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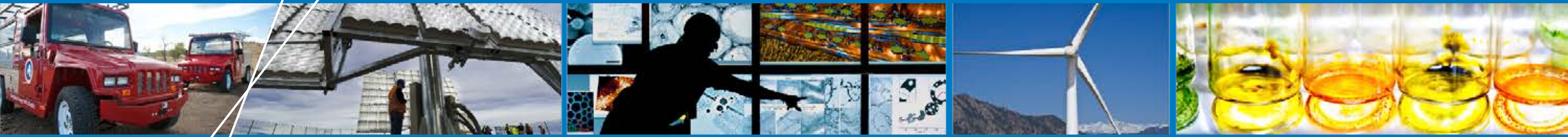
Cost of Wind Energy in the United States: Trends from 2007 to 2012



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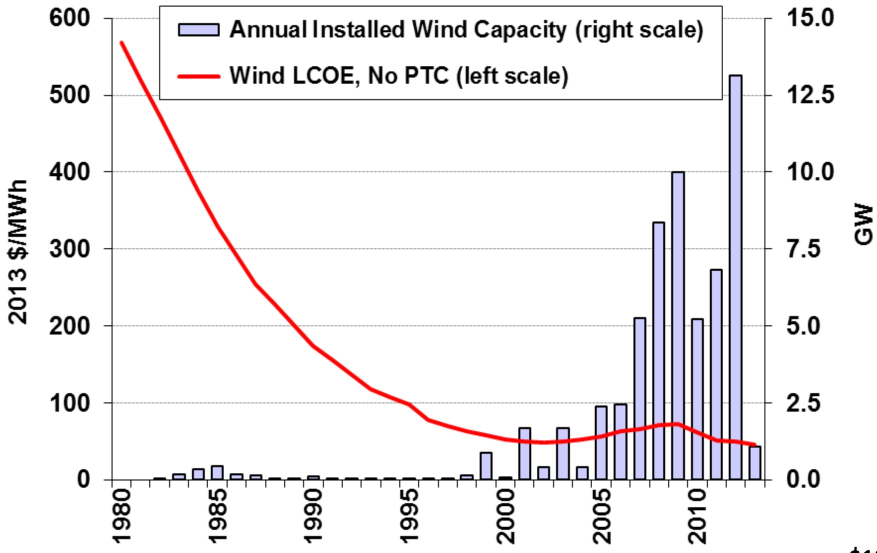
Outline

- **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.

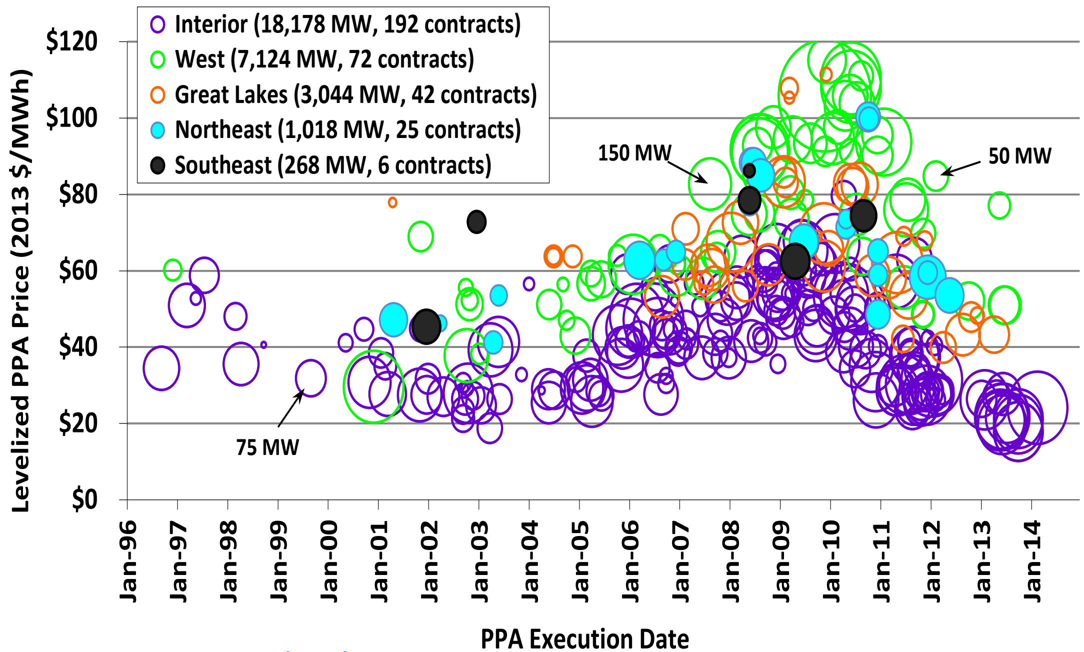
U.S. Cost of Wind Energy Trending Downward



Source: Bolinger and Wiser 2014

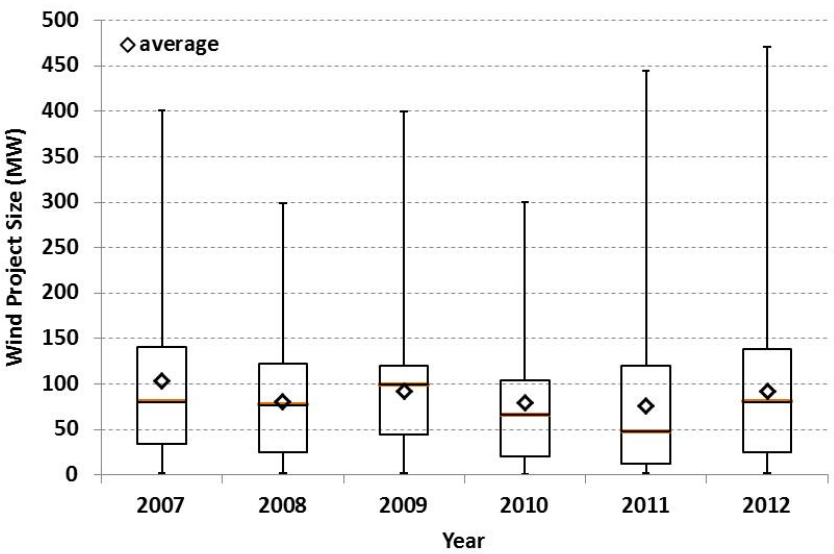
After a brief period of increasing costs coupled with increasing annual deployment, the downward cost of energy trajectory returns and is expected to continue in 2014.

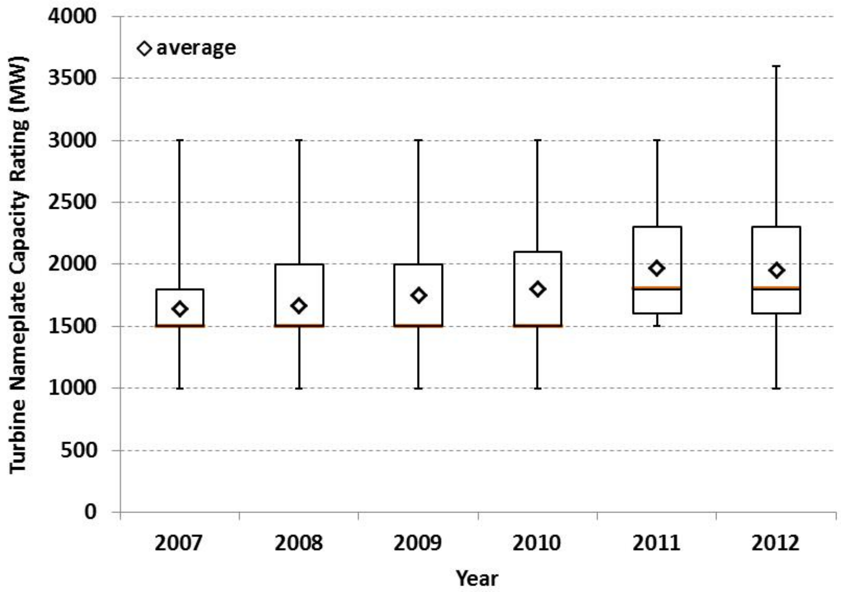
Power purchase agreements (PPAs) reflect long-term prices for electricity after accounting for incentives, such as the production tax credit, whereas cost of energy represents an expected investment to bring a plant to commercial operation.



Source: Wiser and Bolinger 2014

Project and Turbine Size



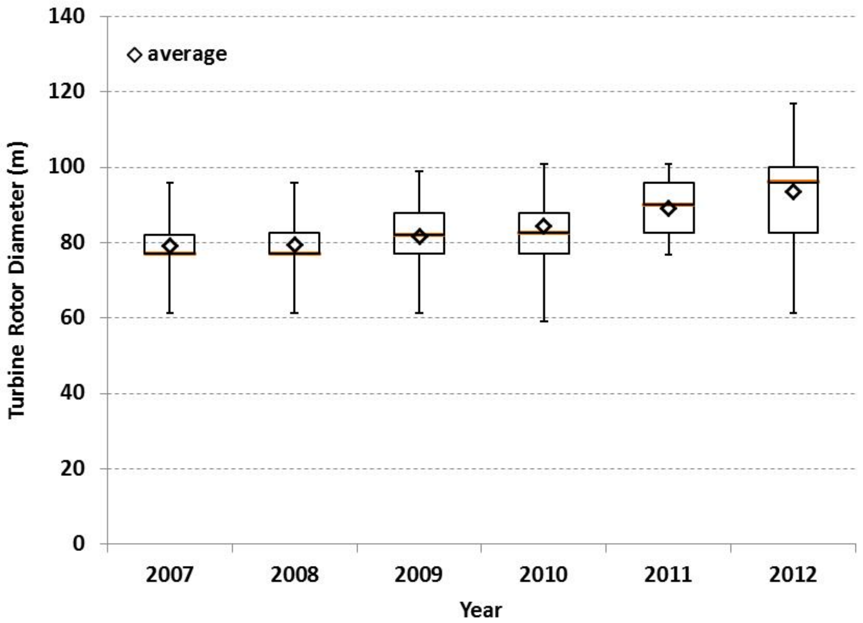


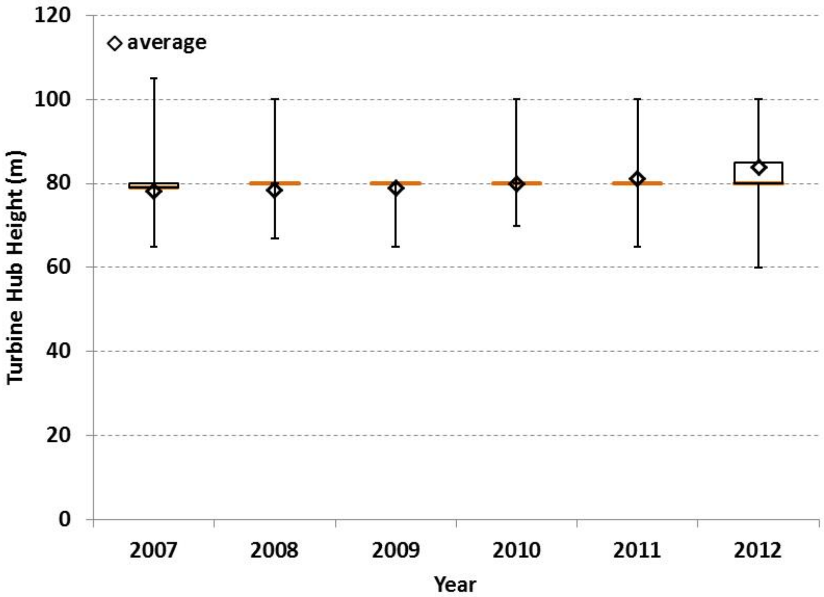
Source: LBNL Wind Project Database

- 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



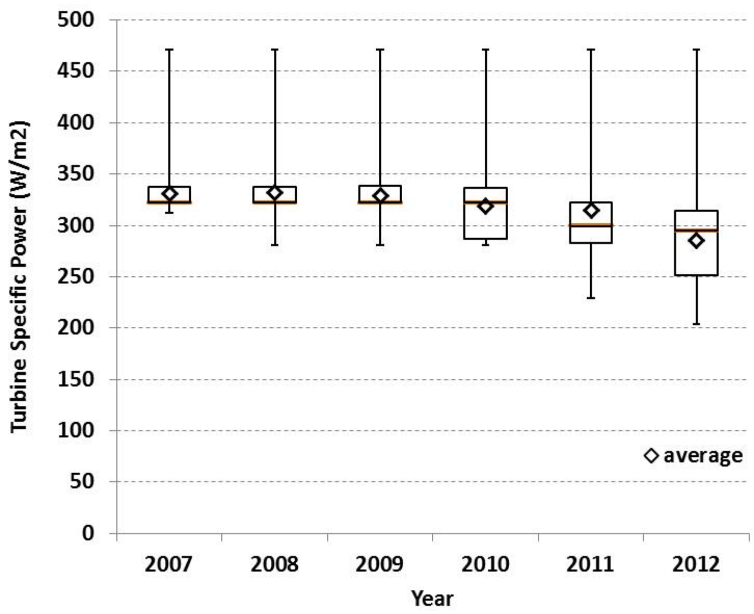


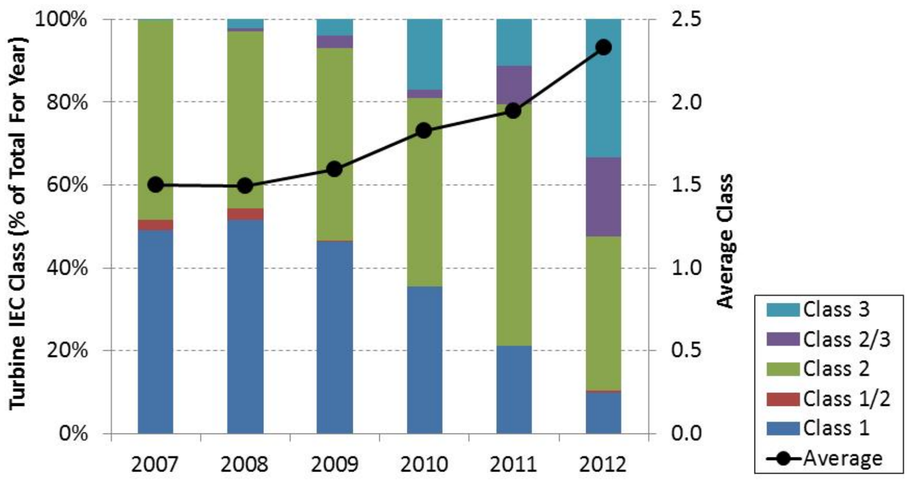
Source: LBNL Wind Project Database

- 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

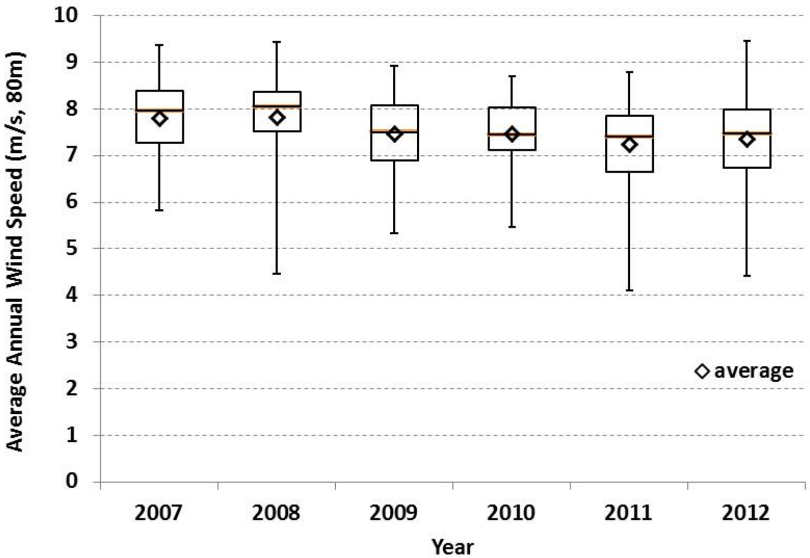


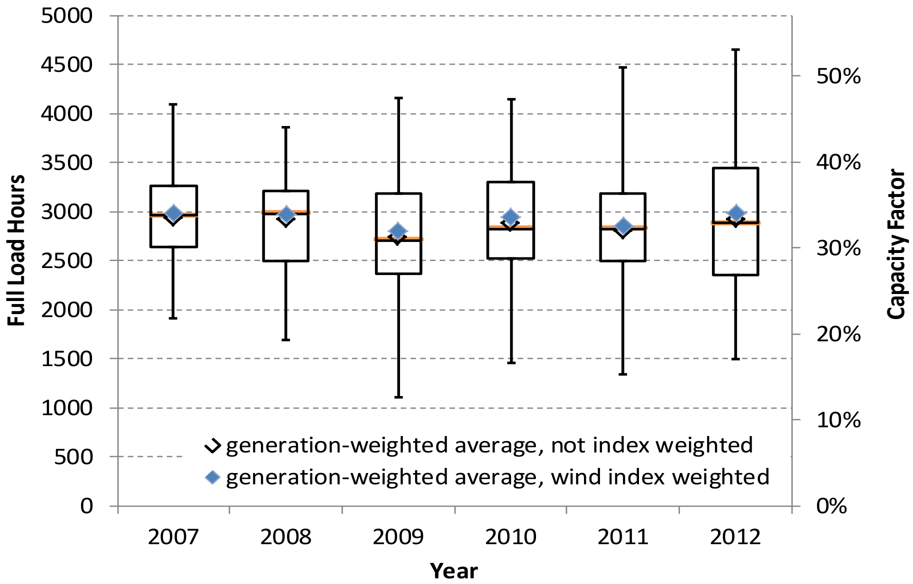


Source: LBNL Wind Project Database

- 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%.

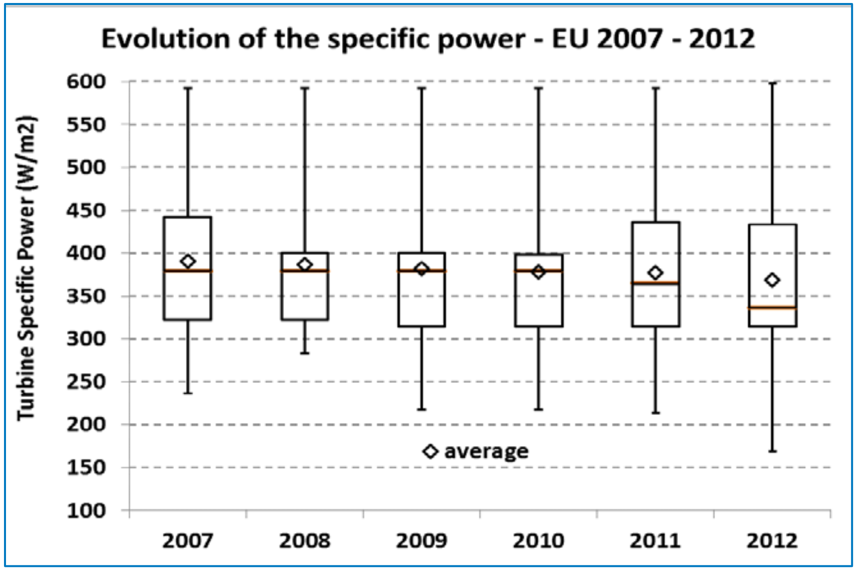
Cost of Energy is Impacted by Physical Characteristics

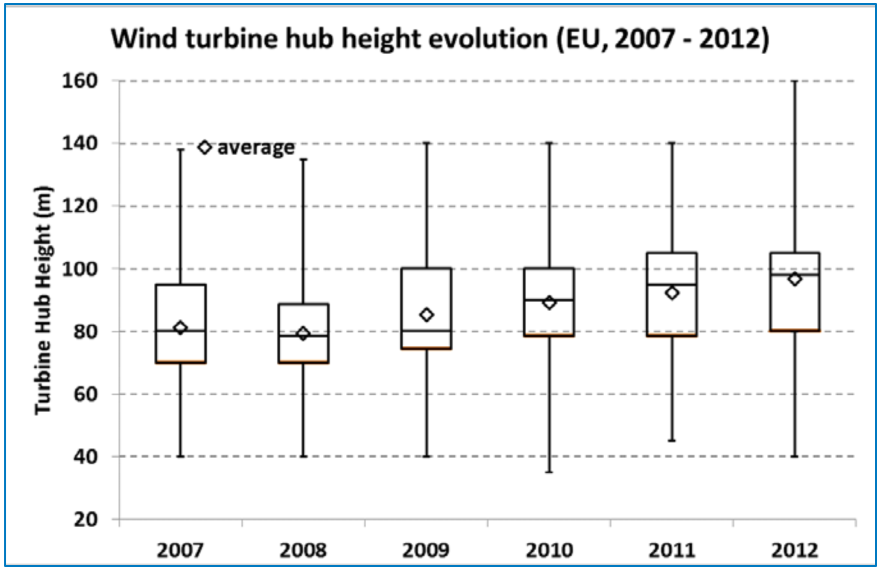
Parameters	Reference Project	Taller Tower	Larger Rotor	Taller Tower and Larger Rotor	Higher Wind Speed	Combination
Nameplate (megawatts [MW])	1.9	1.9	1.9	1.9	1.9	1.9
Rotor diameter (m)	96.9	96.9	110	110	96.9	110
Hub height (HH) (m)	82.7	100	82.7	100	82.7	100
Avg. speed at 50 m (m/s) (Avg. speed at HH)	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

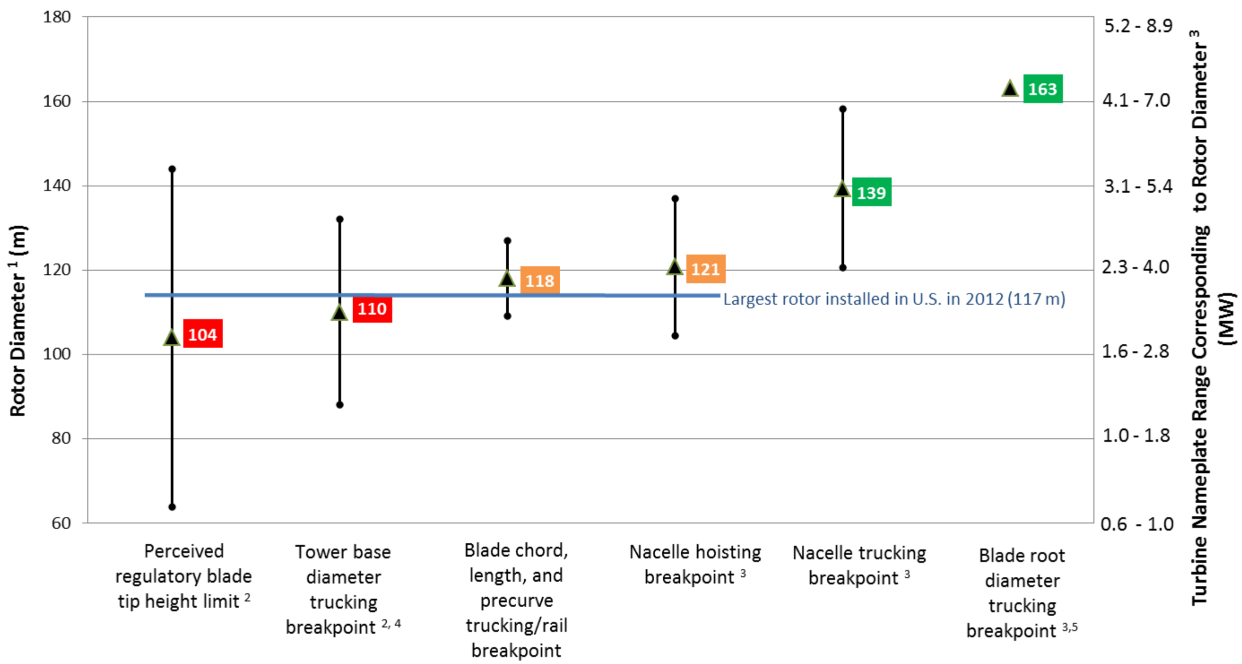




Source: European Commission-Joint Research Centre Wind Project Database

- 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



Footnotes

1. The variability in rotor diameter reflects the variability in U.S. wind turbine design parameters (specific power rating, tower heights, blade precurve, etc…); the variability does not reflect the uncertainty or error in the data
2. Assumes hub height range of 80 m to 120 m
3. Assumes specific power rating range of 204 to 350 W/m2
4. Assumes rotor diameter to tower height ratio of 1.1
5. The very strong correlation between blade root diameter and blade length results in a negligible range of rotor diameters.

Legend

- Affects U.S. turbine installations today
- Potentially affects U.S. turbine installations today
- Potentially affects future U.S. turbine installations
- ▲ Average value

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!

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