Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, the European Union, and the United States: 2007 – 2012

IEA Wind Task 26 Report Launch Event

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Mission of IEA Wind

"…to stimulate co-operation on wind energy research and development and to provide **high quality information and analysis to member governments** and commercial **sector leaders** by addressing **technology development** and deployment and its **benefits, markets, and policy instruments**." – IEA Wind Strategic Plan

- 85% of the world wind capacity is in IEA Wind member countries

Task 26
Cost of Wind Energy

Objective: Provide information on cost of wind energy to understand past, present, and anticipated future trends using consistent, transparent methodologies as well as understand how wind technology compares to other generation options in the broader electric sector.

- Comparing land-based wind cost of energy among participating countries
- Exploring cost of offshore wind energy and drivers
- Investigating value of wind energy
- Studying historic and potential future trends for cost of wind energy

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Report Content

- For each country represented and the European Union:
  - Statistical representation of wind projects installed from 2007 through 2012 to illustrate trends in technology, cost, and performance
  - Most comprehensive wind project databases assembled worldwide!
- For each country represented:
  - Estimated cost of energy for typical wind projects in 2008 and 2012
  - Comparison of cost of energy to expected revenue and policy incentives
- Update and enhancement to prior work: Multi-National Case Study of the Financial Cost of Wind Energy

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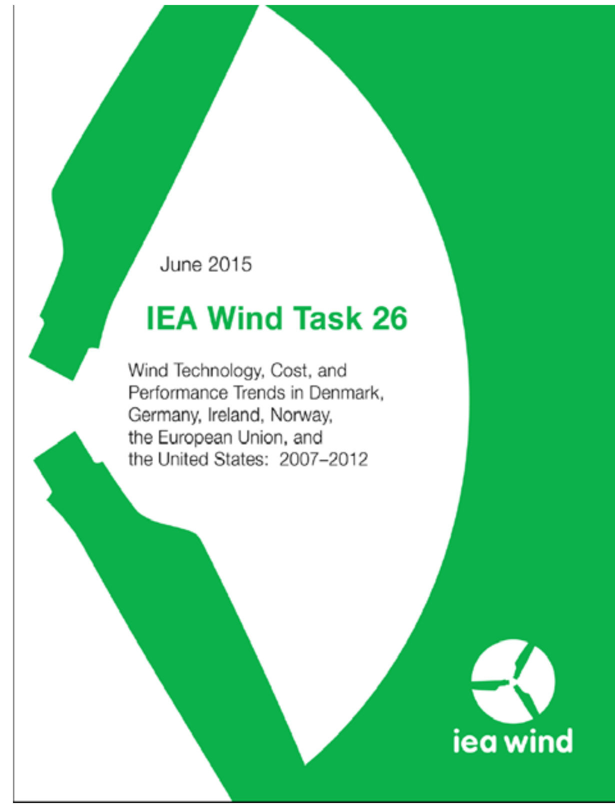
Technology, Cost and Performance Trends from 2007 to 2012

- Denmark - Aisma Vitina
- Germany - Silke Lüers
- Ireland – Maureen Hand (for Aidan Duffy)
- Norway - David Weir
- European Union – Roberto Lacal-Arántegui
- United States – Ryan Wiser



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Levelized Cost of Energy (LCOE)

Capital Investment

Financing

Operating Expense

$$LCOE = \frac{(FCR \times CAPEX)}{AEP_{net}} + \frac{OPEX}{AEP_{net}}$$

Annual Energy Production

Source: Short et al. 1995

- Four basic parameters
  - Capital Expenditure (CAPEX, Annualized Operating Expenses (OPEX), project finance parameters (e.g., Fixed Charge Rate (FCR)), and net Annual Energy Production (AEP)
- Metric is useful to explore
  - Long-term trends or projections
  - Relative differences in resource quality, geographic locations, or technology options

Cost of Energy Calculations

- Use of publicly available ECN model to estimate wind LCOE in five countries
- Originally designed to set Dutch feed-in tariff or feed-in tariff premium levels
- Model customized for this task; estimates *unsubsidized* country LCOE
- Represents the perspective of the project's investor/developer
- Model also used to estimate impact of typical revenue and policy incentives

Cash flow model for financial gap calculations
Wind: Netherlands 2008

	Symbol	INPUT PARAMETERS	Unit	Fixed or average value
Project features	U	Unit size	kW_e	15000
	H	Operational time / full load hours	h/yr	2200
	T_b	Economic life	yr	20
Costs	C_{tot}/U	Investment costs	€/kW	1325
		Decommisioning costs	€/kW	0
	c_f	Maintenance costs fixed	€/kW	31.39238321
	c_v	Maintenance costs variable	€/kWh	0.013363553
Market	p_e	Other revenues	€/kWh	0.080
		Other costs	€/kWh	0.0097
Policy support		Upfront tax-based investment subsidy		20%
		Upfront cash investment subsidy		0%
		Feed-in tariff	€/kWh	0.028
		Production-based tax credit	€/kWh	0.000
		Production-based tax deduction	€/kWh	0.000
Project financing features	R_d	Return on debt		5.0%
	R_e	Required return on equity		15.0%
	e	Equity share (excluding EIA benefit)		20%
	d	Debt share (including EIA benefit)		80%
		Corporate tax rate (Municipal/state)		0%
	□	Corporate tax rate (National/federal)		25.5%
Time horizons	T_r	Loan duration	yr	15
	T_d	Depreciation period	yr	15
	T_p	Economic life	yr	20
Output	FG	Financial gap	€/MWh	-3
	LC	Levelized electricity generation cost	€/MWh	94

Project Level Data

- Ideal data set consists of details for each individual project in each year
- Variety of sources used to assemble data sets including:
  - Government agencies which require regular reporting of data
  - Public filing of individual business financial reports
  - Newspaper or trade articles
- Large sample sizes are necessary to assess trends and to understand ranges (e.g., range of hub height in a given year)

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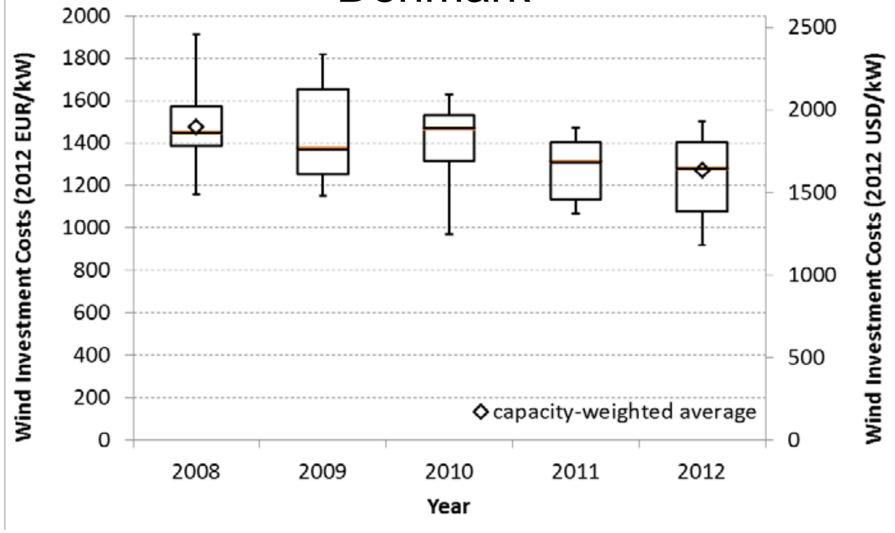
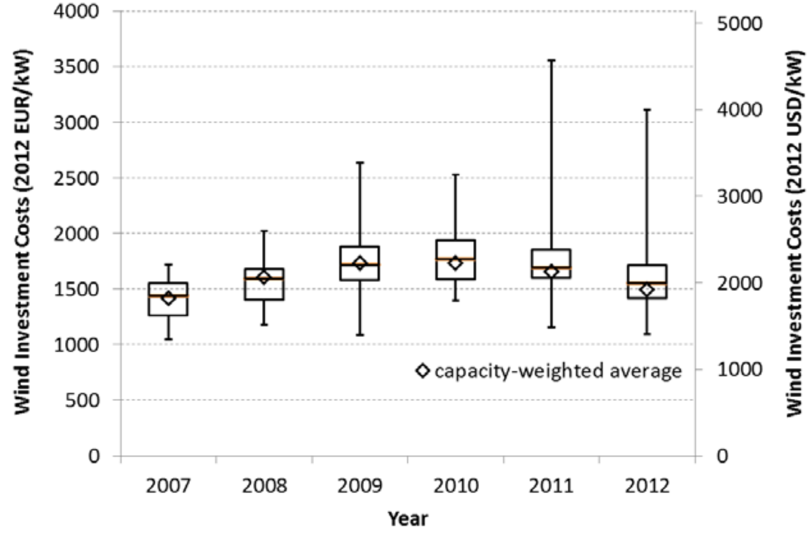
CAPEX Peak Followed by Decline

Denmark



United States



- Well-known trend of rising CAPEX in early 2000s has peaked and is declining in many countries
- Rising costs attributed to tight turbine supply, commodity prices, labor rates, larger turbines, and other influences

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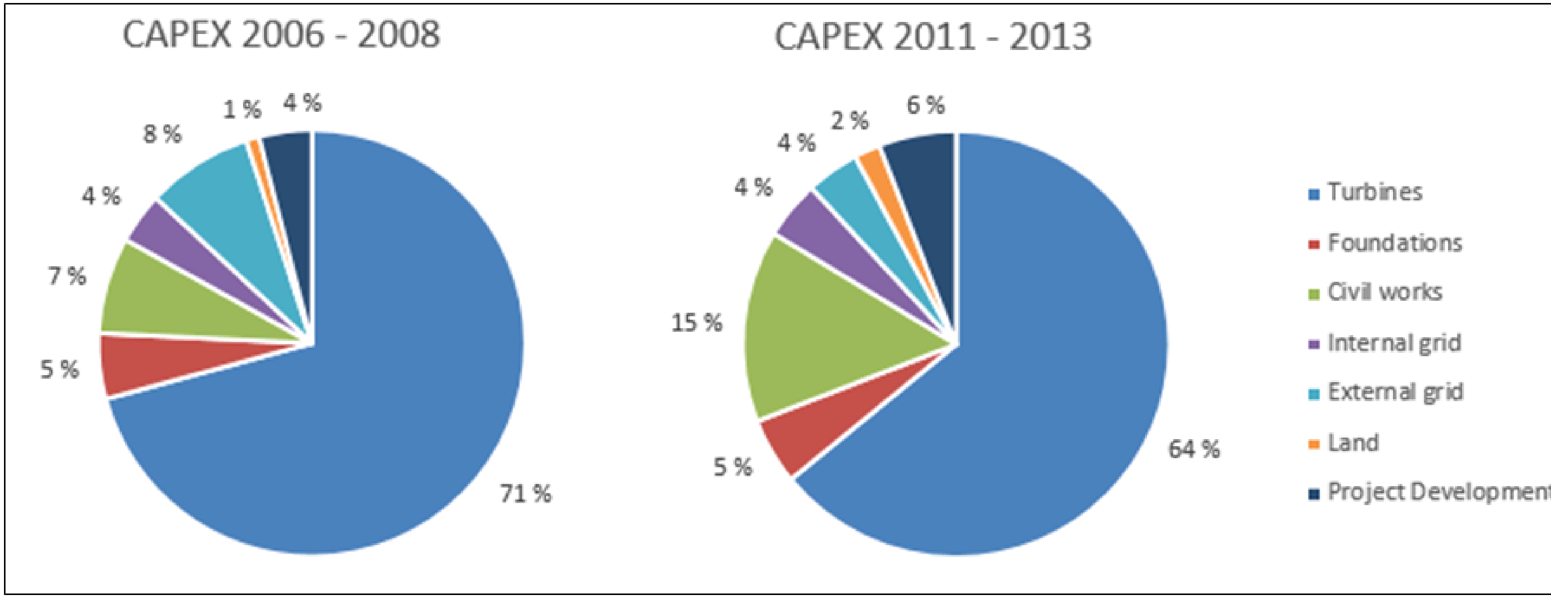
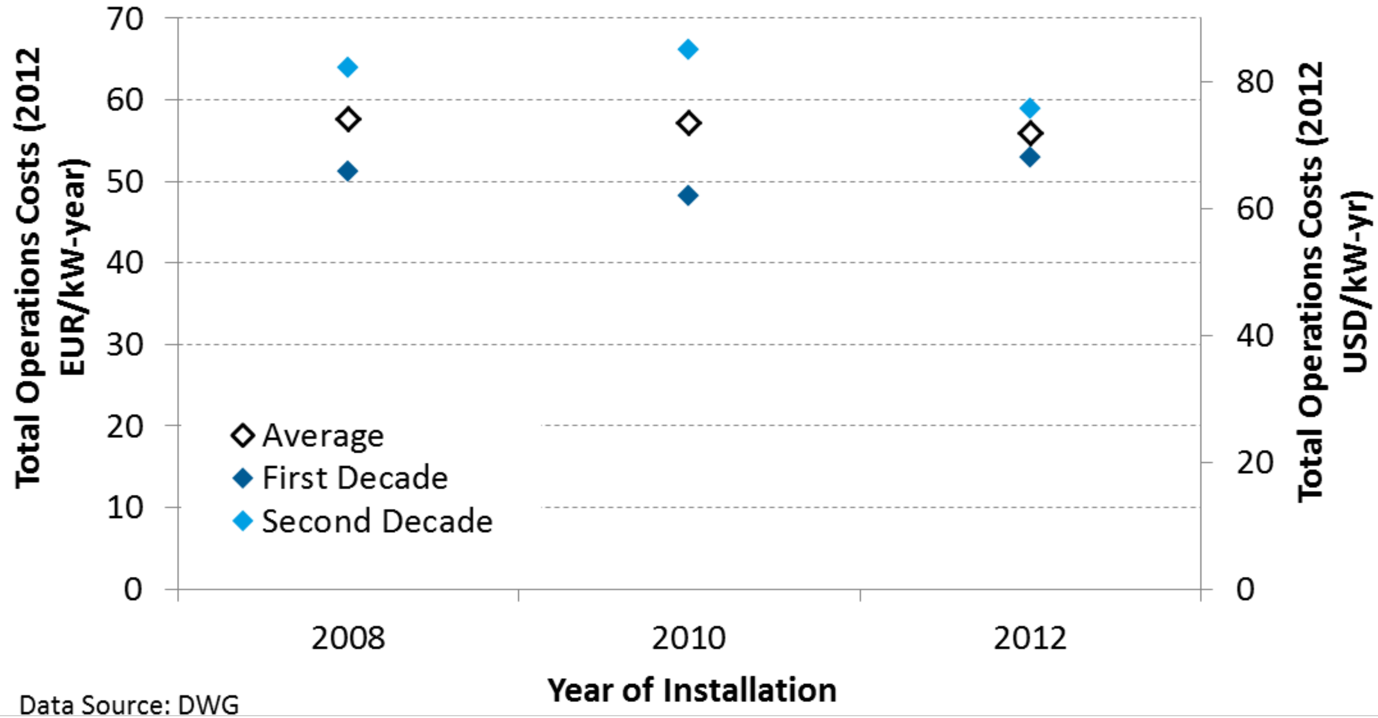
CAPEX = Total Expenditures to Achieve Project Operation



- In Norway, civil works and project development costs increased over study period
- Detailed CAPEX data is rare, but necessary, to isolate CAPEX differences among countries

Operational Expenditures (OPEX)



- Germany has unique record of long-term OPEX which illustrates variation over life of project
- Expectations of OPEX difficult to predict with limited data in most countries

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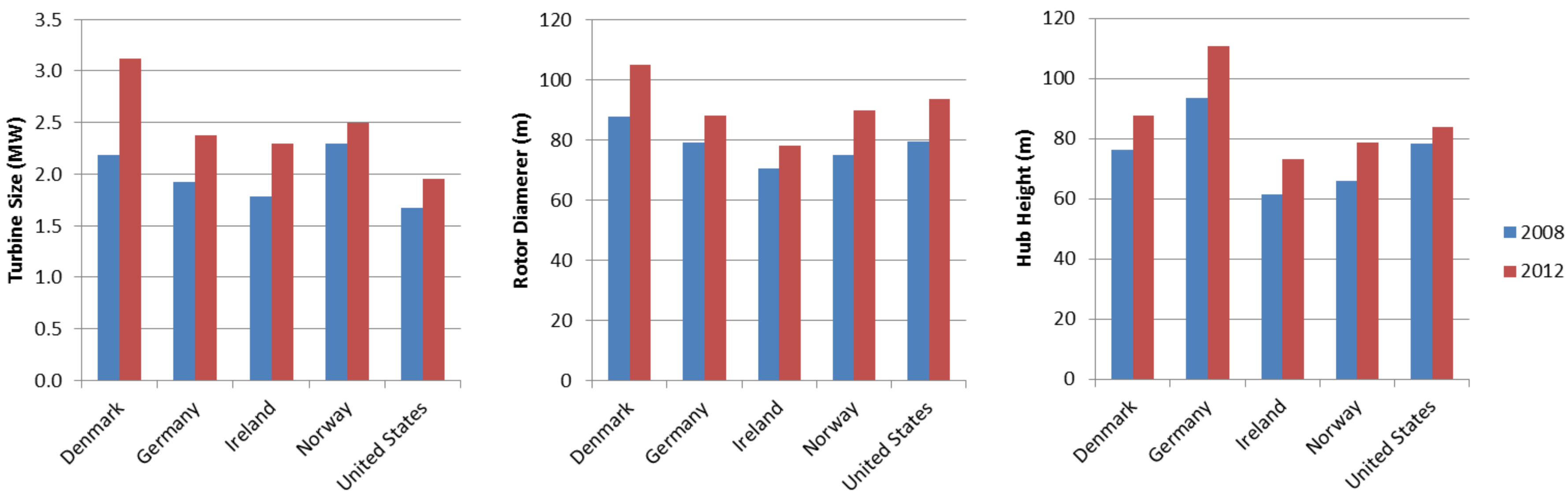
Turbine Size Increasing



- Since 2008 turbine size, rotor diameter, and hub height have increased in each country;
- Consistent with historic trends from advent of modern wind industry in 1980s

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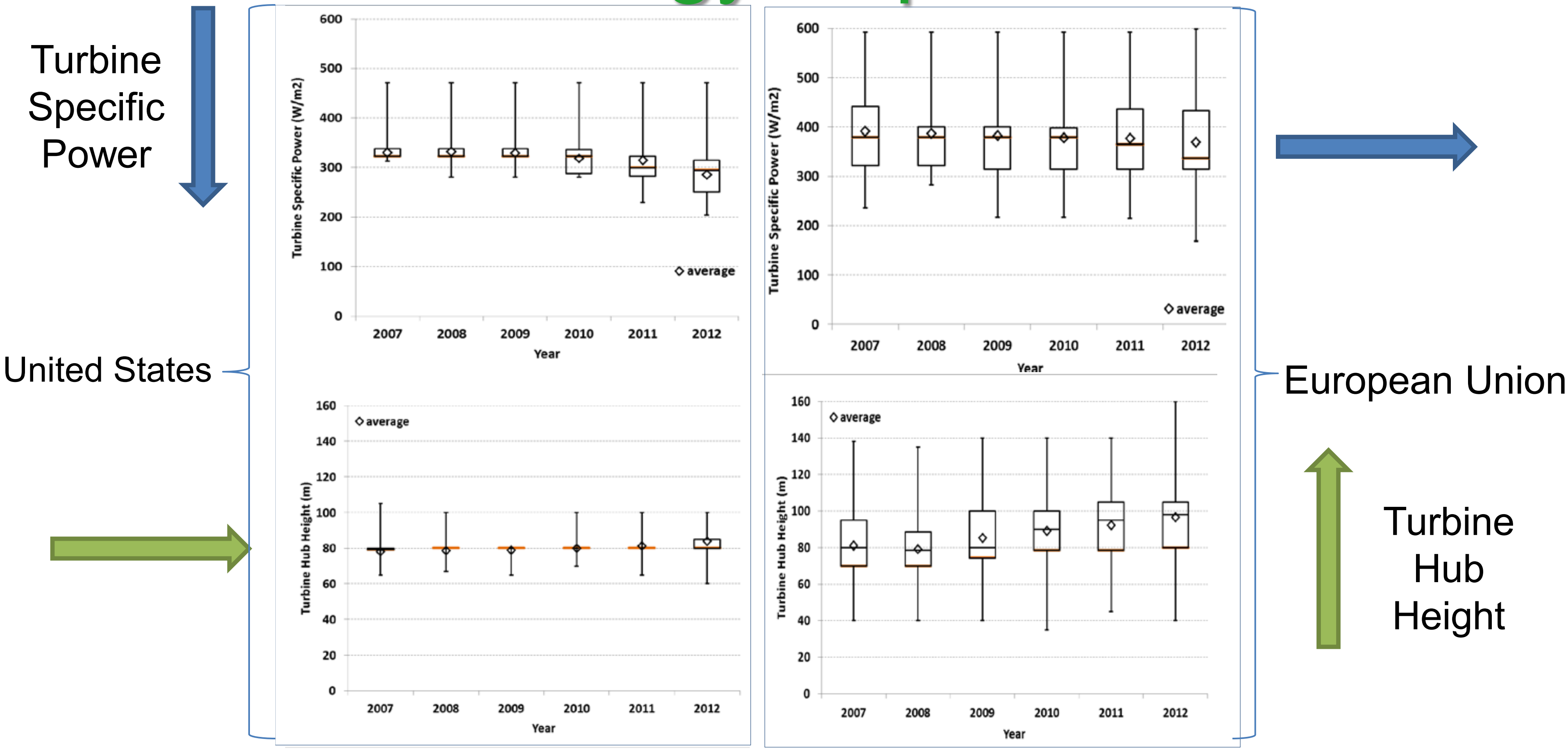
Larger Turbines Intended to Increase Energy Capture



- Although turbine size trends differ between U.S. and E.U., increased energy capture is the objective.

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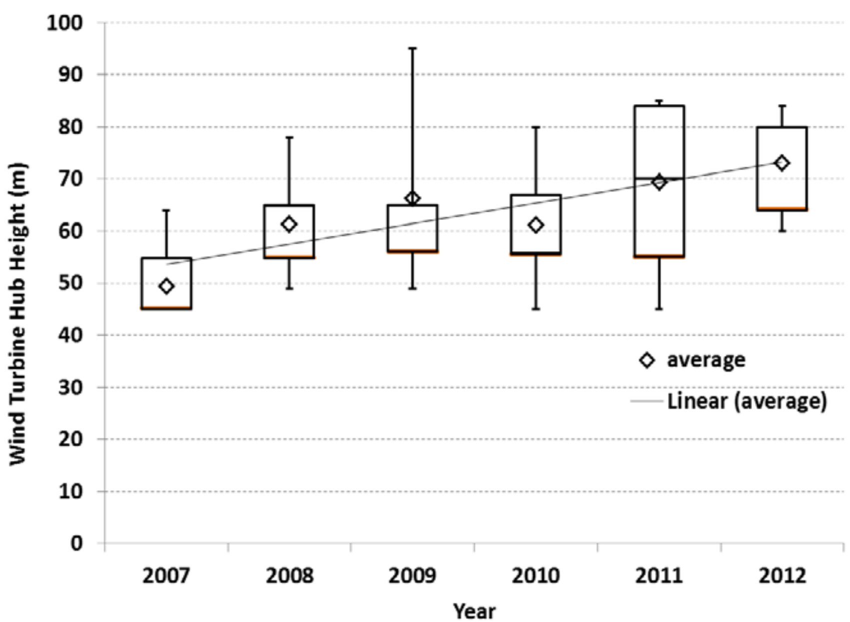
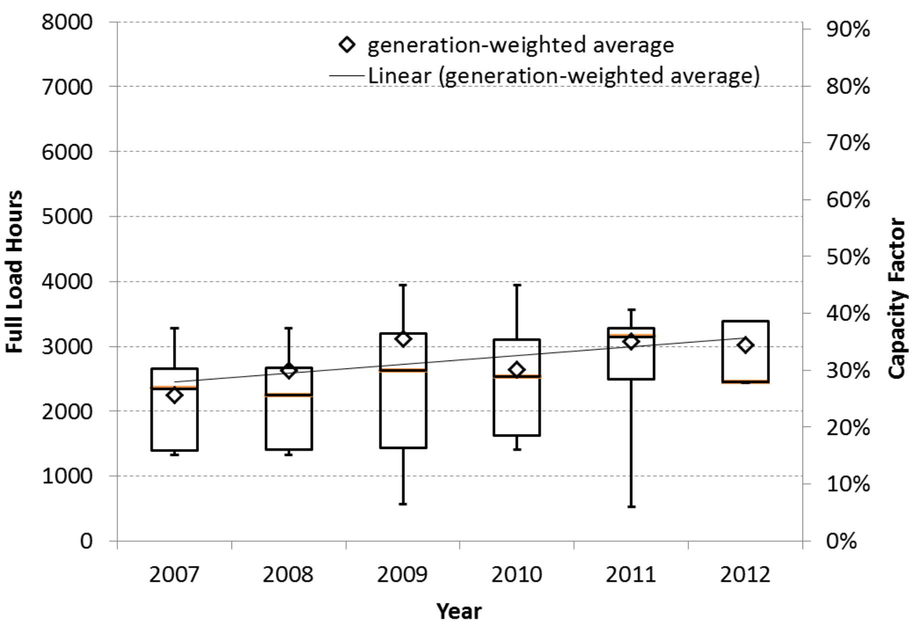
Taller Towers Yield Increased Energy Production





- In Ireland, increased energy capture correlated with increased hub height while average wind resource remains relatively constant over this period.
- In other countries, increased energy capture somewhat offset by reduced average wind speed at project location

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Project Finance

	Denmark	Germany		Ireland	Norway	US	
	2012	2012 (coastal)	2012 (inland)	2012	2012	2012	2014 (Interior)
Return on equity	11%	10%	9%	14%		8%/12%	N/A / 12%
Return on debt	5%	4%	4%	6%		4%	4%
Equity share	20%	22%	22%	20%		38%/35%	0%/43%
Debt share	80%	78%	78%	80%		28%	57%
Loan duration	13	16	16	15	20	15	15
Corporate tax rate	25.0%	29.6%	29.6%	12.5%	28.0%	40.2%	40.2%
WACC (after tax, nominal)	5.2%	4.1%	4.0%	7.0%	7.6%	8.3%	7.2%

Note: project finance structure in Norway not specified; in United States equity parties include tax equity and sponsor equity associated with tax credit incentive.

- Examples of project finance structures in each country although variation exists
- In Europe greater share of debt financing leads to lower Weighted Average Cost of Capital (WACC) in general

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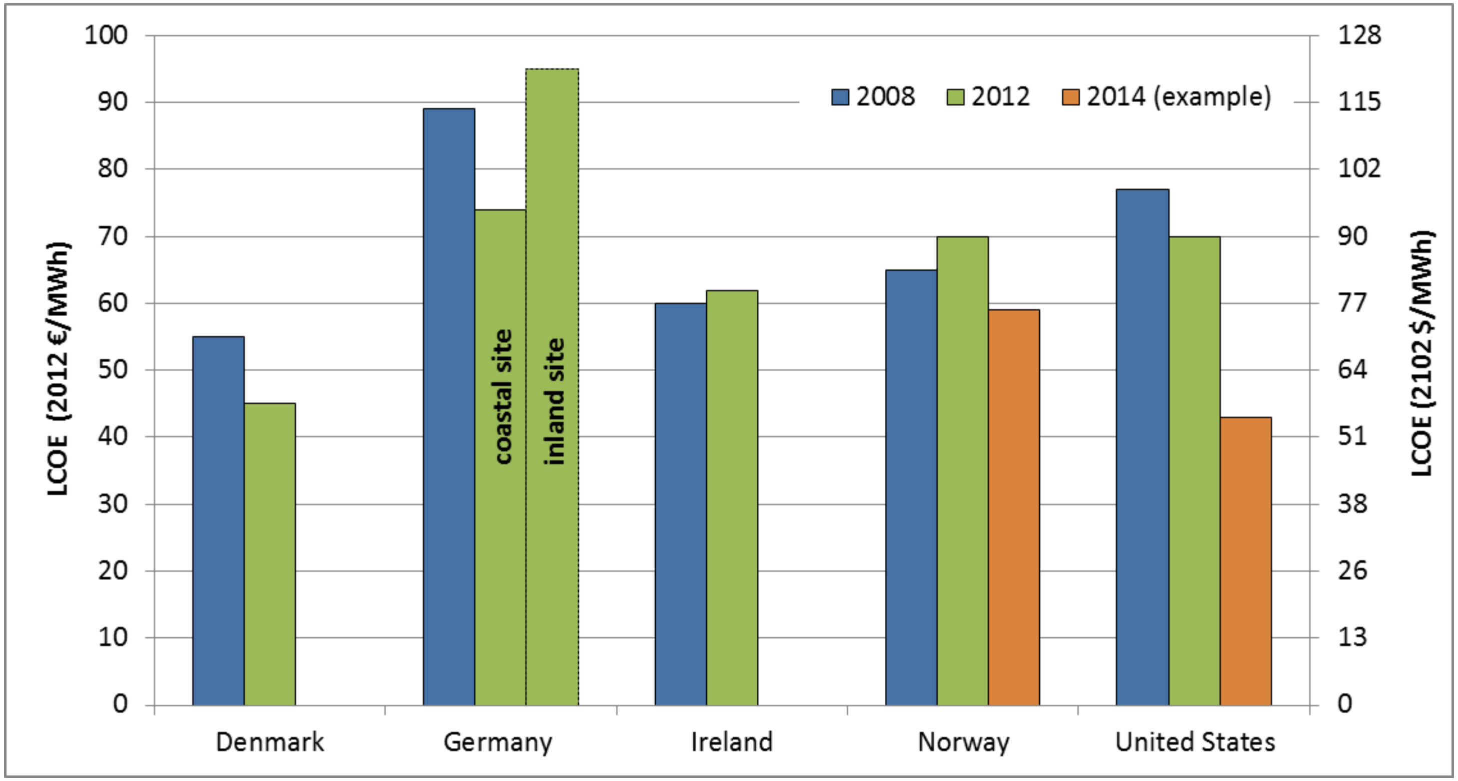
Levelized Cost of Energy



- Life-cycle cost of producing energy from a wind plant influenced by technology, resource, project finance – does not include revenue or policy incentives
- Analysis assumes 20 year straight-line depreciation for all countries

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Primary Revenue and Policy Mechanisms

Country	Market Price Electricity	Feed-in Tariff (FIT) or Feed-in Premium (FIP)	Upfront Capital or Production-Based Incentive	Accelerated Depreciation	Significant Changes for 2014 and Beyond
Denmark	X	X		X	
Germany		X		X	FIT replaced with FIP and market price electricity since August 2014
Ireland	X	X			
Norway	X		X		Upfront capital subsidy replaced with electricity market certificates in combined Sweden/Norway certificate market
United States	X		X	X	Production Tax Credit expired Dec. 31, 2014 and not available for projects beginning construction after 2014.

- Unique application of market prices and policy incentives in each country result in viable wind projects where life-cycle costs are expected to be recovered
- General trend toward increased reliance on market prices (e.g., FIP over FIT) and eventually toward tenders

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Future Directions for IEA Wind Task 26

- Annual update to project statistics with periodic update to land-based wind cost of energy analysis
- Online survey of wind industry experts about future cost of energy in process with publication planned in 2016
- Offshore wind cost of energy baseline and sensitivity analysis to identify country-specific cost drivers

Thank you!

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