Solar Energy III

Wind Power.

Original slides provided by Dr. Daniel Holland
Would you like to see and increase in wind power production?

1. Yes
2. No
Which statement best captures your opinion of the appearance of wind farms?

1. They are a blight on the landscape
2. I don’t really notice them
3. They are really cool looking.
4. By day they are fine, but I hate the lights at night
Approximately 2% of the solar power that reaches the earth’s surface is converted into wind.

This is \(\sim\) 30 times our present energy usage.
History

- Large sailing ships could generate 10,000 hp.
- Used extensively in Europe in the 19th century
- Used for pumping water in the US.
- Most new development for generating electricity
• Early wind generators focused on single large generators
• Grandpa’s Knob (Vermont) could generate up to 1.2 MW of power in the 1940’s.
• 200 ft diameter blades
- Early NASA wind generator (1975) could generate 100kW of power in 18mph wind. 125 ft long blade diameter.
- Boeing Mod 5B wind turbine on Oahu could generate 3.2 MW of electricity.
- 320 ft diameter on a 192 ft tall tower
Many Different Styles

Savonius Rotor

American multivane

2-Blade Wind Turbine

Darius Rotor

3-Blade Wind Turbine
Choice of style depends on application

- Multi-blade has good starting torque. Good for applications like pumps.
- 3-blade has low starting torque but is more efficient at high rotation rates. Used for generating electricity
Wind Farms

- Rather than using single large generator, we usually use several smaller generators to make wind farms
Practicalities

- Wind speed tends to increase with increasing height. Optimal height is ~300 m.
- Most commercial wind mill towers are ~50m high. Get ~80% of wind potential at this height.
Power in the wind
(Betz Limit)

\[ P = 2.83 \times 10^{-4} \, D^2 \, v^3 \, kW \]

D is the diameter in meters
v is the wind speed in meters per second

\[ D^2 \text{ because area of windmill increase with } D^2 \]
\[ v^3 \text{ because KE in wind is proportional to } v^2 \text{ and an additional } v \text{ because of rate at which energy is brought to windmill} \]
Maximum theoretical efficiency is 59% of the Betz limit.
Modern windmills are around 50-70% of maximum theoretical efficiency.
Note $v^3$ indicates that a wind of 15 miles per hour generates $3^3=27$ times as much power as a wind of 5 miles per hour.

You want to place windmills in a location that get consistently high wind power.
Average Wind Speed at 80 m
US Power Grid
A wind generator has a rated power output at a particular wind speed, e.g. 10 kW at 20 mph.

If wind speed drops so does power, e.g. if wind drops to 15 mph, \( P = (15/20)^3 \times 10\text{kW} = 4.2\text{kW} \).

If wind speed increases too much, usually feather the blades so they don’t get damaged.
Home Wind Power?

- HORNET - LOW WIND SPEED turbines with Split-Core PMA

- Hornet's are designed for class 3 to 7 or AVERAGE wind zones.

- Super low cost turbines!
- 59" diameter blade
- 800 Watts @ 33 MPH
- 1200 Watts MAX. @ 65 MPH (under load)
- ~$500.00
- Note at 11mph P=800/27=30W

![Hornet #HT12 Graph](image)
2010 Year End Wind Power Capacity (MW)

Total: 40,180 MW
(As of 12/31/2010)

Wind Power Capacity
Megawatts (MW)
- U.S. Department of Energy
  National Renewable Energy Laboratory

1,000 - 10,100
100 - 1,000
20 - 100
1 - 20

Data from the American Wind Energy Association Fourth Quarter 2010 Market report.
Seven states exceeded 2000 MW generating capacity in 2010. How many states exceed that benchmark capacity in 2018?

https://windexchange.energy.gov/maps-data/321

Seven states exceeded 2000 MW generating capacity in 2010. How many states exceed that benchmark capacity in 2018?
There has been tremendous growth since 2000.
<table>
<thead>
<tr>
<th>#</th>
<th>Nation</th>
<th>2005</th>
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Wind Power Capacity 2005 to 2015

by Curious Cat Economics Blog
**TOP 10 CUMULATIVE CAPACITY DEC 2017**

<table>
<thead>
<tr>
<th>Country</th>
<th>MW</th>
<th>% Share</th>
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<tr>
<td>PR China</td>
<td>188,392</td>
<td>35</td>
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<tr>
<td>USA</td>
<td>89,077</td>
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<td>Germany</td>
<td>56,132</td>
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<td>India</td>
<td>32,848</td>
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<tr>
<td>Spain</td>
<td>23,170</td>
<td>4</td>
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<tr>
<td>United Kingdom</td>
<td>18,872</td>
<td>4</td>
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<tr>
<td>France</td>
<td>13,759</td>
<td>3</td>
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<tr>
<td>Brazil</td>
<td>12,763</td>
<td>2</td>
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<tr>
<td>Canada</td>
<td>12,239</td>
<td>2</td>
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<tr>
<td>Italy</td>
<td>9,479</td>
<td>2</td>
</tr>
<tr>
<td>Rest of the world</td>
<td>82,391</td>
<td>15</td>
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<tr>
<td><strong>Total TO P10</strong></td>
<td>456,732</td>
<td>85</td>
</tr>
<tr>
<td><strong>World Total</strong></td>
<td>539,123</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: GWEC
Installed Wind Capacity

Concerns About Wind Power

- Wind is intermittent so you don’t want to rely on it too much. ~15-20% is considered safe.
- Aesthetics: Actually more opposed to by people who don’t live near them.
- Noise: New designs are very quiet
- Danger to birds and bats. Needs more study.
- Potential electromagnetic disturbance for TV/ Radio
Potential Solutions

- Use large scale batteries to even out supply.
- Research on Vanadium Redox batteries.
- Mid scale test facility is being constructed.
## Pro-Wind Site Estimates

<table>
<thead>
<tr>
<th>Man-made structure/technology</th>
<th>Associated bird deaths per year in US (Source)</th>
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</thead>
<tbody>
<tr>
<td>Feral and domestic cats</td>
<td>Hundreds of millions (AWEA)</td>
</tr>
<tr>
<td>Power lines</td>
<td>130-174 million (AWEA)</td>
</tr>
<tr>
<td>Windows (residential and commercial)</td>
<td>100 million-1 billion (TreeHugger)</td>
</tr>
<tr>
<td>Pesticides</td>
<td>70 million (AWEA)</td>
</tr>
<tr>
<td>Automobiles</td>
<td>60-80 million (AWEA)</td>
</tr>
<tr>
<td>Light communication towers</td>
<td>40-50 million (AWEA)</td>
</tr>
<tr>
<td>Wind turbines</td>
<td>10-40 thousand (ABC)</td>
</tr>
</tbody>
</table>
More on birds and wind energy

http://www.tntrv.com/zero-pollution-and-the-wind-is-free/

This estimate of causes of bird death is from 2002. How much should bird deaths have increased based on the expansion of wind turbines? This data does not distinguish between bird species.
Help for the birds

- Site their farms mostly on land that's already disturbed (I.e. farmland.) Also, keeping them out of migratory flight paths will reduce the threat.
- • Make the transmission lines that connect to wind farms more bird-friendly
- • Monitor the impact of wind farms on birds.
- • Compensate the families of affected birds by buying land to be set aside as bird habitat.
- Paint wind turbines anything but white
- For more information see: https://www1.eere.energy.gov/wind/pdfs/birds_and_bats_fact_sheet.pdf
- Bird hit by turbine
Advantages

- Renewable
- No CO$_2$ emissions
- Competitive price per kW-h
- Less than 1% of the land would be used for foundations and access roads, the other 99% could still be used for farming.