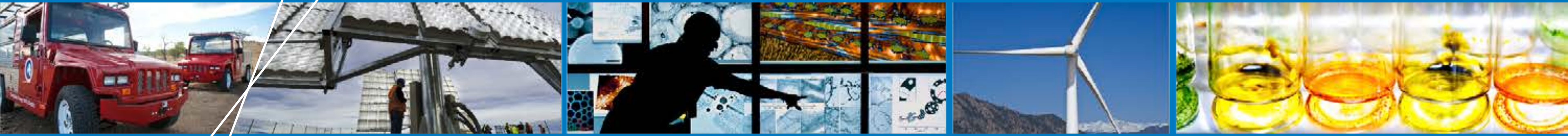
Cost of Wind Energy in the United States: Trends from 2007 to 2012



M. Maureen Hand, Ph.D.

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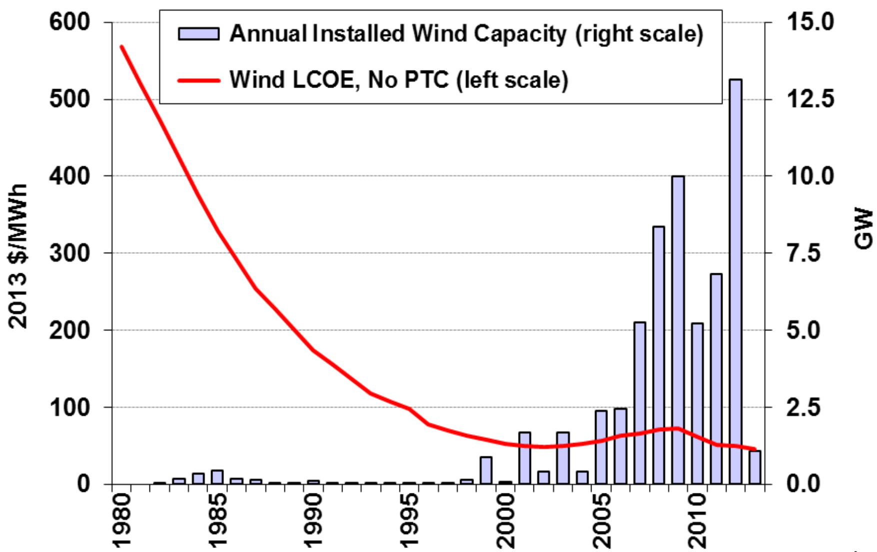
Outline

- **Cost of energy trends in the United States**
- **U.S. technology trends from 2007 to 2012**
  - Project, turbine, rotor, hub height, specific power, and International Electrotechnical Commission (IEC) class
  - Annual average wind speed and energy production
- **System analysis considerations**
  - The impact of physical characteristics on cost of energy
  - European technology trends from 2007 to 2012
  - Taller towers for the southeastern United States.

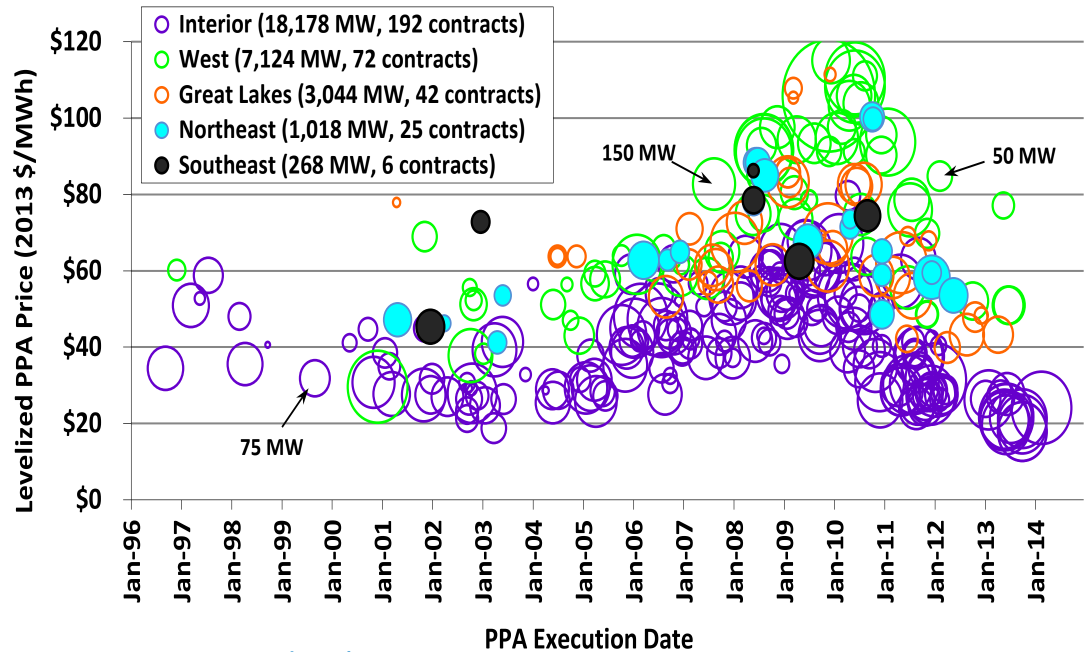
U.S. Cost of Wind Energy Trending Downward



Source: Bolinger and Wiser 2014

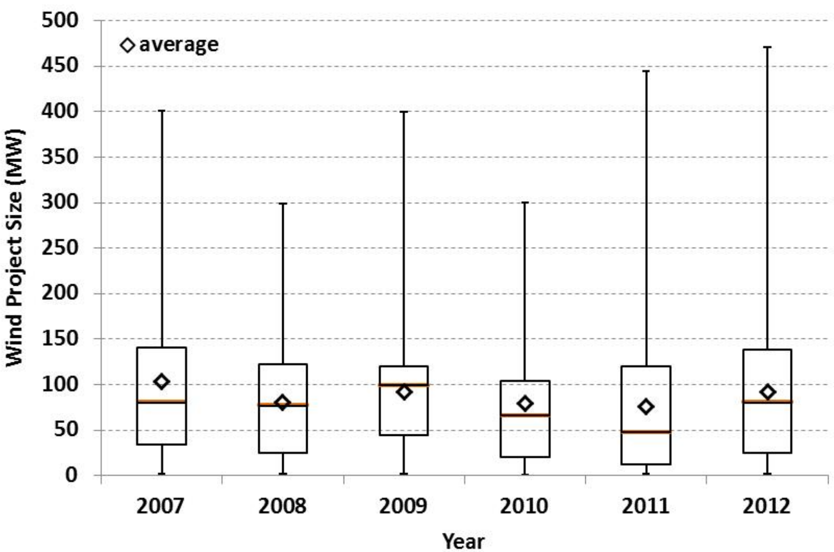
After a brief period of increasing costs coupled with increasing annual deployment, the downward cost of energy trajectory returns and is expected to continue in 2014.

Power purchase agreements (PPAs) reflect long-term prices for electricity after accounting for incentives, such as the production tax credit, whereas cost of energy represents an expected investment to bring a plant to commercial operation.

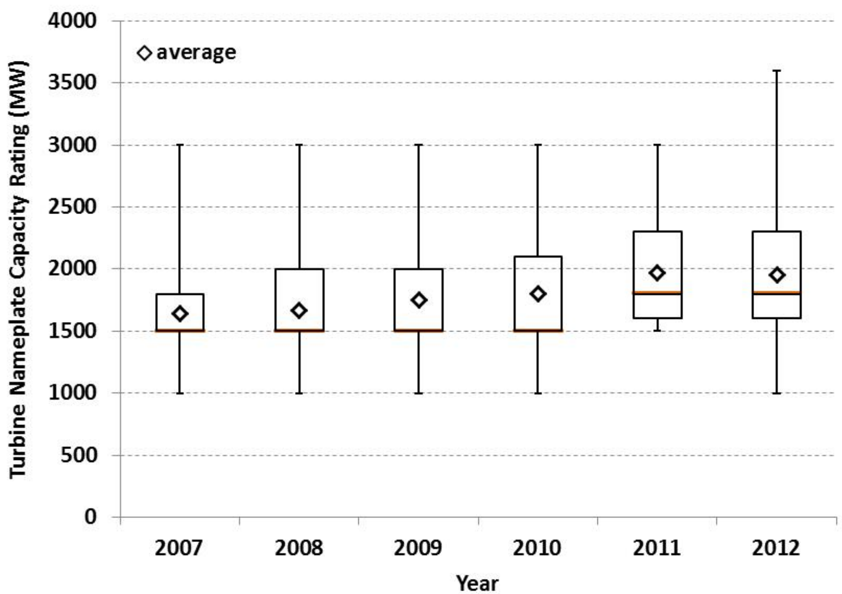


Source: Wiser and Bolinger 2014

Project and Turbine Size

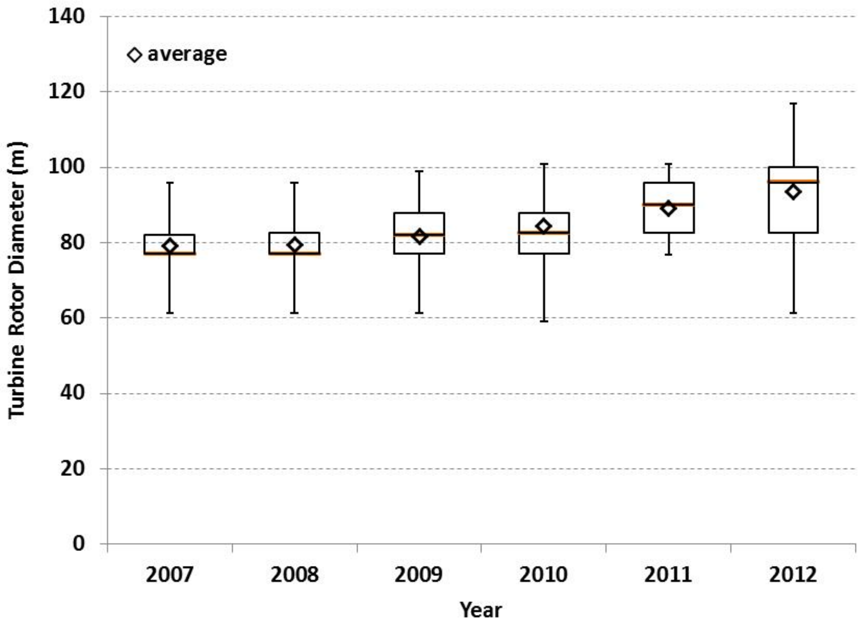


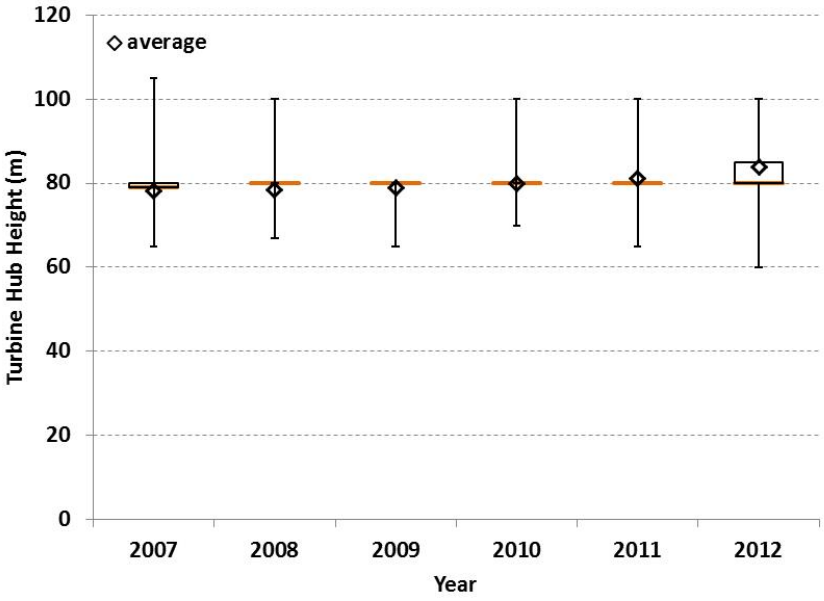
Source: LBNL Wind Project Database



- U.S. project size remained relatively similar from 2007 to 2012 with a wide range.
- Turbine size increased from 2007 to 2012 on average and the range increased as well.

Rotor Diameter and Hub Height

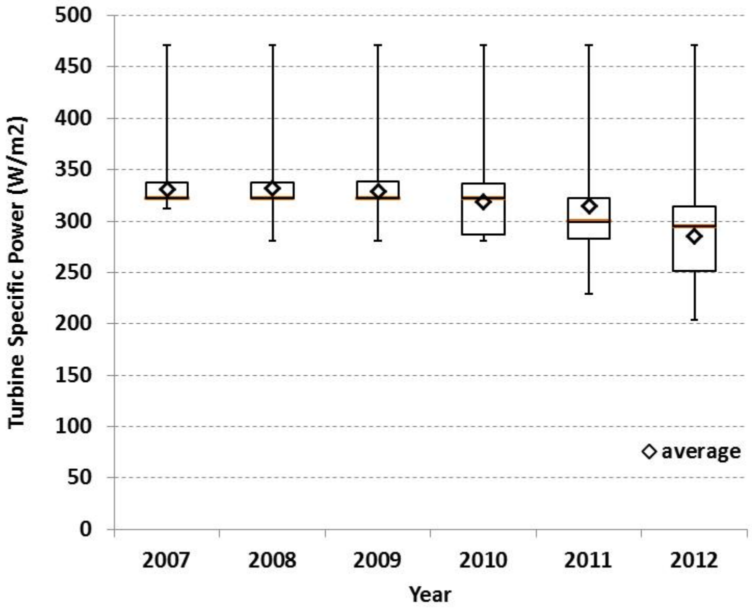


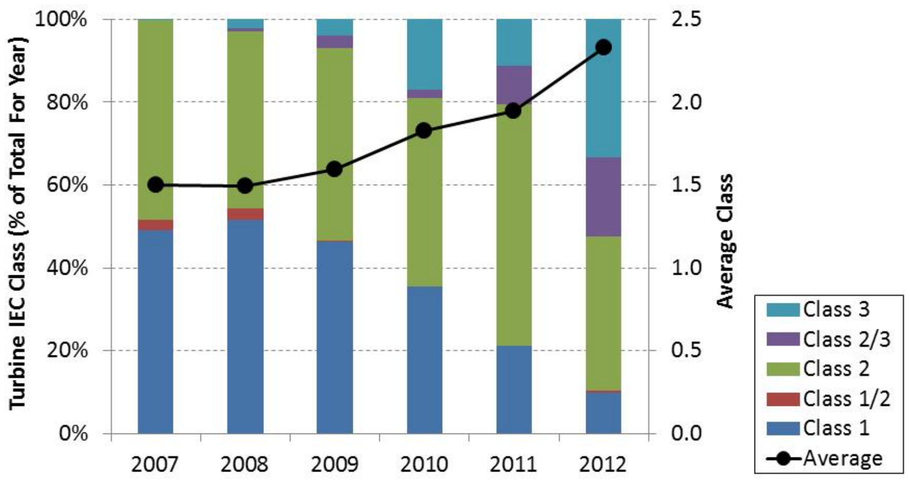


Source: LBNL Wind Project Database

- Average rotor diameter increased 25% between 2007 and 2012 and the range of options was greater in 2012.
- The majority of hub heights were at 80 meters (m) over the entire period, with some upward trend in 2012.

Specific Power and IEC Class

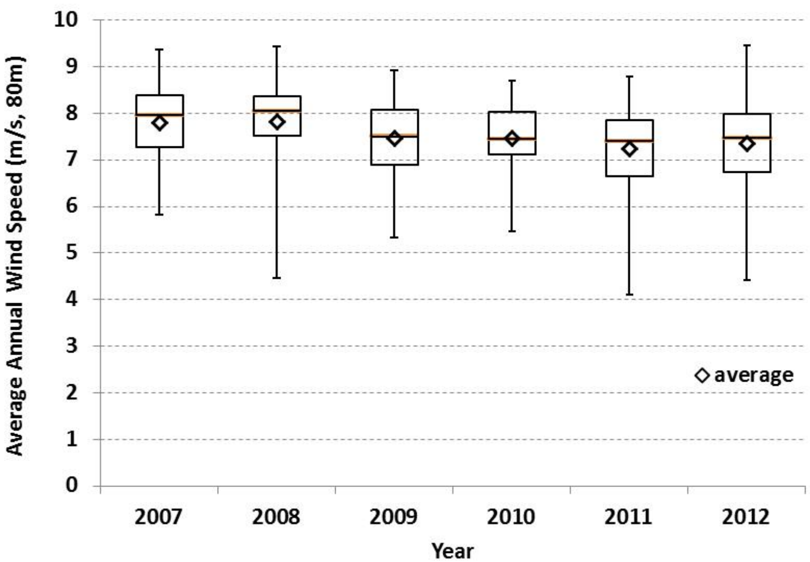


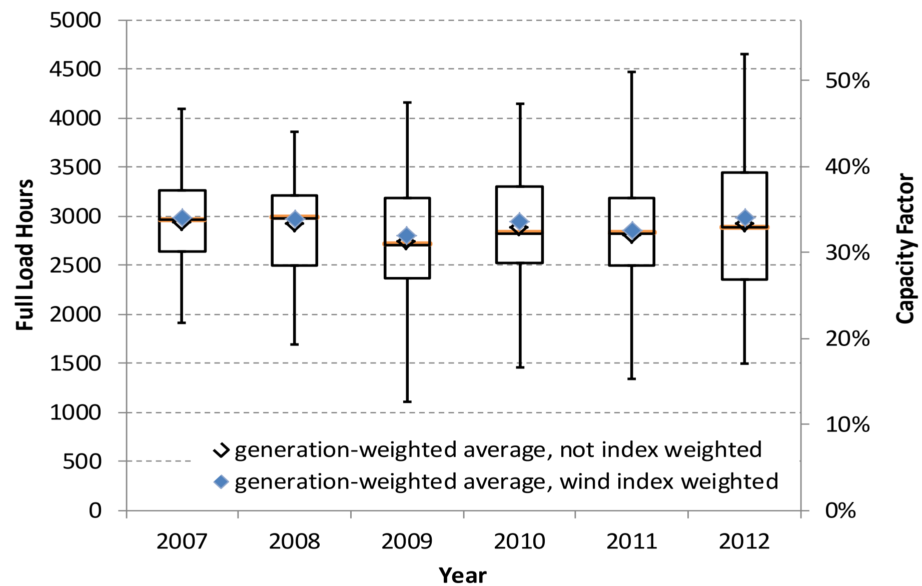


Source: LBNL Wind Project Database

- Since 2007, specific power has decreased such that the 25th–75th percentile in 2012 was lower than the 25th percentile in 2008. The range has grown because of a variety of rotor options and an increased average machine rating. In 2013, the average specific power was 255 watts (W)/m^2.
- Since 2007, there has been a trend toward using Class 2–3 turbines; in 2013, almost all turbines were Class 2/3–3.
- In general Class 3 turbines are designed for lower wind speed sites and have lower specific power.

Average Annual Wind Speed and Energy Production





Source: LBNL Wind Project Database

- Average annual wind speed for projects installed in 2012 was lower than projects installed in 2007. Full load hours in 2012 were slightly higher than 2007, but generally similar.
- Energy gains anticipated from the decrease in specific power are largely offset by the decrease in average wind speed.
- A few projects built in 2013/2014 used low specific power rotors in higher wind speed sites with expectations of capacity factors near 50%.

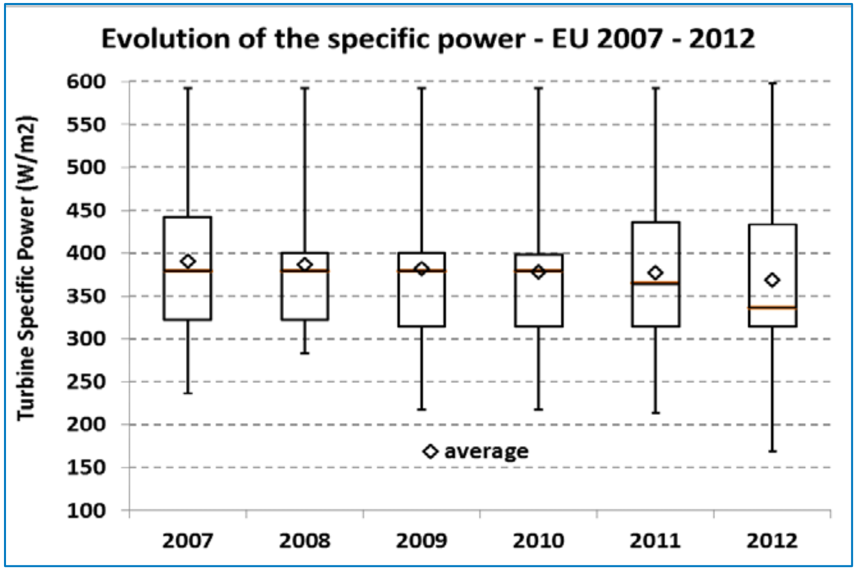
Cost of Energy is Impacted by Physical Characteristics

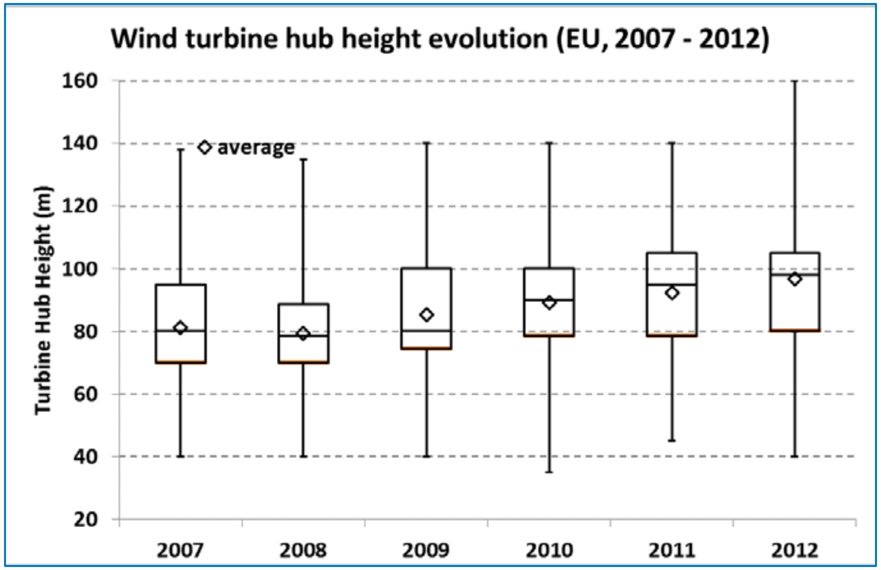
Parameters	Reference Project	Taller Tower	Larger Rotor	Taller Tower and Larger Rotor	Higher Wind Speed	Combination
Nameplate (megawatts [MW])	1.9	1.9	1.9	1.9	1.9	1.9
Rotor diameter (m)	96.9	96.9	110	110	96.9	110
Hub height (HH) (m)	82.7	100	82.7	100	82.7	100
Avg. speed at 50 m (m/s) (Avg. speed at HH)	7.25 (7.79)	7.25 (8.0)	7.25 (7.79)	7.25 (8.0)	8.0 (8.6)	8.0 (8.8)
Annual energy production (AEP) (MWh/MW/yr)	3,410	3,536	3,796	3,918	3,866	4,345
Capacity factor	38.5%	40.4%	43.3%	44.7%	44.1%	49.6%
Levelized cost of energy (LCOE)* ($/MWh)	**66**	**64**	**60**	**58**	**59**	**52**
*CapEx = $1728/kW; OpEx = $50/kW; Fixed charge rate (FCR; real, after tax) = 10.2%; LCOE = ((FCR*CapEx) + OpEx)/AEP						

Source: NREL Analysis Using Cost and Scaling Model from Fingersh et al. 2006

- Adjusting physical characteristics that affect annual energy production (AEP) in isolation of impact on capital and operating costs illustrate the relative impact on the levelized cost of energy (LCOE).
- Full system analysis is needed to represent the cost and performance trade-off that is required to precisely determine cost-of-energy impacts.

Reduced Cost of Energy Observed in Europe, But Technology Trends Differ from the United States

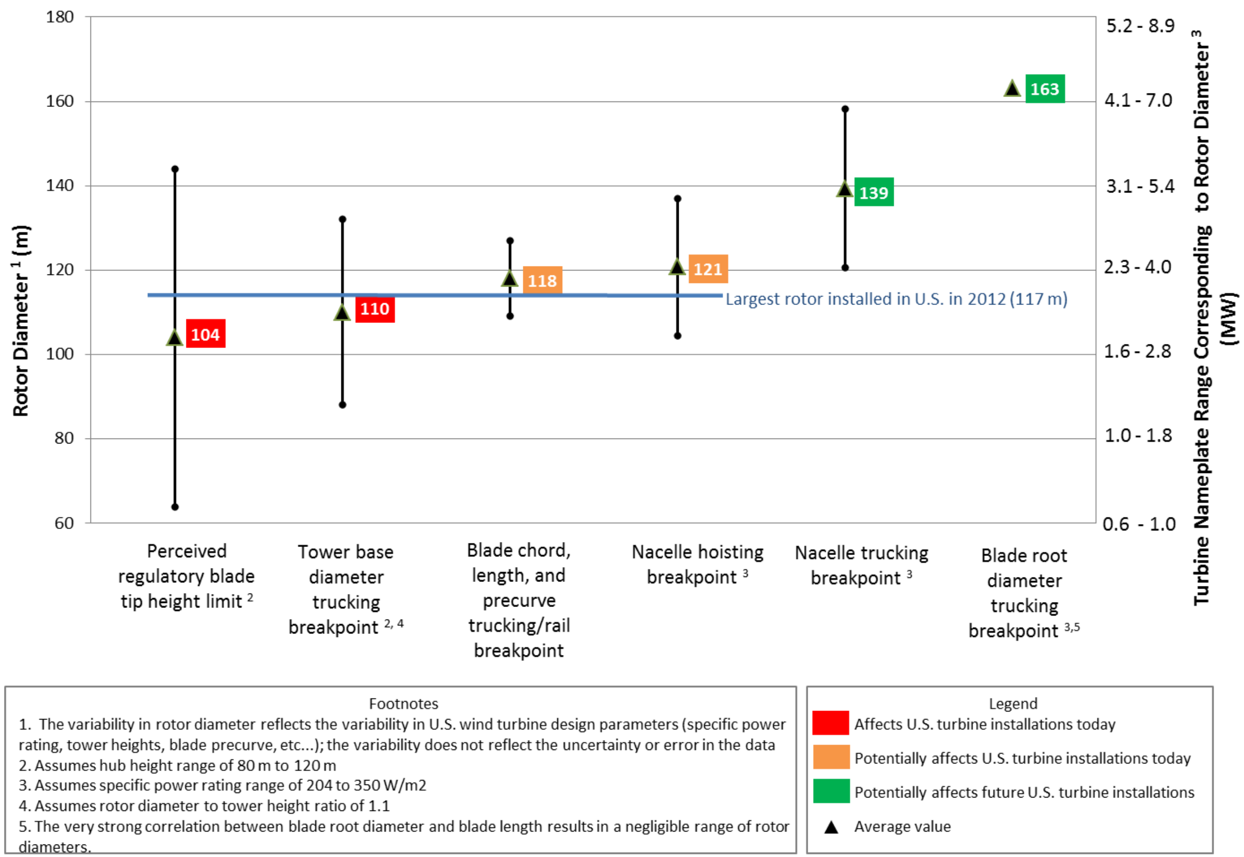




Source: European Commission-Joint Research Centre Wind Project Database

- Specific power was largely constant from 2007 to 2012 while tower height increased. In the United States, specific power declined while tower height remained constant.
- System analysis is required to investigate the motivations behind these different trends. Questions for this analysis include:
  - To what extent do land-use constraints incentivize one pathway over another?
  - How are capital investments affected by increasing turbine rotor options versus tower options?
  - Will operation and maintenance costs be impacted differently by taller towers or siting low specific power turbines in a variety of wind resource conditions?

Continued Turbine Scaling in the United States Limited by Transportation and Logistics Restrictions

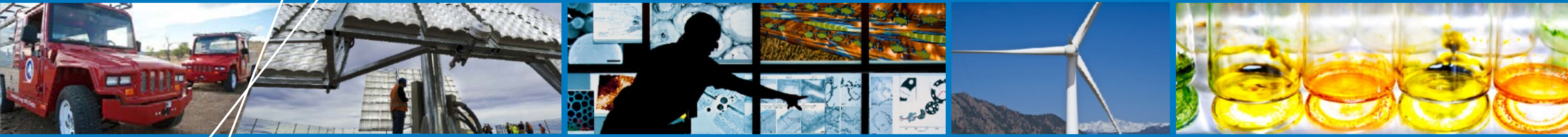


Source: Cotrell et al. 2014.

- Tower diameter, tip height, blade length and chord width, and nacelle weight are approaching limits that strain transport, installation, and regulatory systems and prevent continued turbine scaling.
- Addressing these transportation and logistics challenges is expected to enable the deployment of larger wind turbines on taller towers, which could greatly enhance the deployment of wind energy into low- and moderate-wind-speed regions of the United States.
- System analysis is required to investigate these trade-offs both regionally and nationally.

Conclusions

- **Technology trends that increase energy capture such as lower specific power, taller towers, and higher wind speed sites all lead to lower cost of wind energy.**
- **Understanding the trade-offs between the cost and performance behind recent trends in the United States and Europe or in anticipation of future trends requires system analysis.**
- **System analysis is needed to explore implications on land-use constraints, capital investment, and operating costs, as well as energy capture.**



Thank you!

M. Maureen Hand, Ph.D.
maureen.hand@nrel.gov

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