NEXRAD data
   • Preliminary results below: illustrate the use of artificial intelligence to detect birds in a single NEXRAD sweep
   • Montana State University Project with support form USGS researchers
   • NREL is serving as the technical monitor
   • Exploratory research project to be evaluated in one year

Source: USGS/MSU
Concluding Remark

World-wide electrical energy consumption is projected to grow by about 75% over the next 20 years. All energy technologies have some environmental impacts. Wind Technology is developing rapidly, and a modest investment in environmental R&D now could make the impacts negligible. This would give us a carbon free electricity generating choice that could meet at least 20% of the world’s energy needs.
NREL Avian Studies Available at:
http://www.nrel.gov/wind/avian_lit.html

- A Pilot Golden Eagle Population Study in the Altamont Pass Wind Resource Area, California
- Ponnequin Wind Energy Project – Reference Site Avian Study
- Predicting the Response of Bird Populations to Wind Energy-Related Deaths
- The Response of Red-Tailed Hawks and Golden Eagles to Topographical Features, Weather, and Abundance of a Dominant Prey Species at the Altamont Pass Wind Resource Area, California, April 1999-December 2000
- Searcher Bias and Scavenging Rates in Bird/Wind Energy Studies
- Status of Avian Research at the National Renewable Energy Laboratory (2001)
Offshore Wind
European Environmental References