Forecasting Wind Energy Costs and Cost Drivers: What Do the Experts Say?

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Webinar
September 2016

https://emp.lbl.gov/iea-wind-expert-survey

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Presentation Overview: Summarize Results of IEA Wind Task 26 Expert Survey on Wind Energy Costs

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- **Motivation**
- **Approach**
- **Results**
- **Conclusions**

Nature Energy Article

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Expert elicitation survey on future wind energy costs

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Wind energy supply has grown rapidly over the last decade. However, the long-term contribution of wind to future energy supply, and the degree to which policy support is necessary to motivate higher levels of deployment, depends—in part—on the future costs of both onshore and offshore wind. Here, we summarize the results of an expert elicitation survey of 163 of the world's foremost wind experts, aimed at better understanding future costs and technology advancement possibilities. Results suggest significant opportunities for cost reductions, but also underlying uncertainties. Under the median scenario, experts anticipate 24–30% reductions by 2030 and 35–41% reductions by 2050 across the three wind applications studied. Costs could be even lower: experts predict a 10% chance that reductions will be more than 40% by 2030 and more than 50% by 2050. Insights gained through expert elicitation complement other tools for evaluating cost-reduction potential, and help inform policy and planning, R&D and industry strategy.

As of the end of 2015, wind power capacity installed globally was capable of meeting roughly 4.3% of electricity demand, up from less than 1% at the end of 2006[1]. This growth has been supported by energy policies and facilitated by technology advancements and related cost reductions[2,3]. Although the majority of deployed capacity is onshore (>97%), offshore wind deployment is increasing, especially in Europe[1]. The increasing maturity of wind technology, as well as the scale of the global resource[4], suggests that wind energy might play a significant future role in electricity supply, especially in the context of efforts to reduce greenhouse gas emissions[5–8]. That role, however, is uncertain. A review of 150 long-term energy scenarios by the Intergovernmental Panel on Climate Change (IPCC) shows wind's global contribution to electricity supply in 2050 reaching 13–14% in the median climate change mitigation scenario, but with a range of less than 5% to over 50% (ref. 2). Recent scenarios published by the International Energy Agency[9] and Global Wind Energy Council[10] have ranges of 6–15% (2040) and 17–31% (2050), respectively.

Part of the uncertainty in the contribution of wind to the future energy mix comes from uncertainty in its costs[8,11]. Past studies of wind energy costs have used a variety of approaches. Learning curves have a long history within the wind sector as a means of understanding past cost trends and as a tool to forecast future outcomes[2,12,13], but they have been criticized for largely focusing only on capital costs[14,15], and for simplifying the many causal mechanisms that lead to cost reduction[16–18]. In addition, using historical data to generate learning rates that are then extrapolated into the future implicitly assumes that future trends will replicate past ones[14,19–21]. Engineering assessments provide a bottom-up, technology-rich complement to learning analyses[11]. They involve detailed modelling of specific technology advancements[22–26] and often consider both cost and performance, providing better insights into trends in levelized cost of energy (LCOE). However, they also generally require sophisticated design and cost models, often emphasize more incremental advances, and rarely provide insight into the probability of different outcomes.

This study summarizes the results of a global expert elicitation survey on future wind energy costs and related technology advancements. The research relies on expert knowledge to gain insight into the possible magnitude of future wind energy cost reductions and to identify the sources of and enabling conditions for those reductions. In so doing, we complement learning curve and engineering assessments as well as less-formal means of synthesizing expert knowledge[11,13,27–31] by seeking a more detailed understanding of how cost reductions might be realized and by clarifying the important uncertainties in these estimates. The online elicitation survey is global in scope and covers both onshore and offshore technology. It emphasizes costs in 2030, but with additional markers in 2020 and 2050. With 163 respondents, it is the largest known elicitation ever performed on an energy technology in terms of expert participation[32].

Expert elicitation survey

Expert elicitation is a tool used to develop estimates of unknown or uncertain quantities based on careful assessment of the knowledge and beliefs of experts about those quantities[33]. It is often considered the best way to develop credible estimates when data are sparse or lacking, or when projections are sought for future conditions that are different from past conditions[34,35]. Several formal protocols for conducting elicitations have been developed[36] and a rich literature provides guidance on question design, the importance of clarity in what is being asked, how to minimize the effects of motivational and cognitive biases, and the importance of providing feedback and opportunities to update assessments[33,37,38]. Expert elicitation has been widely used to support decision-making in the private and public sectors. Its use was explicitly called for in a review of the IPCC[39] and by a National Academies review of the US Department of Energy[40]. Expert elicitation is increasingly common as a tool for making estimates of the future costs of energy technologies[32,41]. However, formal elicitation procedures have not yet been widely applied to understand wind energy costs[42,43].

Expert elicitation is not without weaknesses. Most notably, it is impossible to entirely eliminate—or even to fully test for—the possibility of motivational or cognitive biases. Those individuals who are considered subject-matter experts on wind energy, for example, might have a tendency to be optimistic about the future of

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http://rdcu.be/khRk

Full Report

FORECASTING WIND ENERGY COSTS & COST DRIVERS

The Views of the World's Leading Experts

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Background and Motivation

Significant Recent Wind Power Deployment Growth

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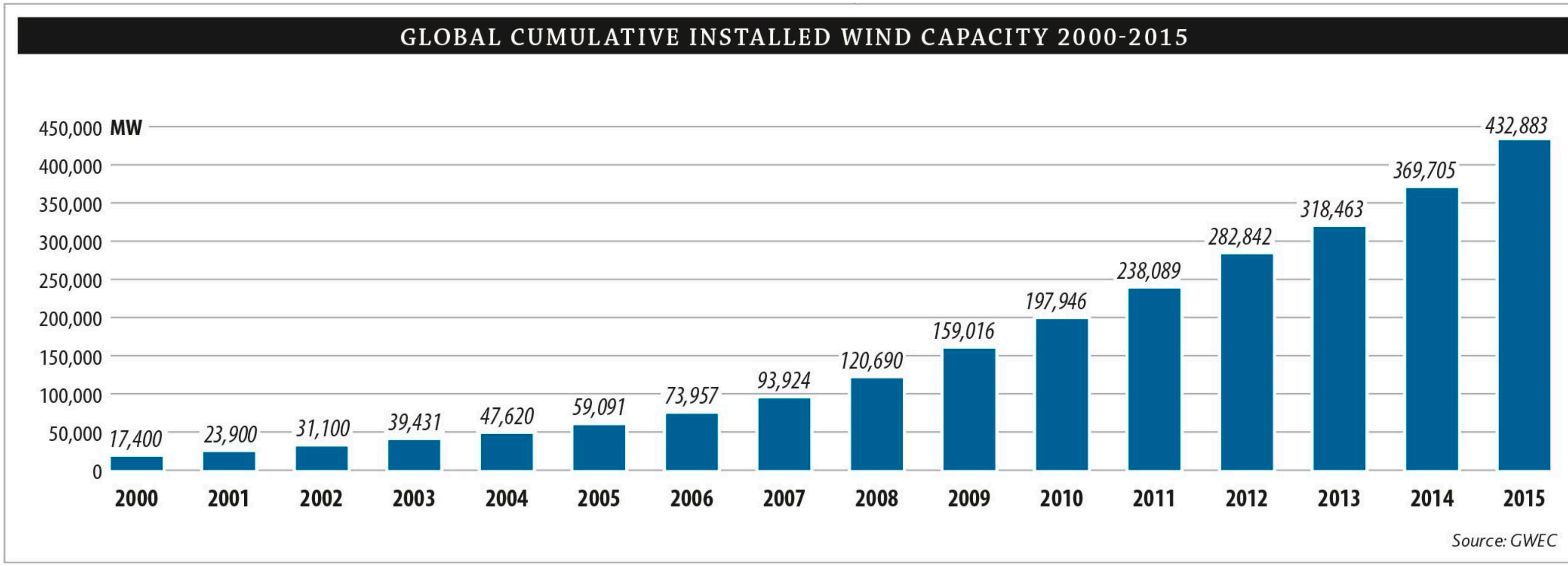
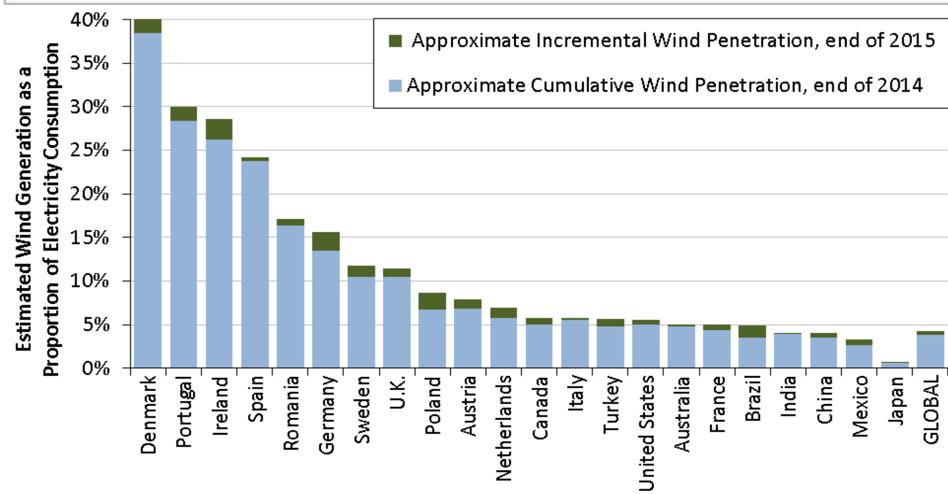
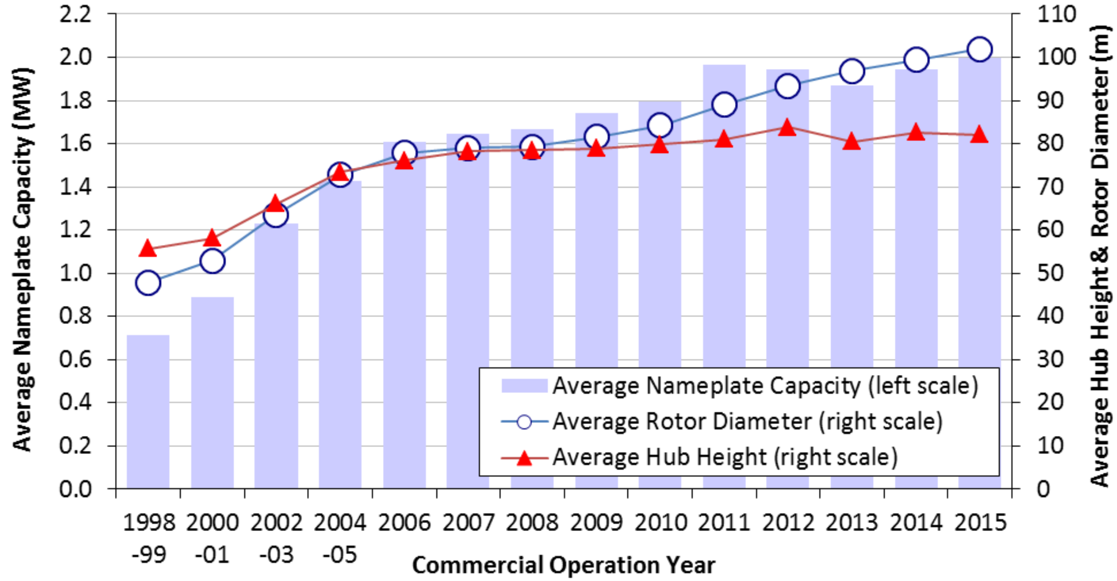




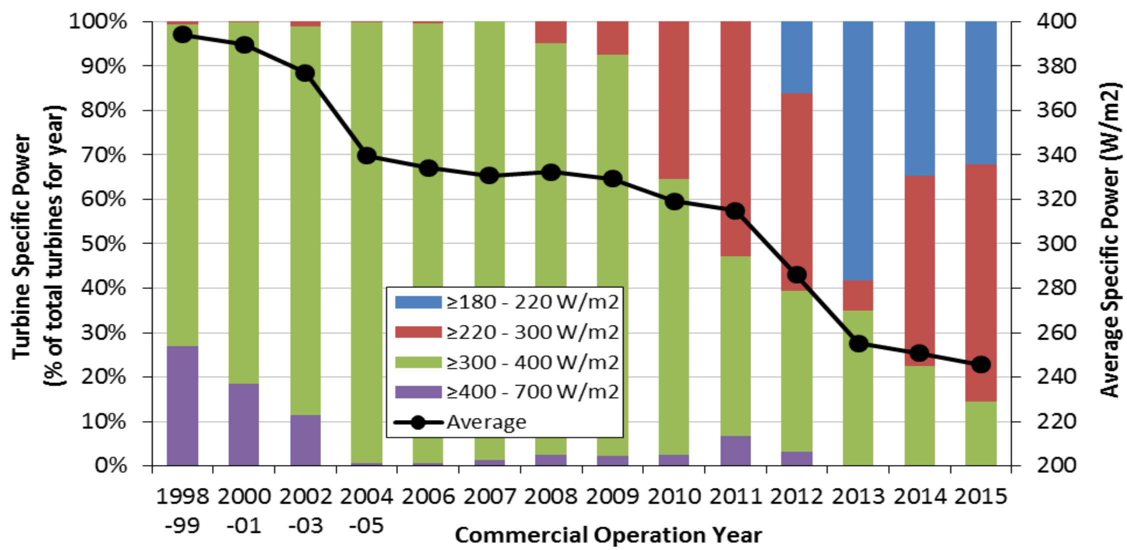
Growth driven by policy as well as technological advancements leading to lower wind energy costs

Onshore (land-based): Turbine Scaling in U.S. Has Reduced Capital Costs, Increased Capacity Factors

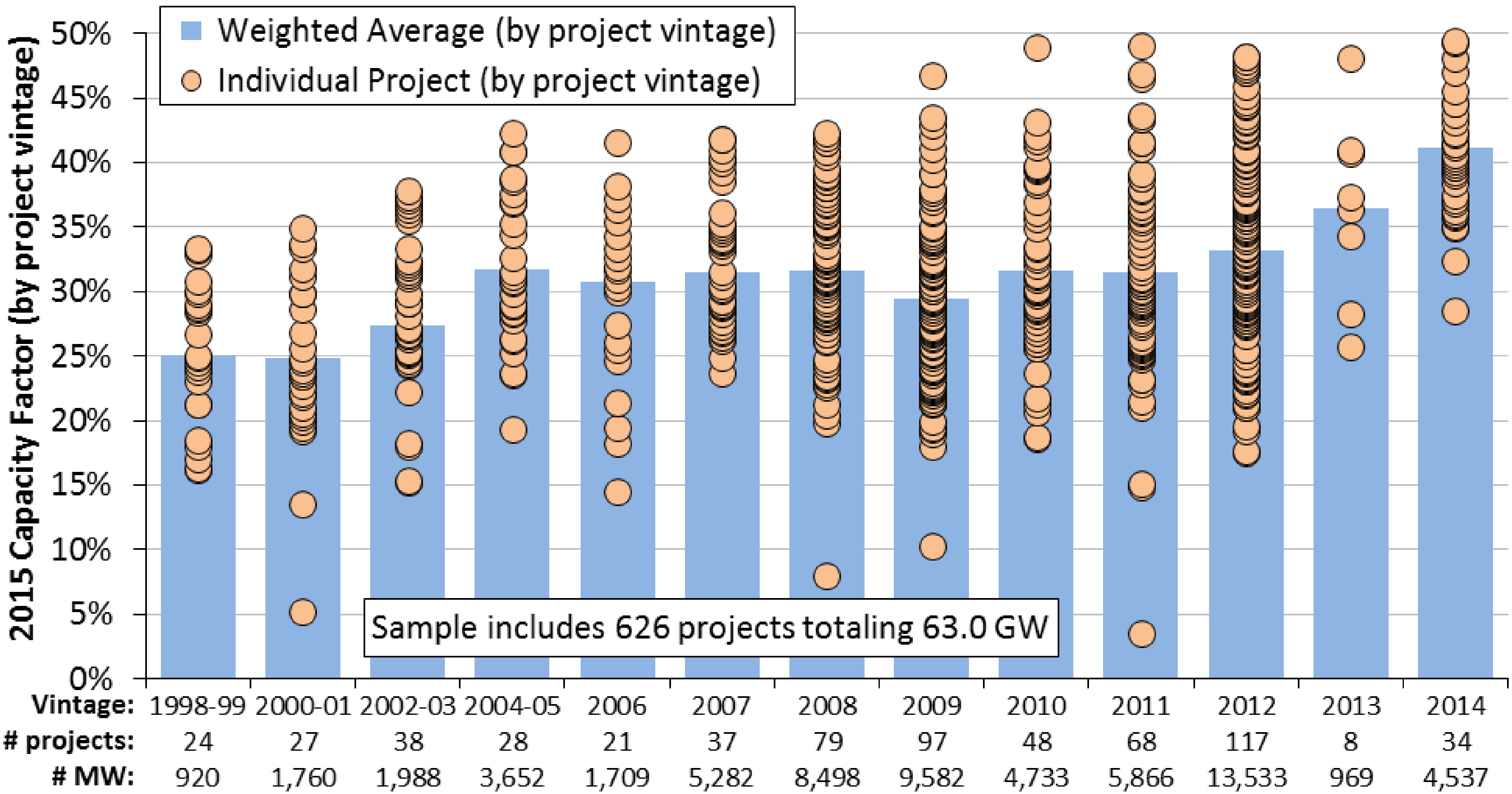
Higher nameplate capacity → to a point, reduced CapEx



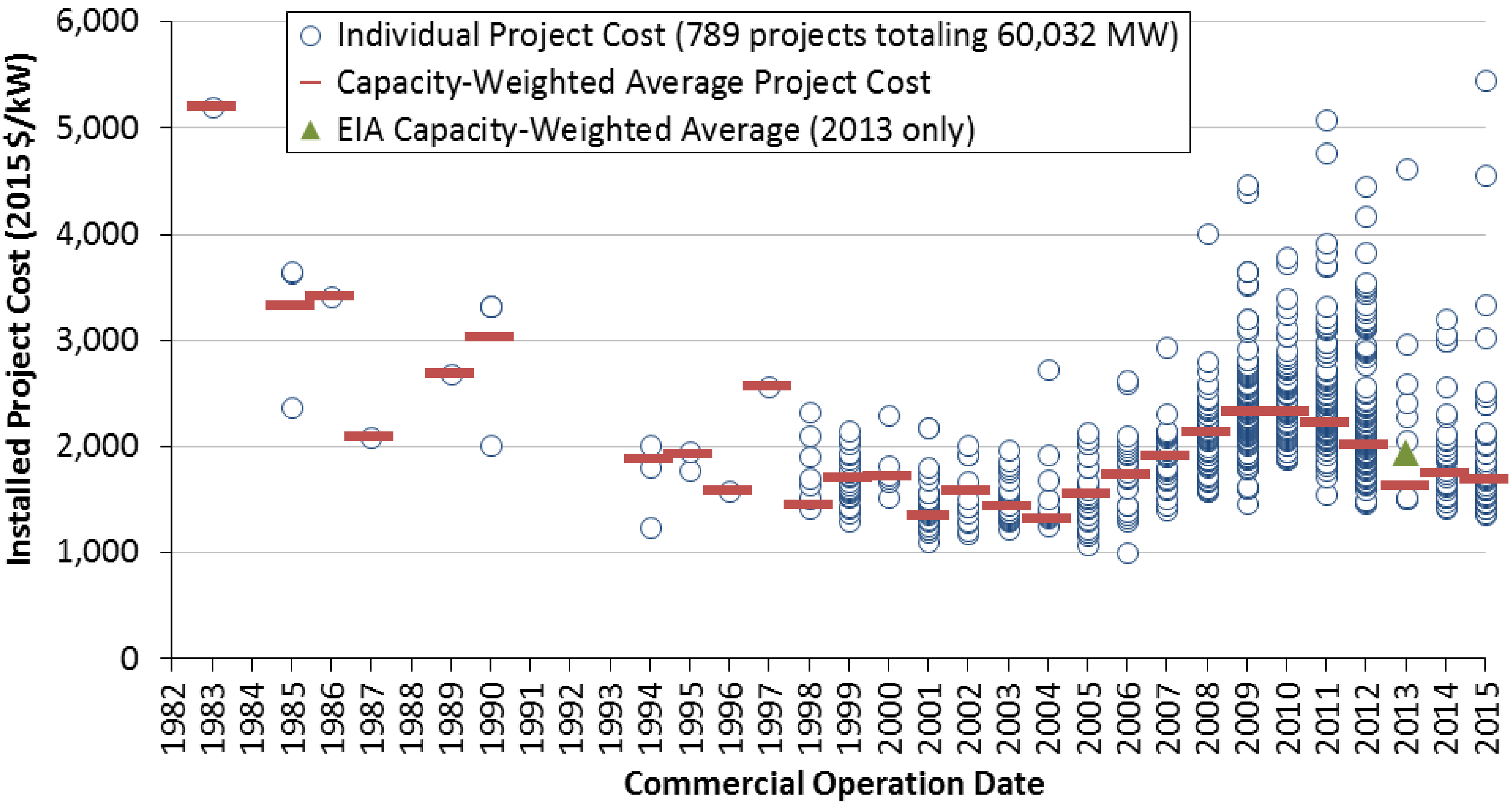
Higher hub heights and longer rotors, especially declining specific power → increased capacity factors



U.S. Capacity Factors by Project Vintage Affected by Multiple Trends, but Show Steep Recent Increase

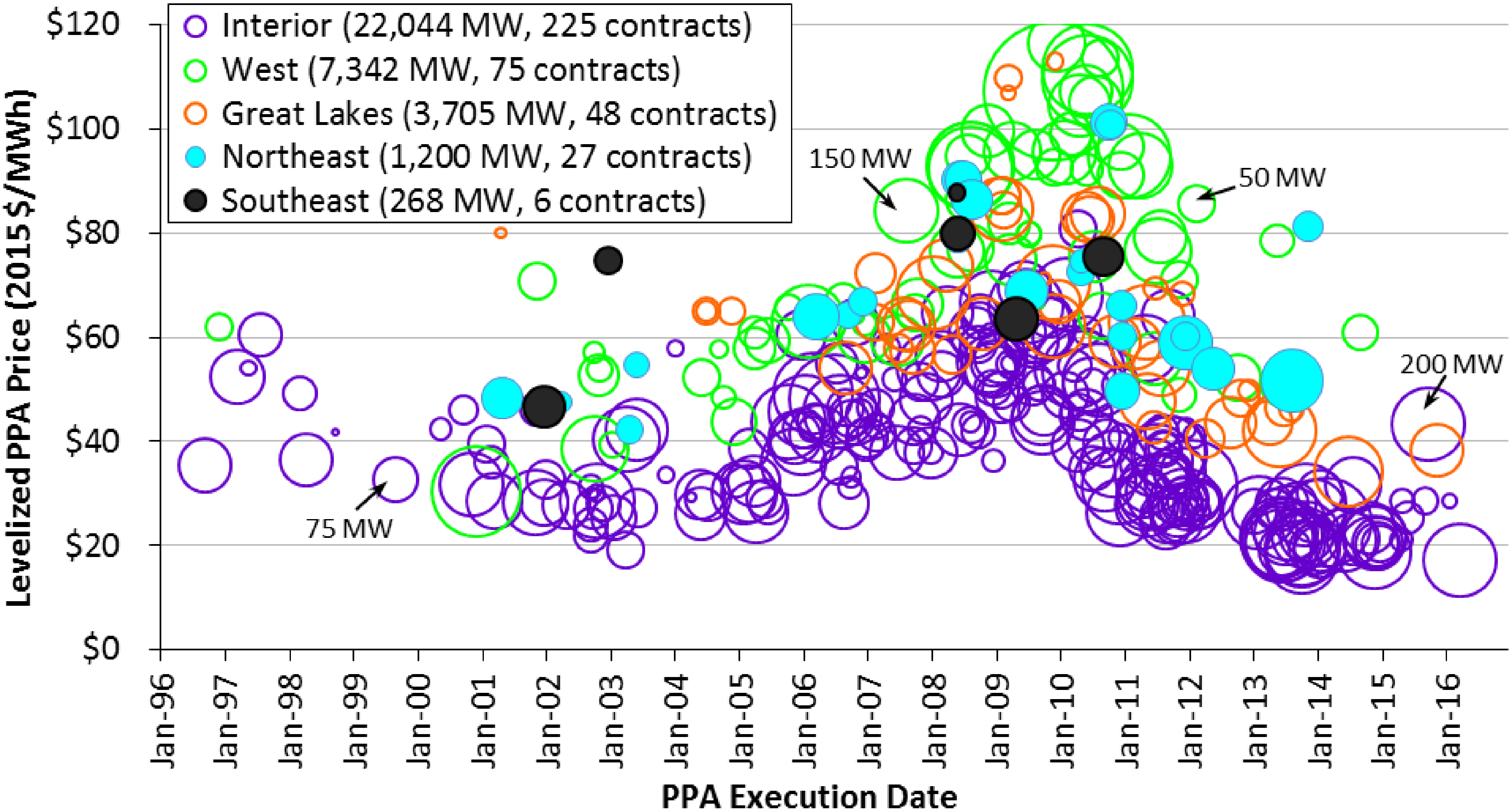


Long-Term Reductions in Total Installed Project Costs in U.S. Notwithstanding Focus on Increased Performance



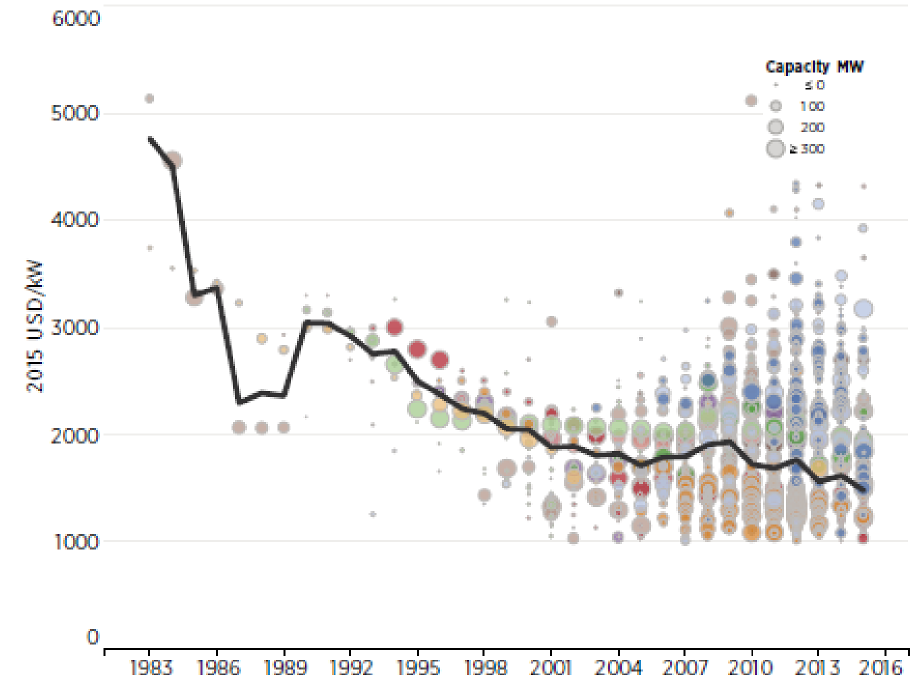
2015 projects had an average cost of $1,690/kW, down $640/kW since 2009 and 2010; limited sample of under-construction projects slated for completion in 2016 suggest no material change in costs

Wind Power Purchase (PPA) Prices Remain Very Low, Especially in U.S. Interior Region ~ $20/MWh (with PTC)



The United States Is Not Alone in Witnessing Significant Onshore Wind Power Advancements

FIGURE 19: TOTAL INSTALLED COSTS OF ONSHORE WIND PROJECTS BY COUNTRY, 1983-2014

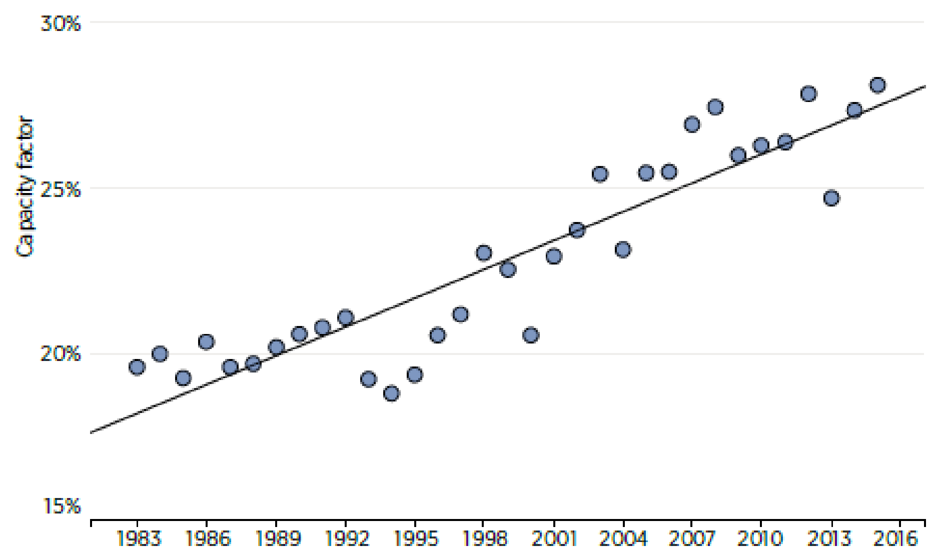


Source: IRENA Renewable Cost Database.

Global CapEx

Global Capacity Factor

FIGURE 20: GLOBAL WEIGHTED AVERAGE CAPACITY FACTORS FOR NEW ONSHORE WIND POWER CAPACITY ADDITIONS, 1983-2014



Source: IRENA Renewable Cost Database.

Offshore: Turbine Scaling and Market Maturity Beginning to Bend the Cost Curve Downward

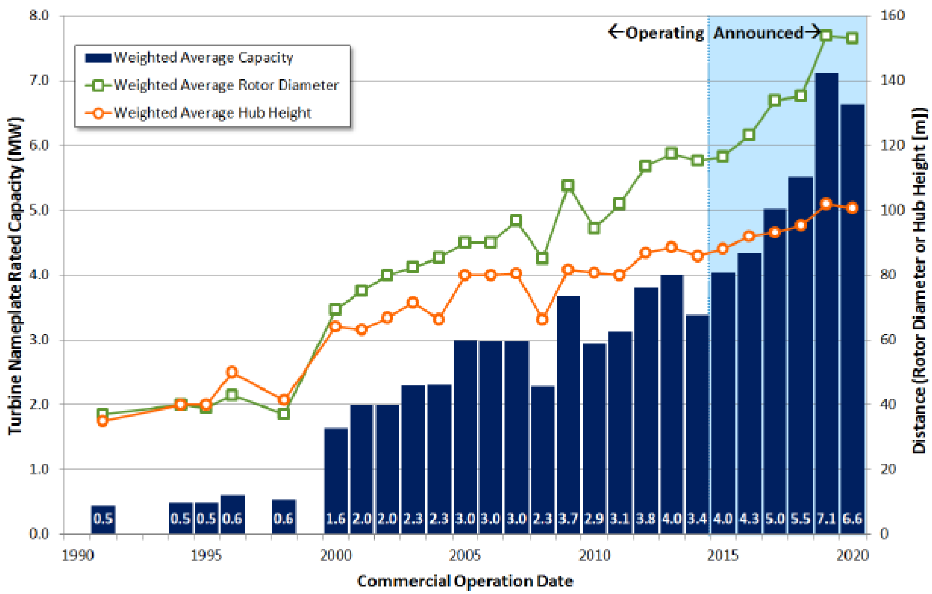


Figure 13. Global turbine capacities, rotor diameters, and hub heights over time

Increased Turbine Size

Deeper Water, Farther from Shore

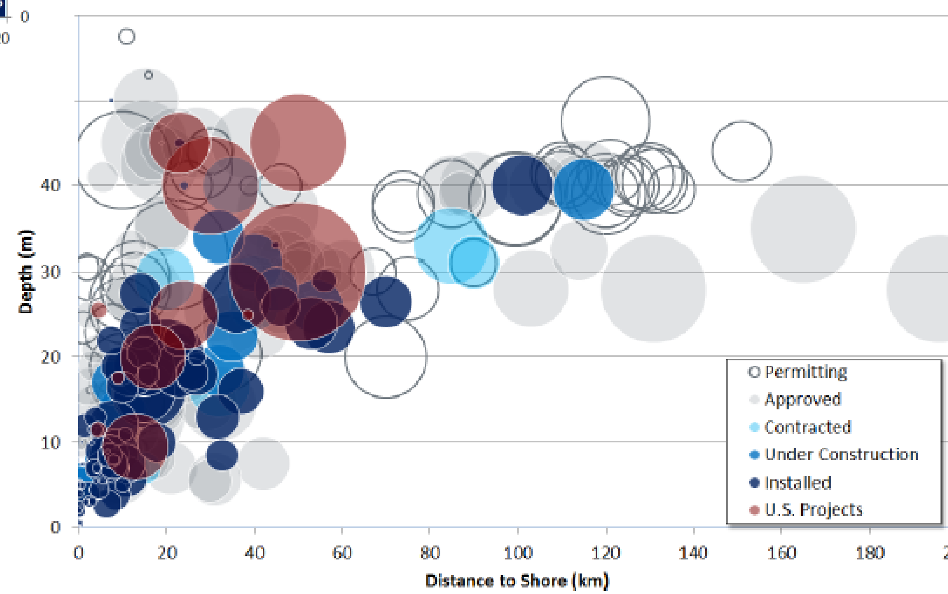


Figure 12. Global offshore wind projects as a function of water depth and distance to shore

Offshore CapEx & Pricing Trends Are Favorable; Steep Reductions Revealed by Most Recent Pricing Points

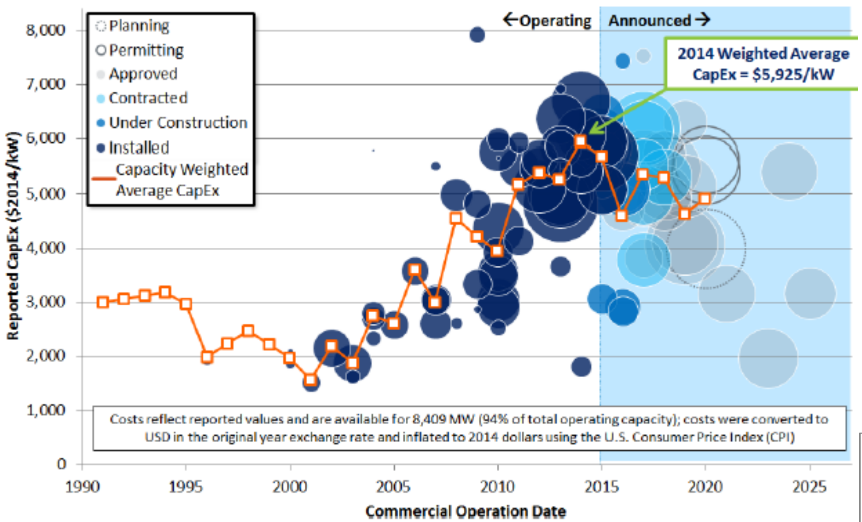
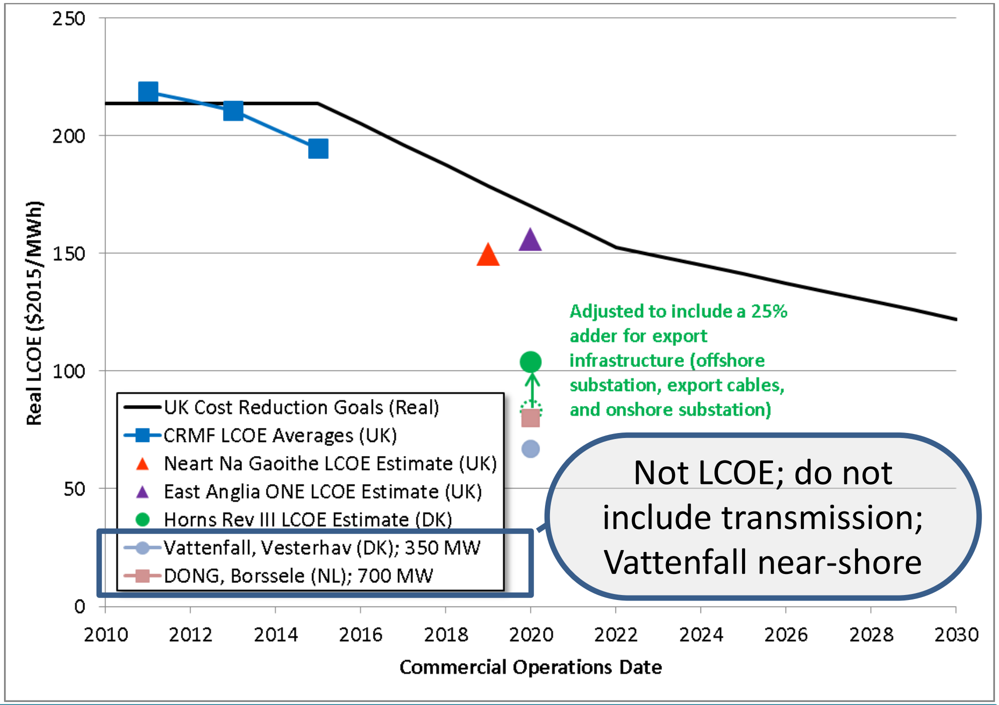


Figure 20. Global offshore wind projects weighted average capital expenditures by commercial operation date

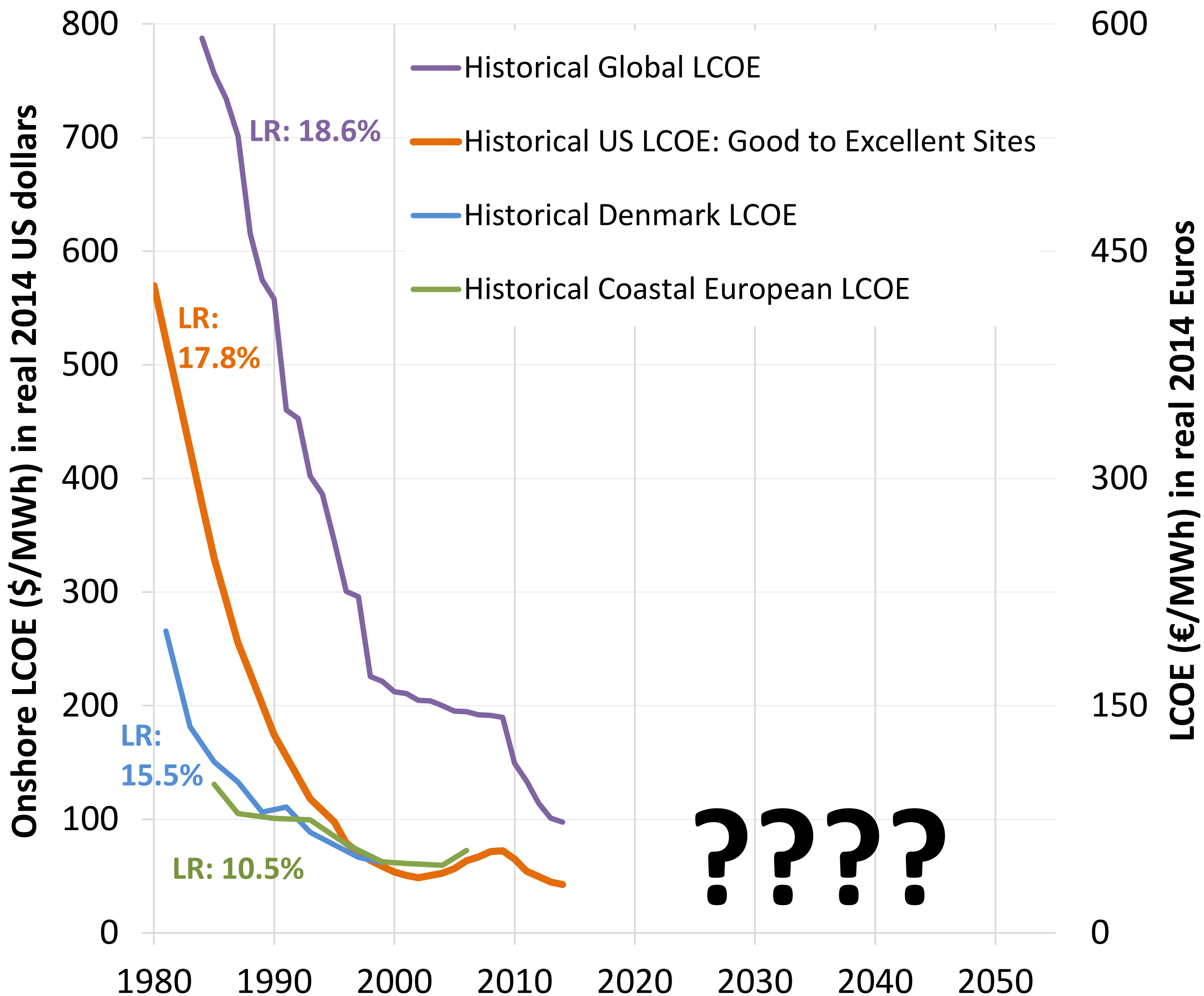
Global CapEx

Global Pricing



Motivation: Where Will Onshore and Offshore Costs Go in Future, and How Might those Costs be Achieved?

- Wind energy has grown rapidly, supported by policies and cost reductions
- Long-term contribution and need for ongoing policy depends on future costs
- Uncertainty about future cost reduction, and conditions that might drive greater reduction



Approach and Implementation

IEA Wind Survey of 163 of the World's Foremost Wind Experts, Focused on Cost and Technology Trends

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What

Expert survey to gain insight on possible magnitude of future wind energy cost reductions, sources of reductions, and enabling conditions needed to realize continued innovation and lower costs

Covering onshore, fixed-bottom offshore, and floating offshore wind applications

Why

Inform policy & planning, R&D, and industry investment & strategy development while also improving treatment of wind in energy-sector planning models

Complement other tools for evaluating cost reduction, including learning curves, engineering assessments, other ways to synthesize expert knowledge

Who

Largest single expert elicitation ever performed on an energy technology in terms of expert participation: 163 of the world's foremost wind energy experts

Led by LBNL and NREL, under auspices of IEA Wind Task 26 on "Cost of Wind Energy," and with numerous critical advisers throughout

Survey focus was primarily on changes in levelized cost of energy (LCOE) from 2014 to 2020, 2030, and 2050 under low/median/high scenarios, and on build-up of LCOE in 2014 & 2030; LCOE excludes any subsidies and excludes grid interconnection costs outside plant boundary

Survey Leadership: Thanks!

IEA Wind Task 26 and U.S. DOE

- Conducted under auspices of IEA Wind "Cost of Wind Energy", and its member countries (US, Denmark, Germany, Ireland, Netherlands, Norway, Sweden, UK, European Commission); funded largely by U.S. DOE (Zayas, Gilman, Tusing, Higgins)

Survey Leadership Team

- Ryan Wiser and Joachim Seel (LBNL); Karen Jenni (Insight Decisions); Maureen Hand, Eric Lantz and Aaron Smith (NREL); Erin Baker (U Mass. Amherst)

Other IEA Wind Task 26 Advisors

- Berkhout, Duffy, Cleary, Lacal-Arántegui, Husabø, Lemming, Lüers, Mast, Musial, Prinsen, Skytte, Smart, Smith, Sperstad, Veers, Vitina, Weir

Online Survey Platform

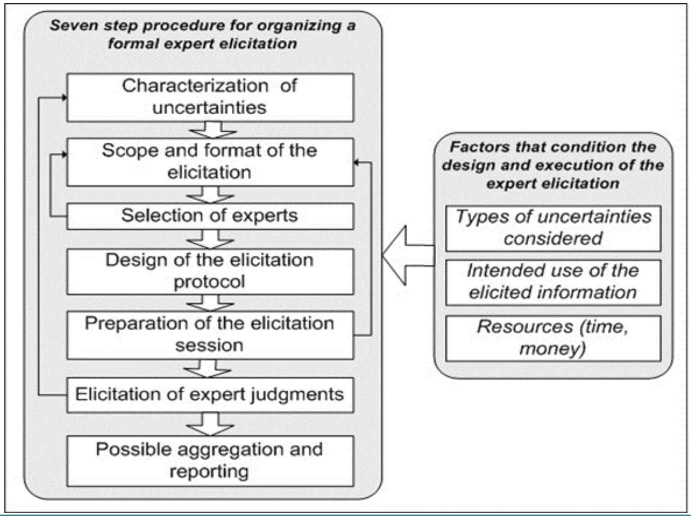
- Survey implemented online via Near Zero platform

The Surveyed Experts

- 163 of the world's leading experts graciously offered their time

Our Approach: Expert Elicitation

- Online survey of large sample of the world's foremost wind experts
- One of the first efforts to use "formal" expert elicitation methods to understand wind cost reduction *(many previous efforts have leveraged expert knowledge)*
- Expert elicitation is a tool—with established protocols—to develop estimates of unknown or uncertain quantities based on careful assessment of the knowledge and beliefs of subject-matter experts
- Often considered best way to develop estimates when data are sparse, or when projections are sought for future conditions very different from past conditions
- Not without challenges, but insights can complement other tools:
  - **Learning curves:** causal mechanisms poorly understood; few studies on wind LCOE; historical trends may be poor guide; some technologies have limited historical data
  - **Engineering assessments:** opportunities captured often incremental and near-term; requires complex models; rarely provides insight on probability
  - **Expert knowledge:** absent care, informal tools to extract knowledge may be prone to bias/overconfidence



Targeted Survey Respondents

Global survey: identified 482 possible survey respondents from IEA Task 26 members, affiliated organizations, others

Of these, selected smaller group of 42 uniquely-qualified “leading” experts to mirror more-traditional elicitation

Casting a Wide Net

- sought relatively wide distribution of survey

Ideal Respondent

- strategic, system-level thought leaders, w/ wind tech, cost, market expertise

Respondent Type

- industry, R&D institutions, academia, others

Technology Specialization

- onshore, fixed-bottom offshore, floating offshore

Geography

- primarily Europe and U.S., but did not foreclose other regions

Diverse Set of 163 Survey Participants (34% response rate), Including 22 from Leading-Expert Group (52%)

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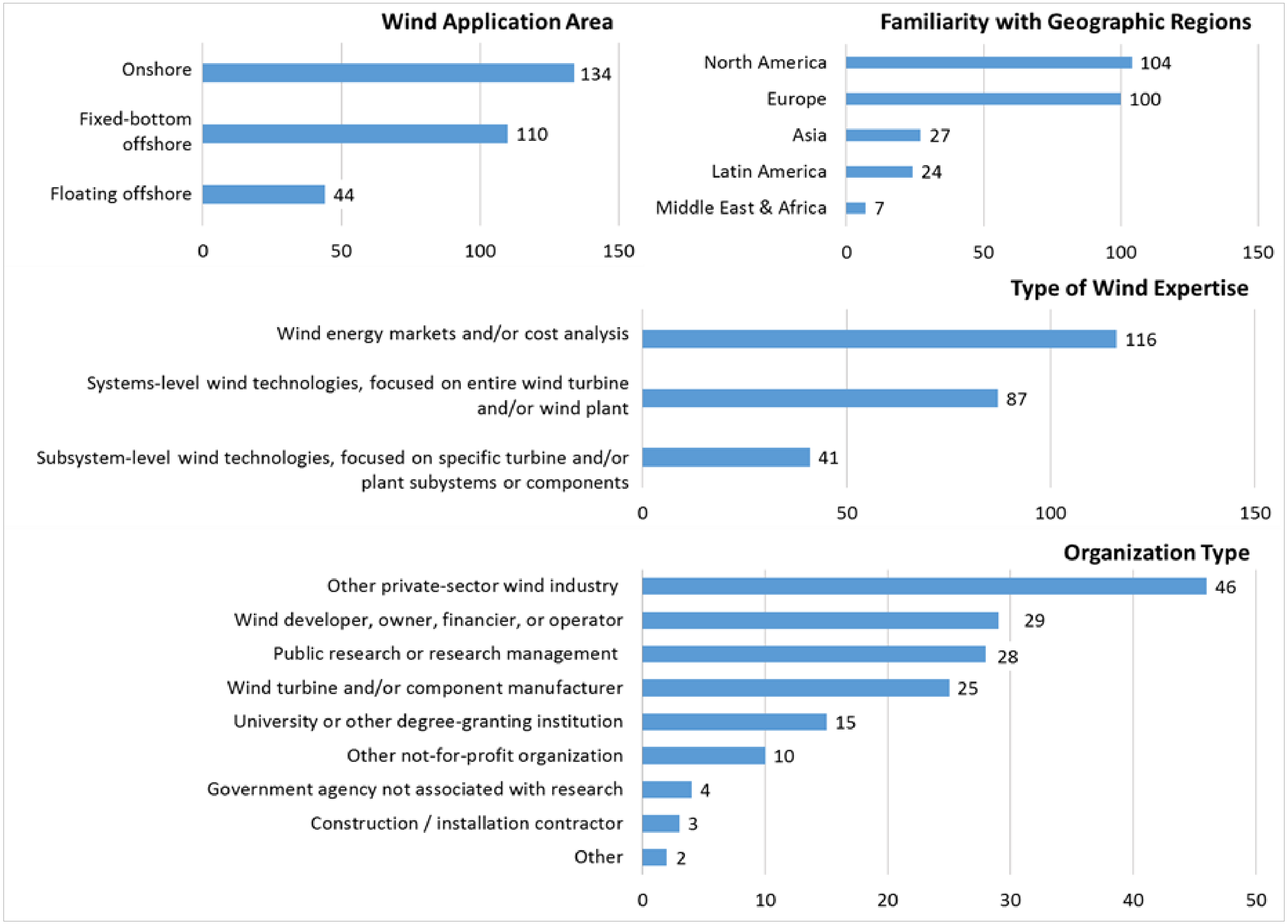
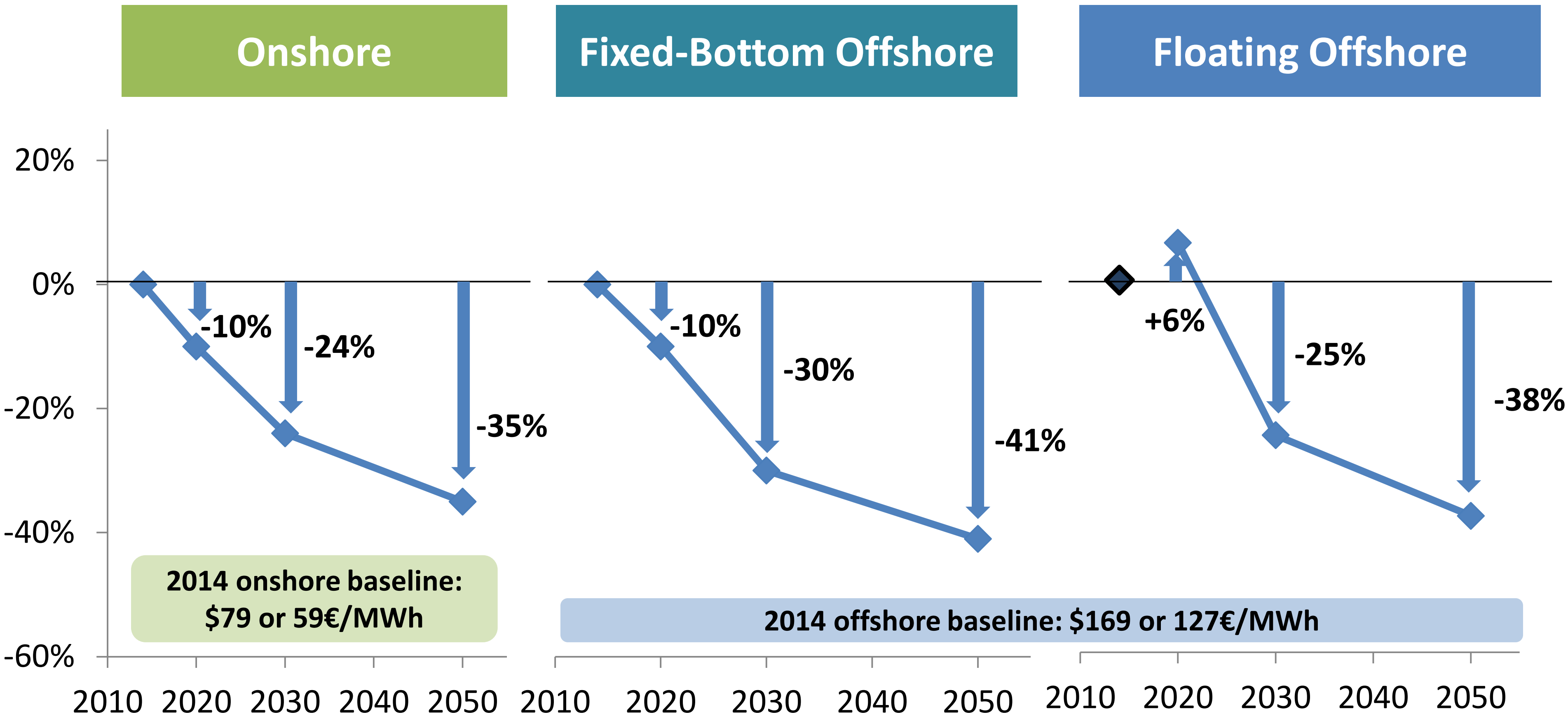


Smaller group of 22 “leading experts” pre-identified as uniquely-qualified

Survey Results

Expectations for Significant LCOE Reduction: Median “Best Guess” Scenario, Median Respondent

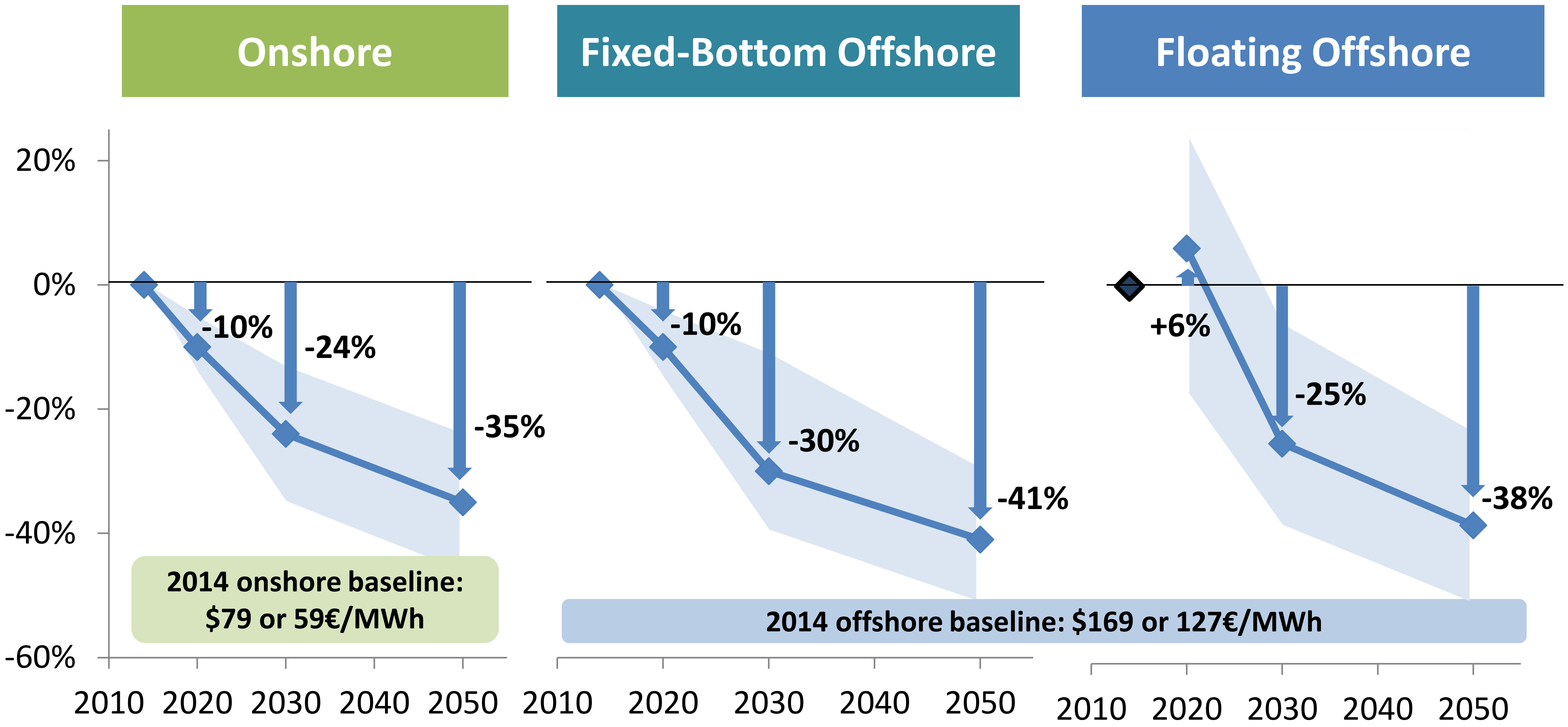


Lines/markers indicate the **median** expert response

For **floating,** change is shown relative to 2014 baseline for fixed-bottom

All dates are based on the year in which a new wind project is commissioned

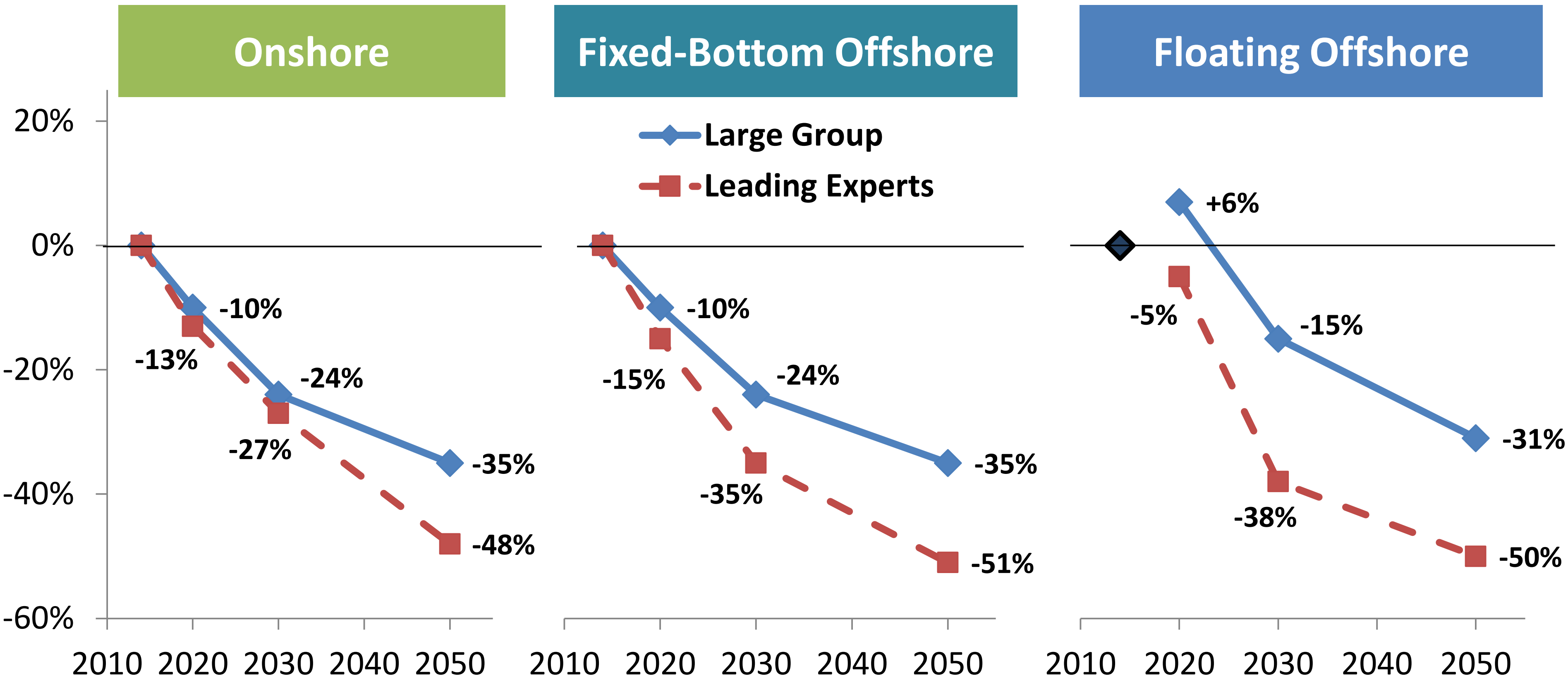
Uncertainty Revealed When Reviewing Range of Expert Responses: Median "Best Guess" Scenario



Lines/markers indicate the **median** expert response

Shaded areas show the 25th to 75th percentile range of expert responses

Smaller "Leading Experts" Group Expects Greater LCOE Reduction than Larger Survey Group: Median Scenario

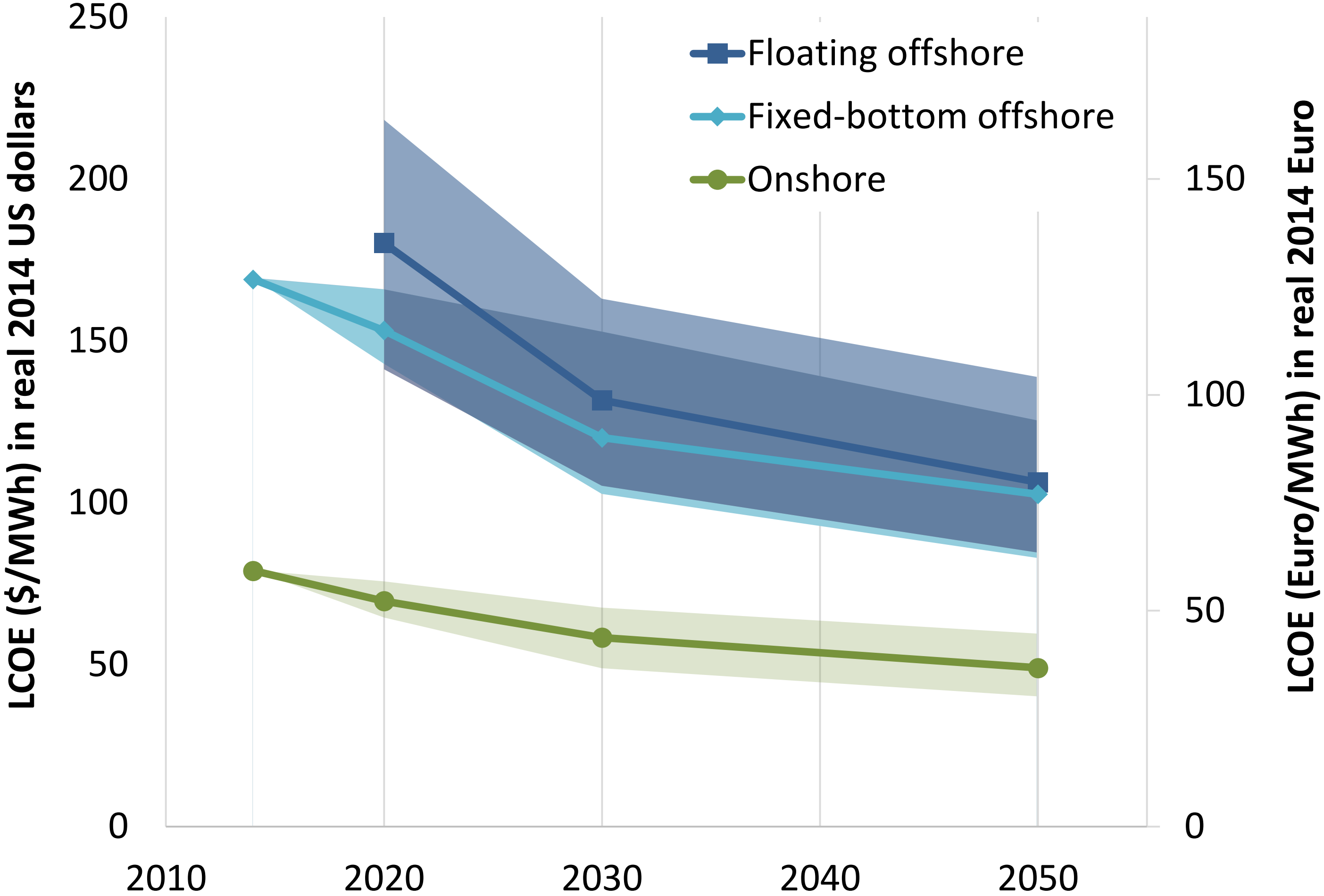


- Leading experts (22) foresee greater LCOE reductions in comparison to larger group less those leading experts (141) in the **median scenario** (shown) as well as in the **low scenario**
- Equipment manufacturers sometimes expect less LCOE reduction, especially in near term for fixed-bottom offshore; respondents who only expressed knowledge of offshore wind (not also onshore) tend to be more aggressive on LCOE reduction

In Absolute Terms, Narrowing Gap Between Onshore & Offshore, and Fixed-Bottom & Floating: Median Scenario

LCOE reductions for floating offshore are expected to be especially sizable between 2020 and 2030

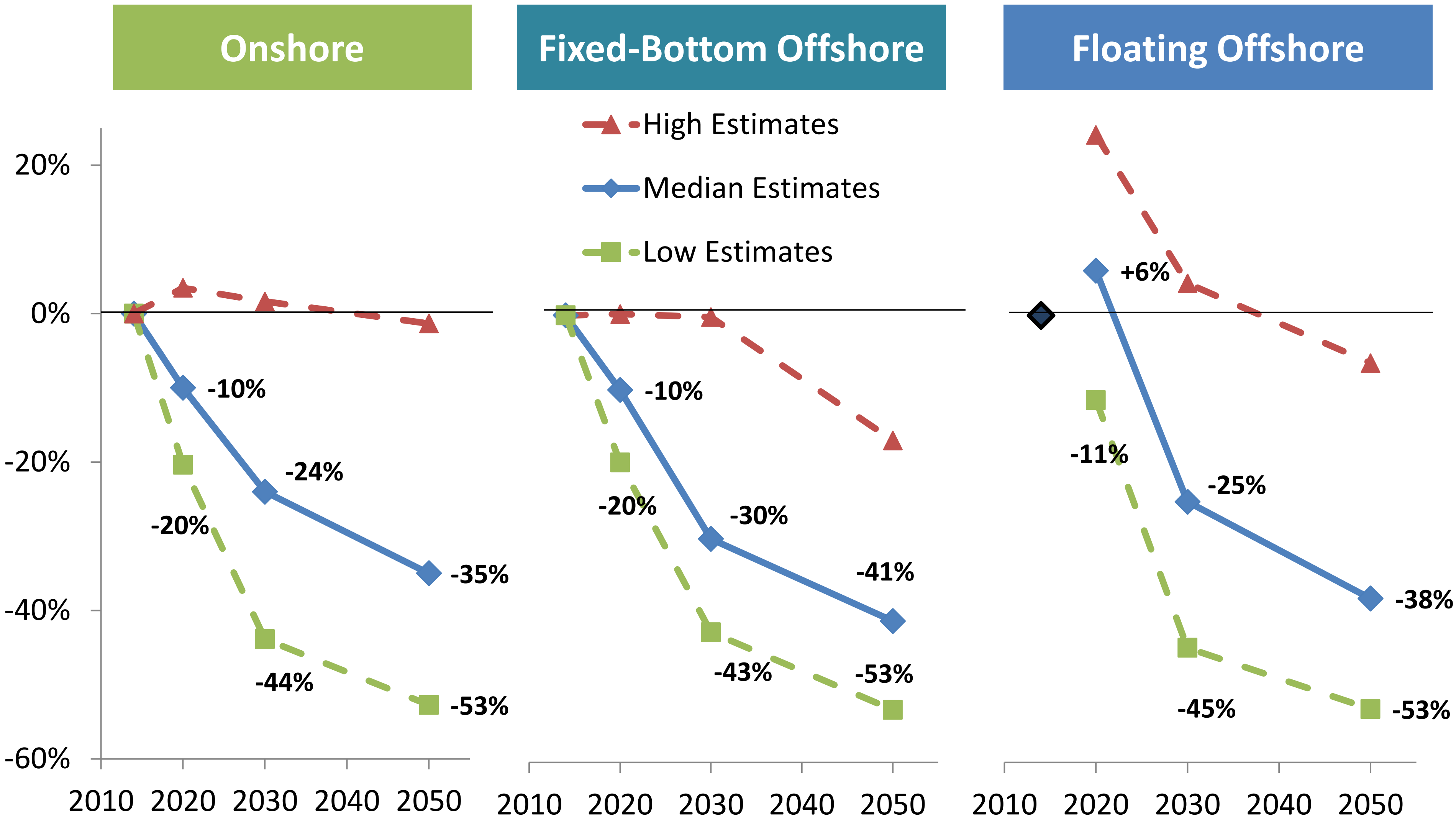
Greater uncertainty in offshore wind LCOE than in onshore LCOE



Lines/markers indicate the **median** expert response
Shaded areas show the 25th to 75th percentile range of expert responses

Note: Percentage changes from baseline are most broadly applicable approach to presenting findings (because each region & expert might have a different baseline value), but the relative absolute values of expert-specified LCOEs are also relevant

Sizable Opportunity Space for LCOE Reductions (and Uncertainty) Illustrated by Low / High Scenario Results



Managing Uncertainty and Aiming for Lower LCOE Is Partly Within the Control of Decision Makers

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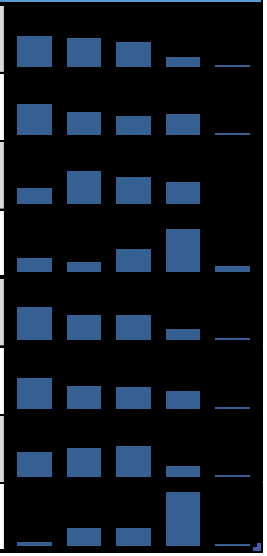
Asked respondents to rank broad drivers that might enable achieving low-scenario LCOE, separately for onshore and fixed-bottom offshore

	Wind technology, market, or other change	Percentage of experts ranking item "most important"	Mean Rating , Rating Distribution Ranking from **1**- most important to 5- least important	
Onshore Wind	Learning with market growth	33%	2.2	
	Research & development	32%	2.4	
	Increased competition & decreased risk	16%	2.5	
	Eased wind project & transmission siting	14%	3.2	
Offshore Wind	Learning with market growth	33%	2.2	
	Research & development	32%	2.3	
	Eased wind project & transmission siting	25%	2.3	
	Increased competition & decreased risk	5%	3.4	



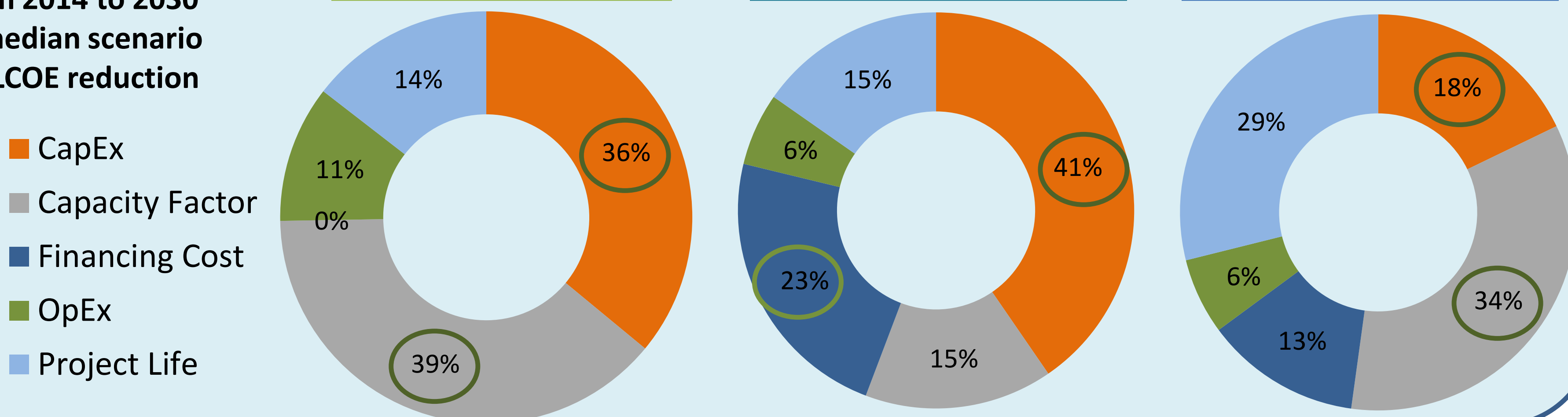
Learning with market growth and **Research and development** are the two most-significant enablers for the low LCOE scenario

How Will We Get There? Factor-Contribution to Median LCOE Scenario, 2014 to 2030

	Onshore -24%	Fixed-Bottom Offshore -30%	Floating Offshore -25%
Absolute Change in five factors from 2014 to 2030 in median scenario (↑)	Capacity Factor: +10% Project life: +10%	Capacity Factor: +4% Project life: +15%	Capacity Factor: +9% Project life: +25%
(↓)	CapEx: -12% OpEx: -9% WACC: 0%	CapEx: -14% OpEx: -9% WACC: -10%	CapEx: -5% OpEx: -8% WACC: -5%

Relative Impact
of five factor changes from 2014 to 2030 in median scenario on LCOE reduction

Onshore | Fixed-Bottom Offshore | Floating Offshore



For **floating offshore wind,** change and impact are shown relative to 2014 baseline for fixed-bottom

How Will We Get There? Factor-Contribution to Low LCOE Scenario, 2014 to 2030

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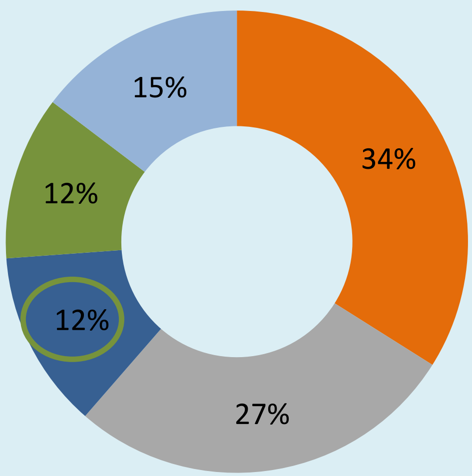
	Onshore -44%	Fixed-Bottom Offshore -43%	Floating Offshore -45%
Absolute Change in five factors from 2014 to 2030 in low scenario (↑)	Capacity Factor: +17% Project life: +25%	Capacity Factor: +11% Project life: +25%	Capacity Factor: +14% Project life: +25%
(↓)	CapEx: -24% OpEx: -25% WACC: -11%	CapEx: -25% OpEx: -21% WACC: -20%	CapEx: -14% OpEx: -18% WACC: -15%

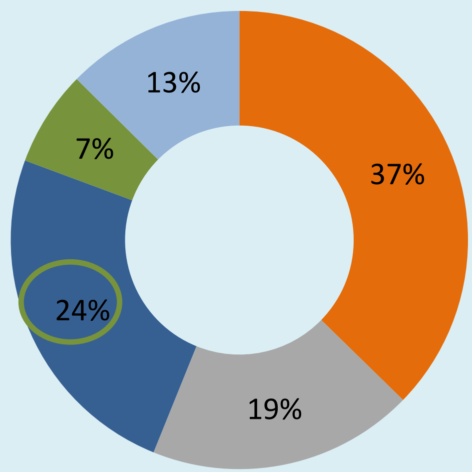
Relative Impact
of five factor changes from 2014 to 2030 in low scenario on LCOE reduction

- CapEx
- Capacity Factor
- Financing Cost
- OpEx
- Project Life

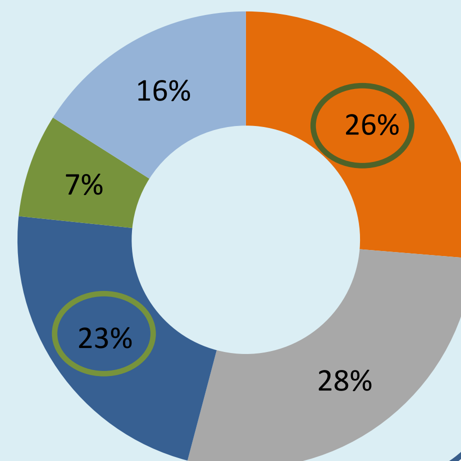
Onshore



Fixed-Bottom Offshore



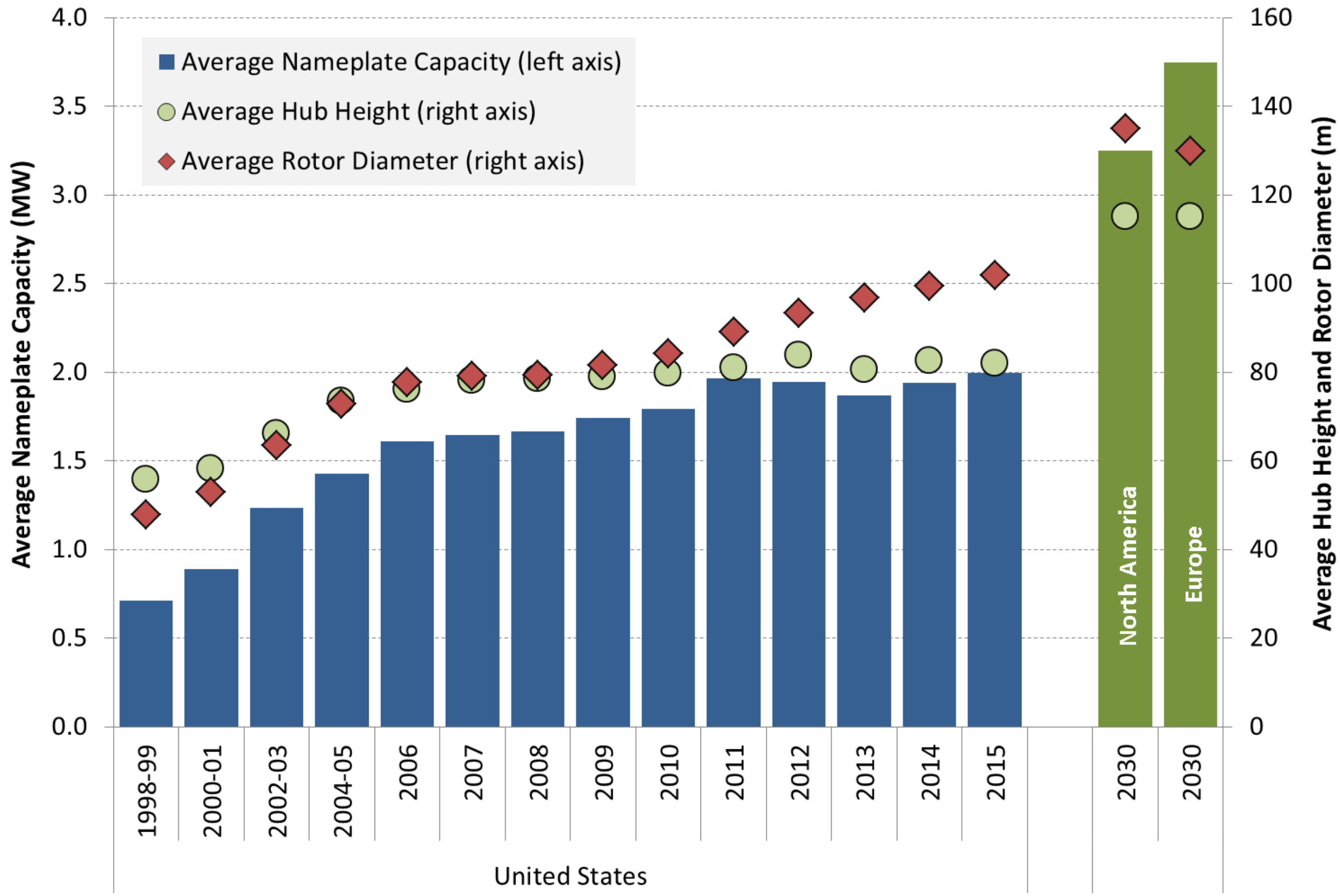
Floating Offshore



For **floating offshore wind,** change and impact are shown relative to 2014 baseline for fixed-bottom

CapEx & Capacity Factor Trends Driven by Growth in Turbine Size: Median Onshore Turbine Stats in 2030

Onshore: Continued scaling in nameplate capacity, hub height and rotor diameter, with decline in specific power globally to current U.S. levels and increase in hub height to current German levels→ focus on capacity factors



Current average specific power

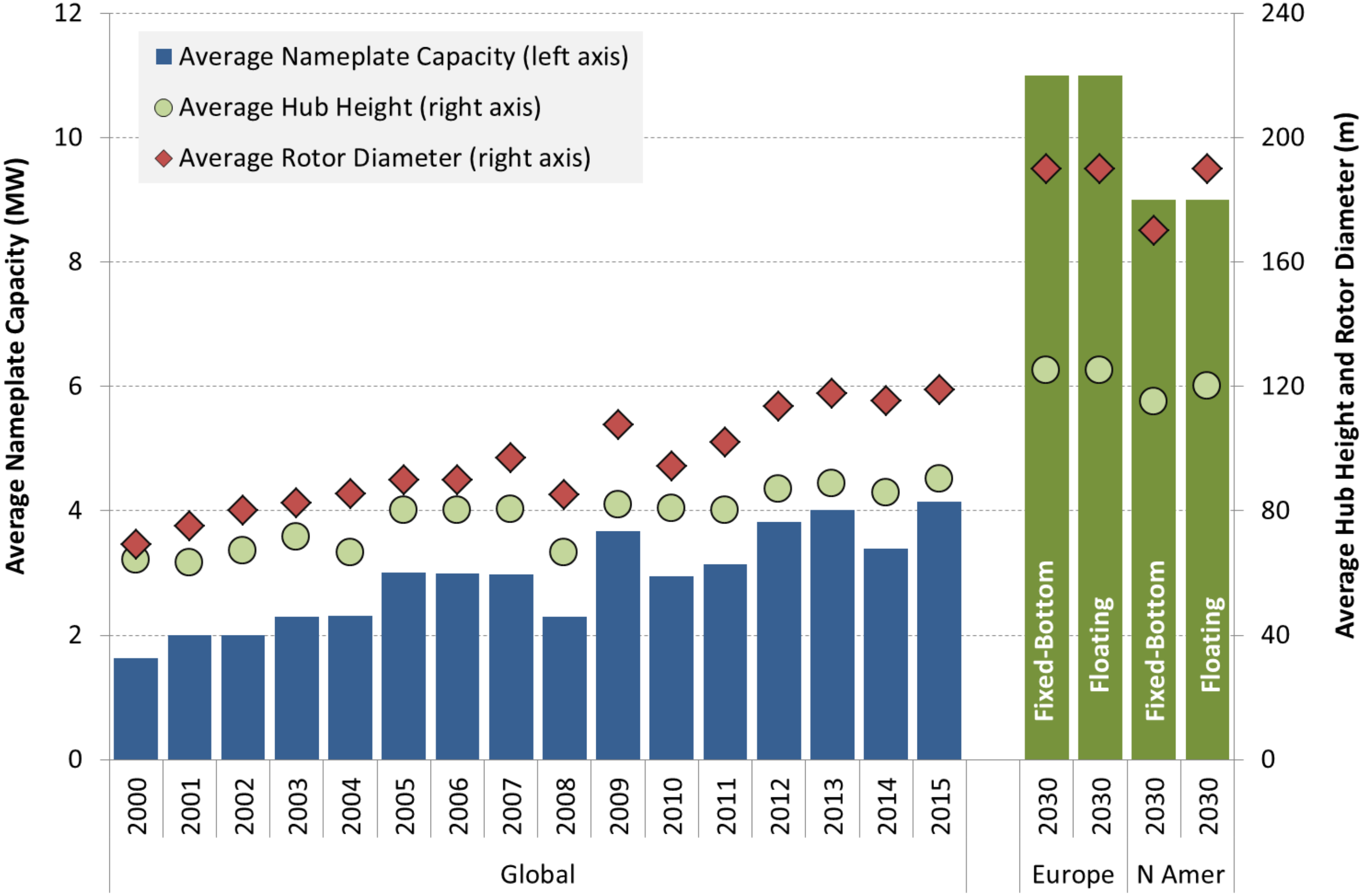
- U.S.: 250 W/m^2
- Germany: 330 W/m^2
- Denmark: 350 W/m^2

2030 average specific power

- N. Amer: 250 W/m^2
- Europe: 260 W/m^2

CapEx & Capacity Factor Trends Driven by Growth in Turbine Size: Median Offshore Turbine Stats in 2030

Offshore: Emphasis on increased nameplate capacity to reduce CapEx, with proportional scaling in hub height and rotor diameter leaving specific power at roughly current levels; somewhat larger turbines in Europe than N. Amer.



Current average specific power

- Global: 370 W/m^2

2030 average specific power

- Global: 380 W/m^2

Drivers for LCOE Reduction by 2030 Are Diverse: It's Not Just Turbine Size

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Survey asked about expected impact of 28 different technology, market, and other changes on LCOE reductions by 2030; Table shows top 5 responses for each turbine application

	Wind technology, market, or other change	% of Experts rating "Large expected impact"	Rating Distribution 3- large impact 2- medium impact 1- small impact 0- no impact
Onshore	Increased rotor diameter such that specific power declines	58%	
	Rotor design advancements	45%	
	Increased tower height	33%	
	Reduced financing costs and project contingencies	32%	
	Improved component durability and reliability	31%	
Fixed-Bottom Offshore	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	55%	
	Foundation and support structure design advancements	53%	
	Reduced financing costs and project contingencies	49%	
	Economies of scale through increased project size	48%	
	Improved component durability and reliability	48%	
Floating Offshore	Foundation and support structure design advancements	80%	
	Installation process efficiencies	78%	
	Foundation/support structure manufacturing standardization, efficiencies, and volume	68%	
	Economies of scale through increased project size	65%	
	Installation and transportation equipment advancements	63%	

Implicit Learning Rates for Onshore Wind from Expert Survey Broadly Consistent with Historical Observations

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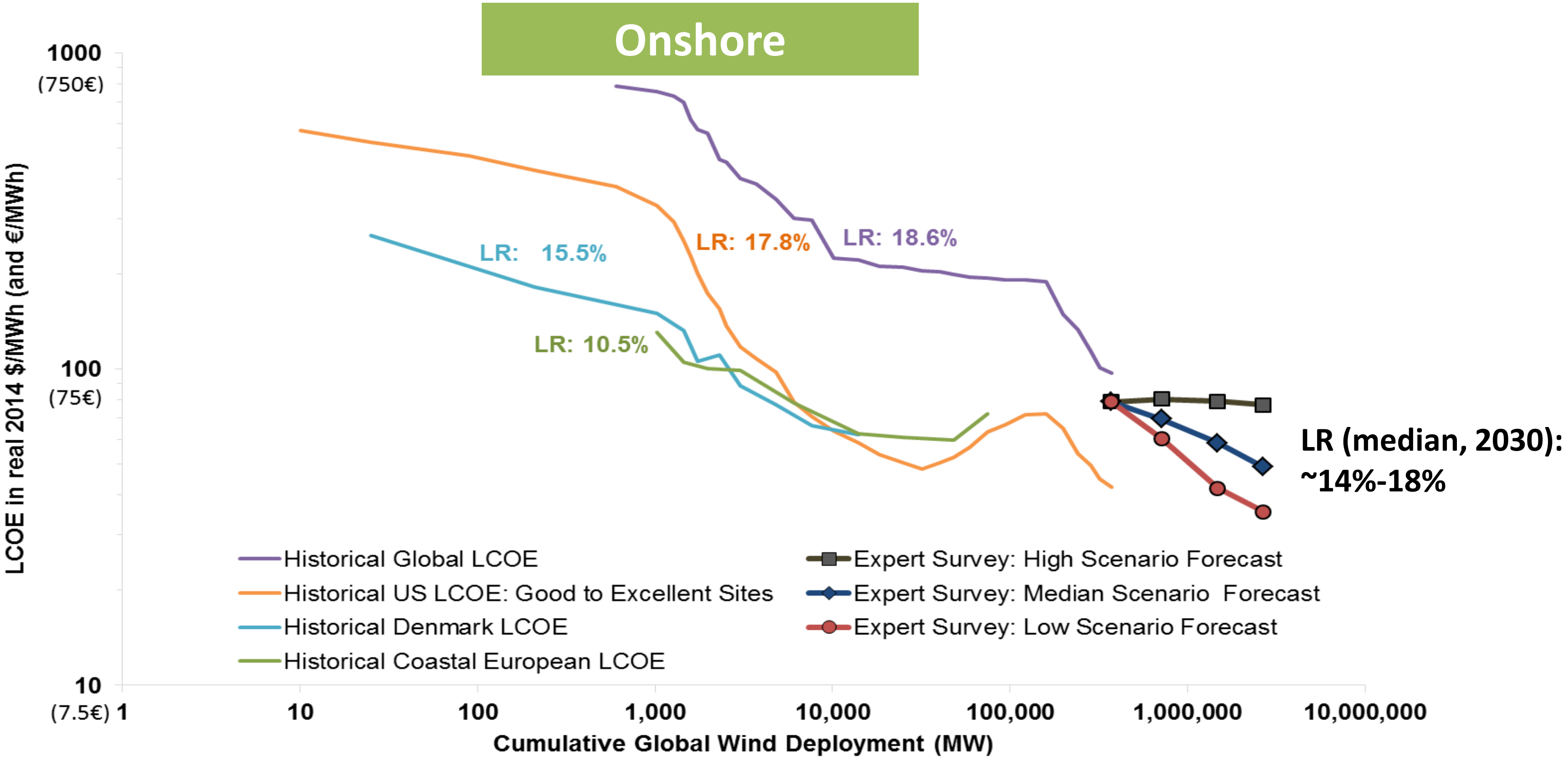
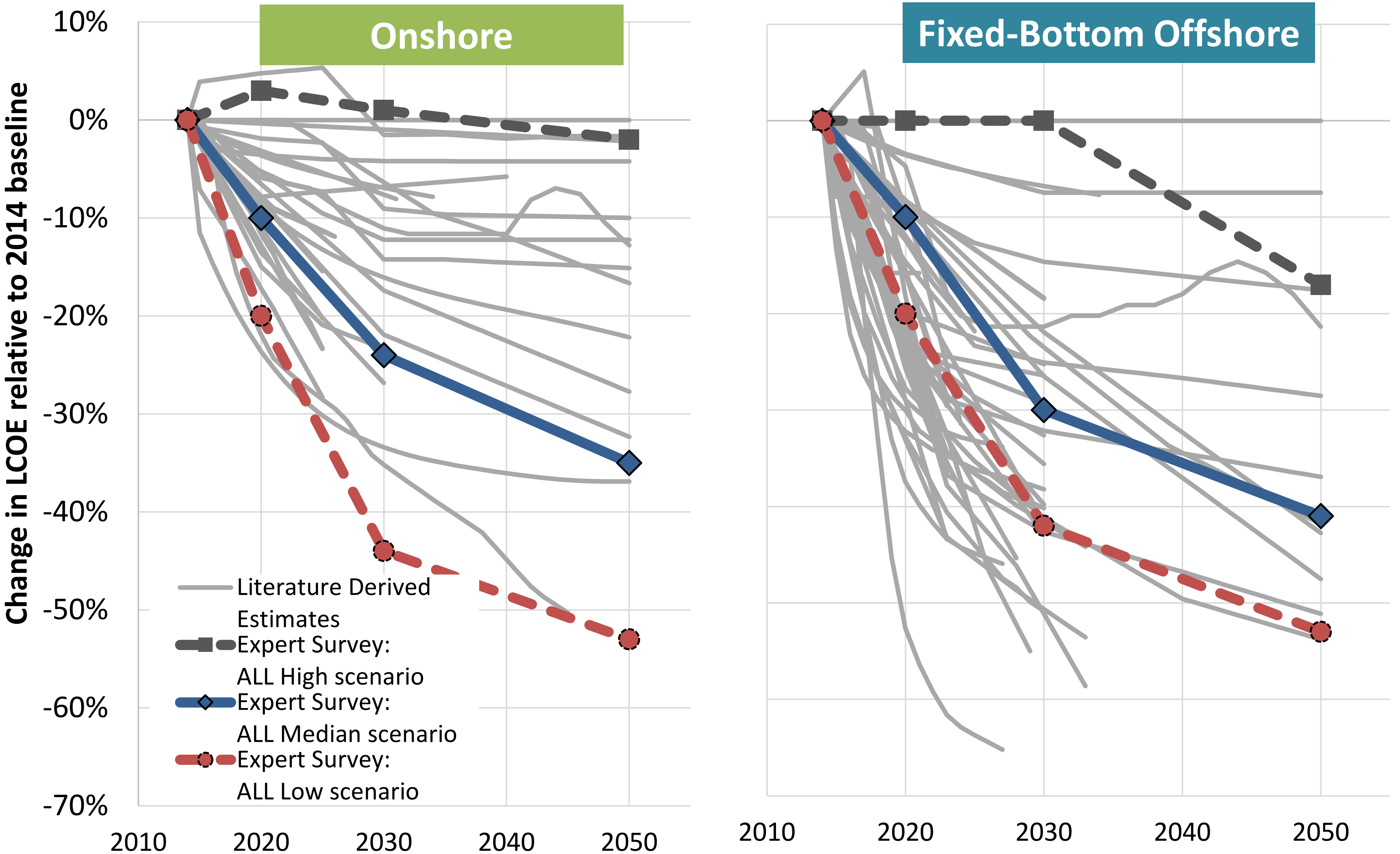
Implicit single-factor onshore learning rate for the Median Scenario in 2030 (14-18%) is in the same range as historical LCOE-based learning (10-19%)

For offshore, experts either anticipate lower offshore-only learning relative to onshore (8%), or expect learning spillovers from onshore to offshore (leading to learning rates of 16%-20%)



Experts Generally More Optimistic for Onshore Wind than Other LCOE Forecasts, but More Cautious for Offshore

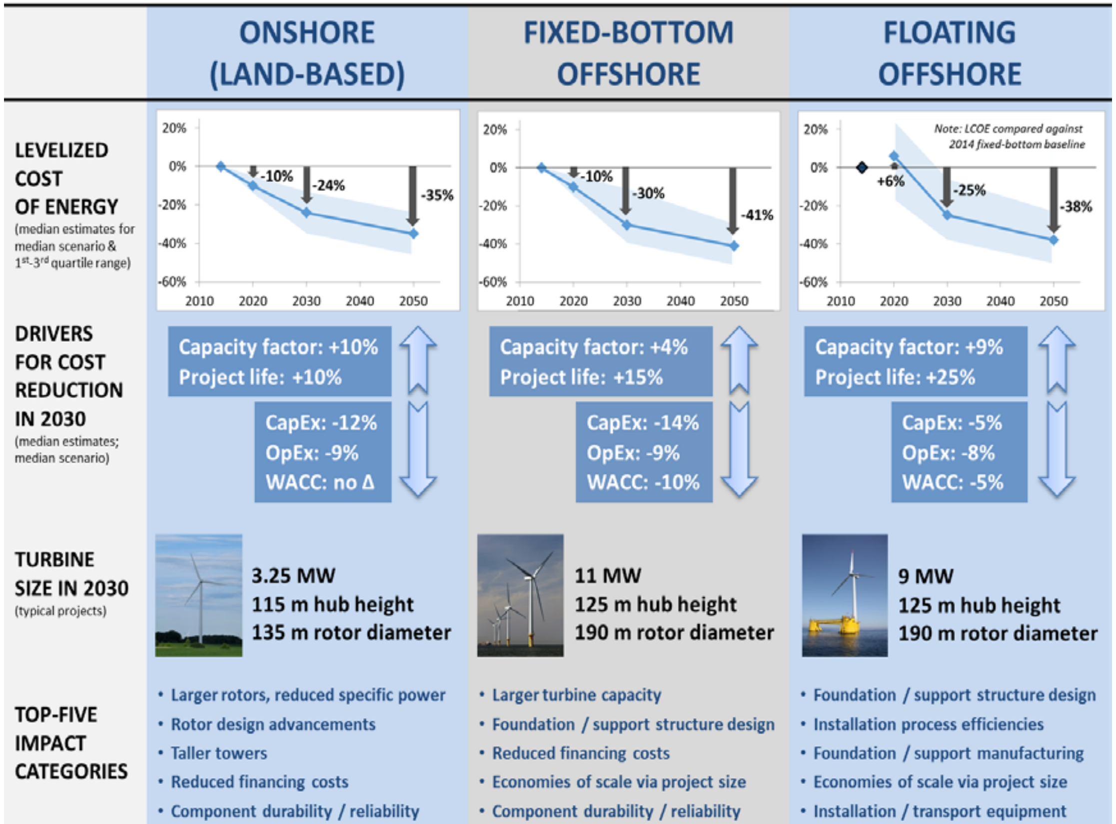


Conclusions

Conclusions

- Significant opportunities remain for LCOE reduction both onshore and offshore, but uncertainties are large
  - Planning-level assessments and decisions ought, ideally, to reflect this
- CapEx improvements are important, but by no means the only or even dominant pathway to LCOE reductions
  - Capacity factor, financing, OpEx, and project life all play important roles, with relative importance varying by wind application
  - Survey results can help identify high-level targets for R&D and policy
- Historical LCOE-based learning <u>may</u> be good guide for future onshore wind LCOE, but most learning estimates have instead been based on CapEx with lower onshore learning rates of 6%-9%
  - Compare to LCOE-based learning (10-19%) and survey findings (14-18%)
- Use of CapEx-based learning may explain relative conservatism of other forecasts, and may result in understatement of cost reduction potential
  - <u>If</u> used to forecast future costs, *LCOE-based* learning rates should be applied

Summary and Contact Information



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For the full report on the survey results and a complete slide deck, see:
https://emp.lbl.gov/iea-wind-expert-survey

Article summarizing survey results published in *Nature Energy:*
http://rdcu.be/khRk