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Forecasting Wind Energy Costs and Cost Drivers:

The Views of the World's Leading Experts

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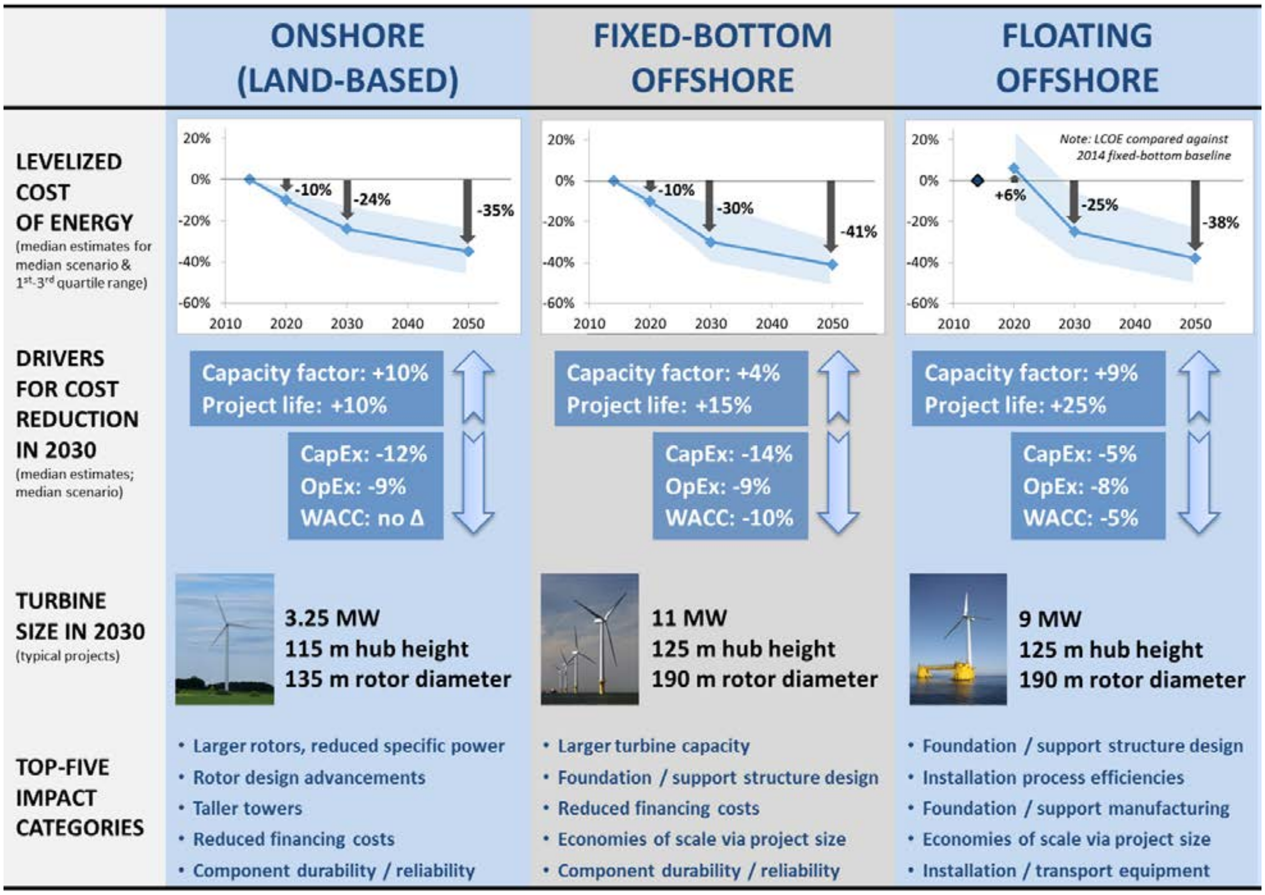
Executive Summary

This report summarizes the results of an expert elicitation survey of 163 of the world's foremost wind energy experts, aimed at better understanding future wind energy costs and technology advancement possibilities. We specifically sought to gain insight on the possible magnitude of future cost reductions, the sources of those reductions, and the enabling conditions needed to realize continued innovation and lower costs. In implementing what may be the largest single elicitation ever performed on an energy technology in terms of expert participation, we sought to complement other tools for evaluating cost-reduction potential, including learning curves, engineering assessments, and other means of synthesizing expert knowledge. Wind applications covered by the survey include onshore, fixed-bottom offshore, and floating offshore wind. Ultimately, the study is intended to inform policy and planning decisions, research and development decisions, and industry investment and strategy development while also improving the representation of wind energy in energy-sector planning models. Some key findings are summarized in Figure ES-1 and discussed below.

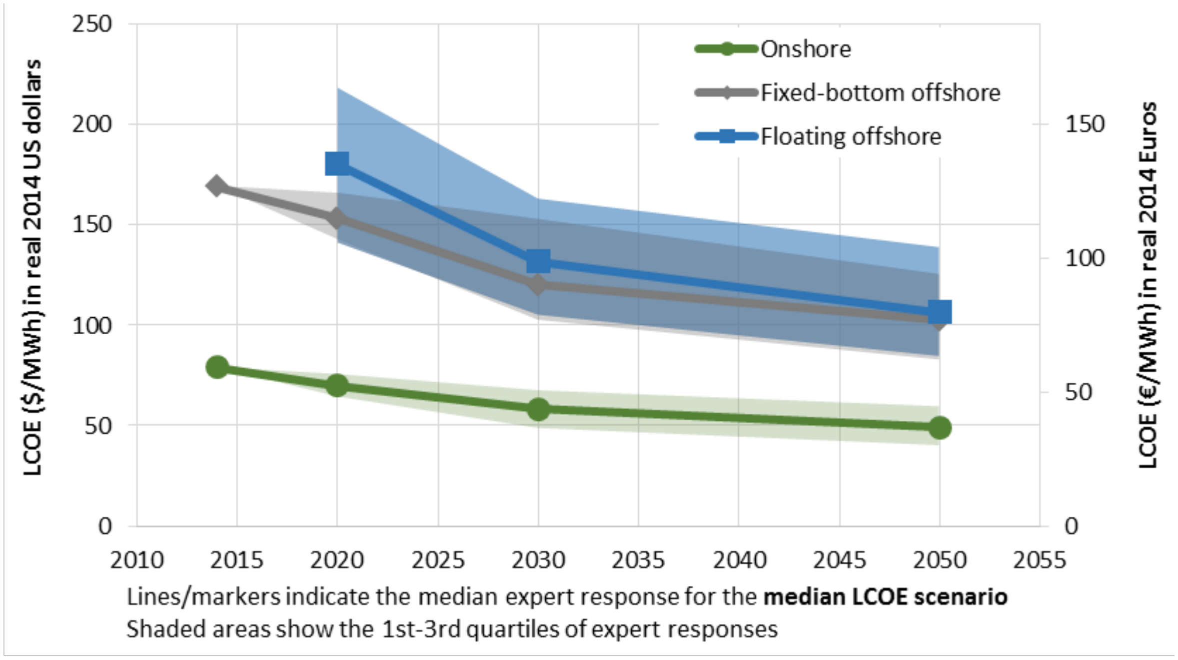


	ONSHORE (LAND-BASED)	FIXED-BOTTOM OFFSHORE	FLOATING OFFSHORE
LEVELIZED COST OF ENERGY (median estimates for median scenario & 1st-3rd quartile range)	-10% -24% -35%	-10% -30% -41%	Note: LCOE compared against 2014 fixed-bottom baseline +6% -25% -38%
DRIVERS FOR COST REDUCTION IN 2030 (median estimates; median scenario)	Capacity factor: +10% Project life: +10% CapEx: -12% OpEx: -9% WACC: no Δ	Capacity factor: +4% Project life: +15% CapEx: -14% OpEx: -9% WACC: -10%	Capacity factor: +9% Project life: +25% CapEx: -5% OpEx: -8% WACC: -5%
TURBINE SIZE IN 2030 (typical projects)	3.25 MW 115 m hub height 135 m rotor diameter	11 MW 125 m hub height 190 m rotor diameter	9 MW 125 m hub height 190 m rotor diameter
TOP-FIVE IMPACT CATEGORIES	• Larger rotors, reduced specific power • Rotor design advancements • Taller towers • Reduced financing costs • Component durability / reliability	• Larger turbine capacity • Foundation / support structure design • Reduced financing costs • Economies of scale via project size • Component durability / reliability	• Foundation / support structure design • Installation process efficiencies • Foundation / support manufacturing • Economies of scale via project size • Installation / transport equipment

Note: All dates are based on the year in which a new wind project is commissioned. LCOE and LCOE drivers are shown relative to 2014 baseline values. Rather than assume that all experts have the same internal 2014 baselines, we offered a default option but allowed experts to provide their own estimates for onshore and fixed-bottom offshore wind. Roughly 80% of experts opted to use the default baseline values. We did not seek a 2014 baseline estimate for floating offshore wind; floating offshore wind changes are therefore compared to expert-specific 2014 baselines for fixed-bottom offshore wind.

Figure ES–1. Summary of Expert Survey Findings

Significant Cost Reductions Are Anticipated: The modern wind industry has matured substantially since its beginnings in the 1970s. Expert survey results show an expectation of continued reductions in the levelized cost of wind energy (LCOE). Figure ES-1 summarizes LCOE-reduction expectations for the median (50th percentile, or "best guess") scenario, focusing on the median value of expert responses. Across all three wind applications, the LCOE is anticipated to decline by 24%–30% in 2030 and by 35%–41% in 2050, relative to 2014 baseline values. Though percentage changes from the baseline are the most broadly applicable approach to presenting survey findings because each region and expert might have different baseline values, depicting the relative absolute value for expert-specified LCOE is also relevant (Figure ES-2). In these terms, onshore wind is expected to remain less expensive than offshore—and fixed-bottom offshore less expensive than floating. However, there are greater absolute reductions (and more uncertainty) in the LCOE of offshore wind compared with onshore wind, and a narrowing gap between fixed-bottom and floating offshore, with especially sizable anticipated reductions in the LCOE of floating offshore wind between 2020 and 2030.



Note: Emphasis should be placed on the relative positioning of and changes in LCOE, not on absolute magnitudes. Because the 2014 baselines shown in the figure are the median of expert responses, they do not represent any specific region of the world. For any specific region, the 2014 baselines and future absolute LCOE values would vary. Additionally, because roughly 80% of experts chose to use the default 2014 baseline values for onshore and fixed-bottom offshore, the 1st and 3rd quartile as well and the median expert response for 2014 are all equivalent to those default baseline values.

Figure ES–2. Expert Estimates of Median-Scenario LCOE for All Three Wind Applications

Drivers of Cost Reduction Are Diverse: Figure ES-1 summarizes expert views on how the median scenario LCOE reductions between 2014 and 2030 might be achieved, in terms of upfront capital costs (CapEx), operating costs (OpEx), capacity factors, project design life, and cost of finance (weighted average cost of capital, WACC). Figure ES-3, meanwhile, highlights the *relative* impact of the changes in each driver in achieving the median scenario LCOE in 2030, while Figure ES-4 summarizes expected turbine characteristics in 2030 for typical projects, relative to selected 2014 baseline values.

For *onshore wind*, CapEx and capacity factor improvements constitute the largest drivers of LCOE reduction in the median scenario. The importance of higher capacity factors is consistent with expert views on turbine characteristics, with scaling expected not only in turbine capacity ratings but also rotor diameters and hub heights. Higher hub heights result in higher wind speeds, and therefore capacity factors. Experts also predict greater scaling in rotor swept area than in turbine capacity (leading to a reduction in specific power, defined as turbine capacity divided by rotor swept area), at least globally, also yielding higher capacity factors. For *fixed-bottom offshore wind*, CapEx and financing cost improvements are the largest contributors to LCOE reduction. The relatively higher importance of CapEx and lower importance of capacity factor is consistent with expert opinions on future offshore turbine size: expected turbine capacity ratings (and hub heights) grow significantly in order to minimize CapEx, but specific power is expected to remain roughly at recent levels. Capacity factor improvements play a larger role for *floating offshore wind* (relative to the 2014 baseline for fixed-bottom), perhaps reflecting a belief that floating technology will tend to be deployed in windier sites as enabled by the ability to access deeper water locations. Financing cost reductions are more important for offshore than for onshore wind, presumably due to its lower level of market maturity.

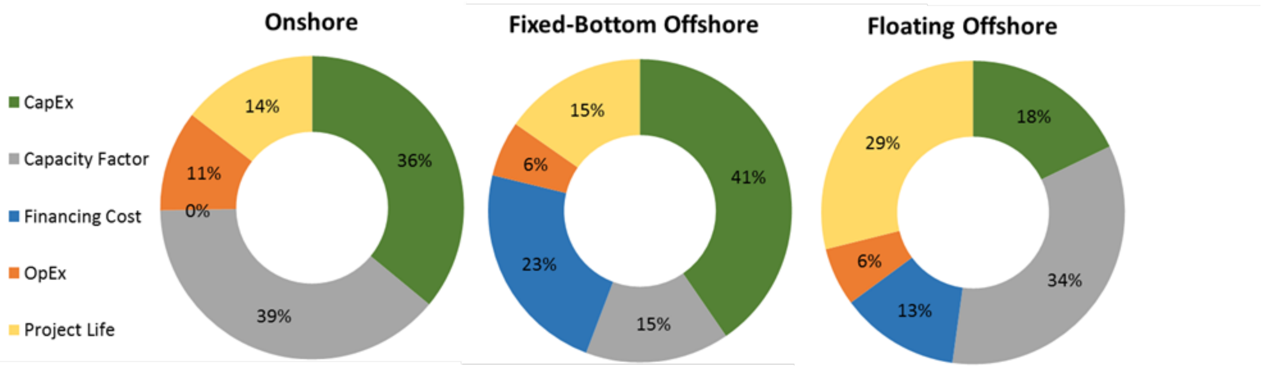


Figure ES–3. Relative Impact of Drivers for Median-Scenario LCOE Reduction in 2030

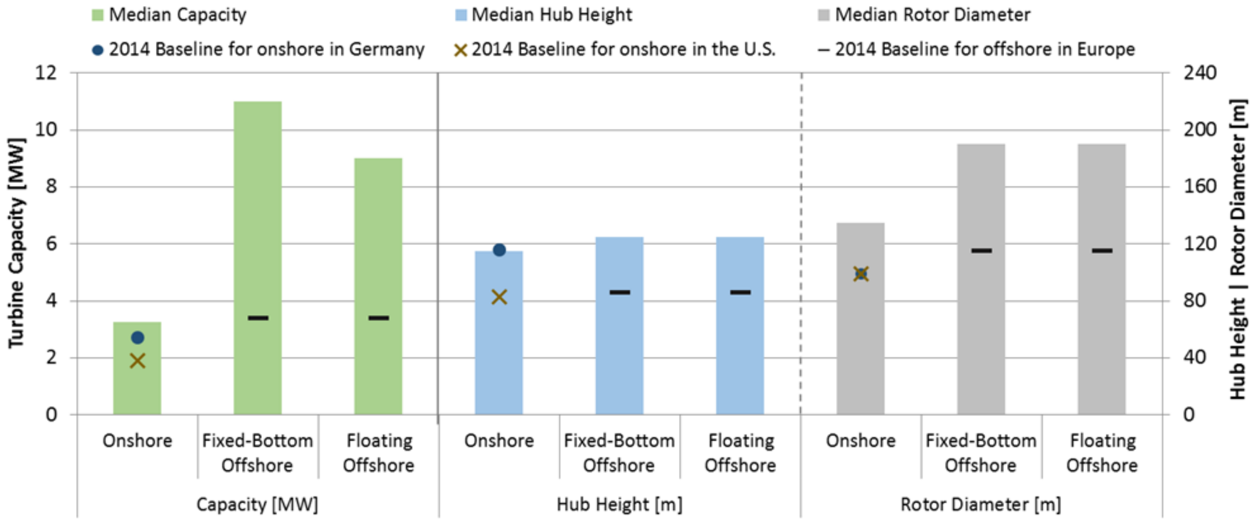
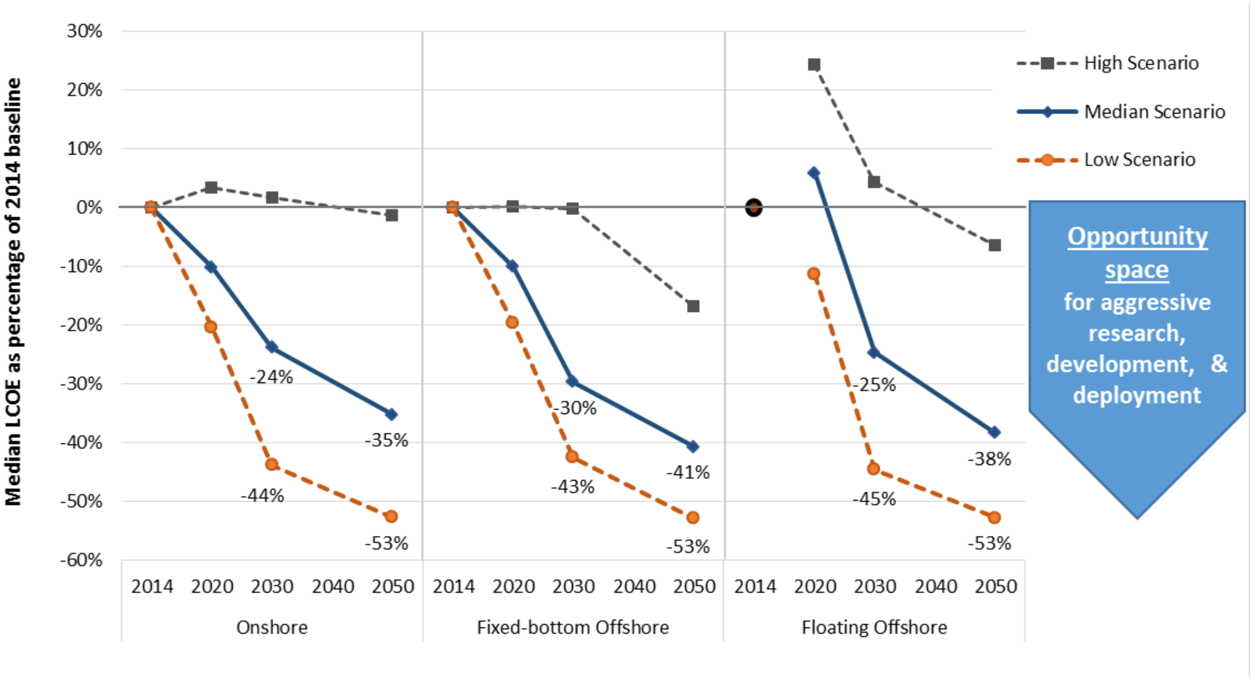


Figure ES–4. Wind Turbine Characteristics in 2030 for All Three Wind Applications

Opportunity Space for Greater Cost Reductions Is Sizable: We sought expert insight not only on the median (50th percentile) LCOE scenario, but also on less-likely scenarios for high and low future LCOEs. The sizable resulting range in expert-specified LCOEs (Figure ES-5) suggests significant uncertainty in the degree and timing of future advancements. On the other hand, managing this uncertainty is—at least partially—within the control of public and private decision makers; the low scenario, in particular, represents what might be possible through aggressive research, development, and deployment. Under the low scenario and across all three wind applications, experts predict LCOE percentage reductions of more than 40% by 2030 and more than 50% by 2050. The full report highlights how survey respondents believe that such LCOE reductions might be achieved. Those results further show that “learning with market growth” and “research and development” are the two most-significant broad enablers for the low LCOE scenario for both onshore and offshore wind.



Note: Floating offshore wind is compared against the 2014 baseline for fixed-bottom offshore.

Figure ES–5. Estimated Change in LCOE over Time for All Three Wind Applications

Many Advancement Opportunities Exist: A variety of development, technology, design, manufacturing, construction, operational, and market changes might contribute to reducing LCOE. Respondents rated 28 different drivers based on their expected impact on LCOE. The top-5 responses for each wind application are listed in Figure ES-1, and a general summary of the findings is shown in Figure ES-6. That the two leading drivers for LCOE reduction for onshore wind are related to rotors—increased rotor diameters and lower specific power, and rotor design advancements—confirms earlier survey results highlighting capacity factor improvements as a major contributor to LCOE reduction. Increased hub heights, coming in at number three on the ranked list, are also consistent with this theme. The relative ranking differs for offshore wind. For fixed-bottom offshore, the most highly rated advancements include increased turbine capacity ratings, design advancements for foundations and support structures, and reduced financing costs and project contingencies. Some of the same items rate highly for floating offshore wind, with an even greater emphasis on foundations and support structures as well as installation processes.

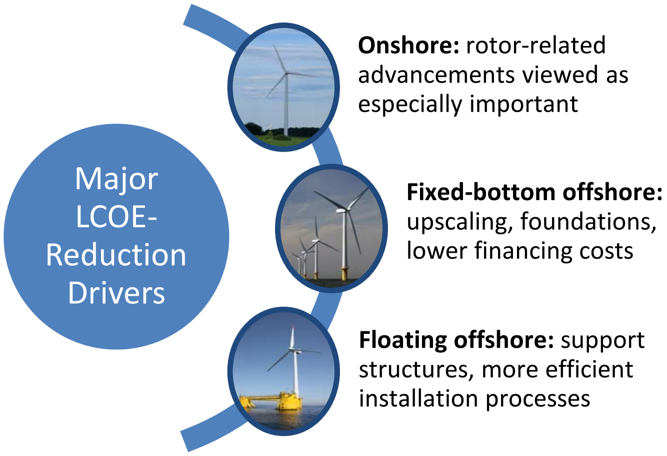
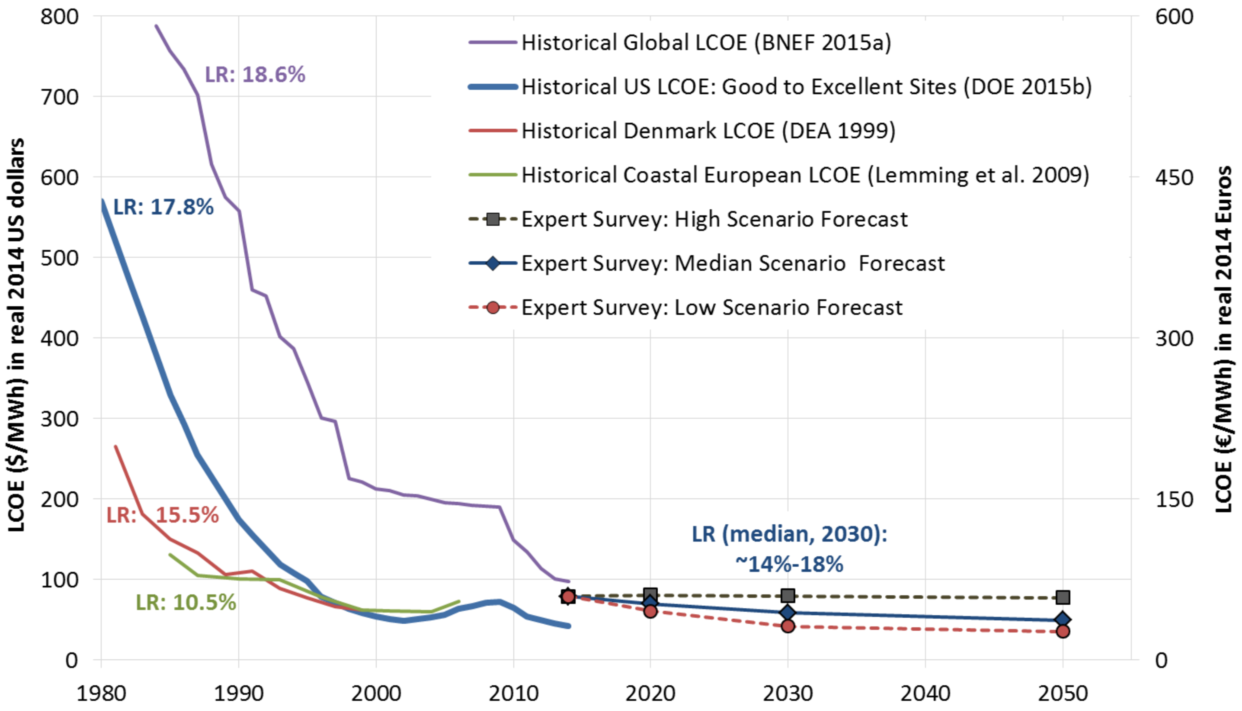


Figure ES–6. Top Advancement Opportunities

Cost Reductions Are Uncertain, Differ by Respondent Demographics: Considerable uncertainty exists across all of these variables and factors, partly reflected in the range between the low, median, and high scenarios shown in Figure ES-5. Differences are also found when reviewing the range in expert-specific responses, as shown in the 25th to 75th percentile expert ranges depicted in Figures ES-1 and ES-2. Some of the variation in expert-specific responses can be explained by segmenting respondents into various categories. For example, we find that a smaller "leading-expert" group generally expects more-aggressive wind energy cost reductions than the larger set of other survey respondents, whereas equipment manufacturers are more cautious about nearer-term advancement possibilities.

Comparing Survey Results with Historical LCOE Estimates and Other Forecasts: Notwithstanding the sizable range in LCOE estimates reflected in the expert survey results, those results are found to be broadly consistent with historical LCOE trends—at least for onshore wind. Figure ES-7 depicts four separate estimates of historical onshore wind LCOE and associated single-factor learning rates (LRs = 10.5%–18.6%, meaning that LCOE declines by this amount for each doubling of global cumulative wind capacity). Though learning rates are an imperfect tool for understanding the drivers of past cost reduction or forecasting future costs, the implicit learning rate embedded in the median-scenario LCOE forecast from our experts to 2030 (about 14%–18%, depending on the magnitude of future wind capacity deployment in that median scenario) is squarely within the range of these past, long-term learning trends for onshore LCOE. Turning to offshore wind, historical cost trends are mixed, with an initial reduction in costs for the first fixed-bottom offshore wind installations in the 1990s, following by steeply increasing costs in the 2000s and, most recently, some indication of cost reductions. Given this history, there have been few attempts to fit a learning curve to offshore data. It is also unclear what learning specification might best be used to understand past trends or to forecast future ones, as offshore wind costs might decline as a result of both onshore and offshore experience. Overall, expert survey findings on offshore LCOE reductions suggest that experts either anticipate lower offshore-only learning (relative to learning for onshore wind) or expect learning spillovers from onshore to offshore.



Note: For the expert survey results, emphasis should be placed on the relative positioning of and changes in LCOE, not on absolute magnitudes. Because the 2014 baselines shown in the figure are the median of expert responses, they do not represent any specific region of the world. For any specific region, the 2014 baselines and future absolute LCOE values would vary. For similar reasons, it is not appropriate to compare expert-survey results in terms of absolute LCOE magnitudes with the historical LCOE estimates shown on the chart for specific regions. Finally, learning rates are calculated based on a log-log relationship between LCOE and cumulative wind installations; as such, while historical learning rates closely match expected future learning predicted by the expert elicitation, visual inspection of the figure does not immediately convey that result.

Figure ES–7. Historical and Forecasted Onshore Wind LCOE and Learning Rates

Expert elicitation results can also be compared to other forecasts of LCOE—whether derived from learning curves, engineering assessments, expert knowledge, or some combination of the three (Figure ES-8). As shown, expert survey results are broadly within the range of other forecasts, but the elicitation tends to show greater expectations for LCOE reductions for onshore wind in the median scenario than the majority of other forecasts. Survey results for offshore wind, on the other hand, tend to be more conservative than the broader literature, with a large number of the other forecasts showing steeper cost reductions than even the low-scenario expert survey results.

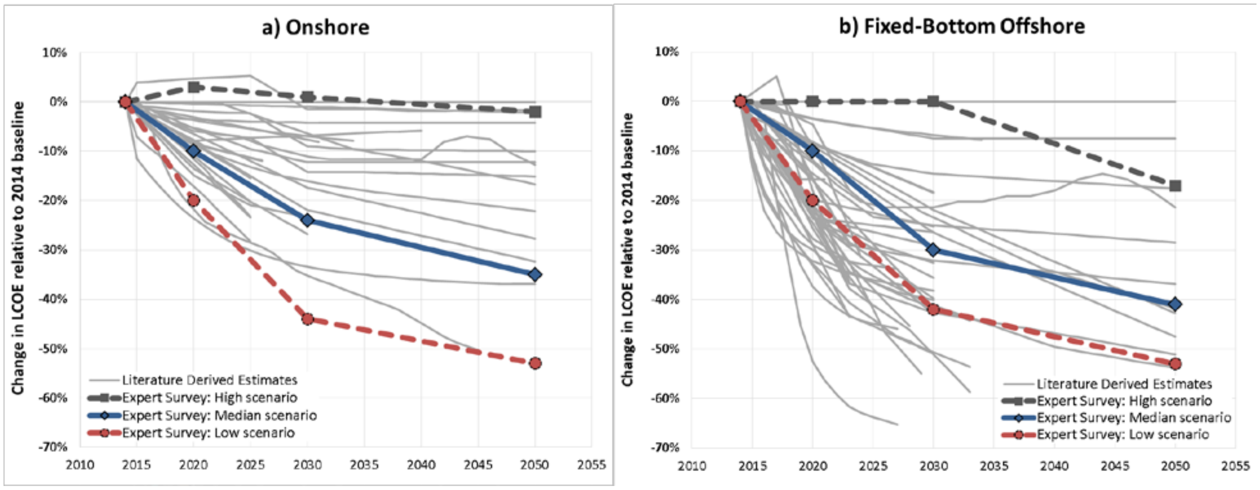


Figure ES–8. Estimated Change in LCOE: Expert Survey Results vs. Other Forecasts

Learning Estimates: Getting it Right: As shown earlier in Figure ES-7, elicitation results for onshore wind are consistent with historical LCOE learning, suggesting that properly constructed learning rates may be reasonably used to forecast future costs in more mature applications. However, the majority of the literature assessing historical learning rates for wind has emphasized only upfront capital costs, and some energy-sector and integrated-assessment models rely on those capital-cost-based learning estimates when forecasting future costs. Expert elicitation findings demonstrate that capital-cost improvements are only one means of achieving LCOE reductions, however, and not always the dominant one. Extrapolation of past capital-cost-based learning models therefore likely understates the opportunities for future LCOE reduction by ignoring major drivers for that reduction. This is illustrated by the fact that the elicitation-based forward-looking LCOE learning rates are twice as high as recently estimated CapEx-based learning rates for onshore wind of 6-9%, and may explain why onshore cost reduction estimates from wind experts are more aggressive than many past forecasts.

1. Introduction

Wind energy supply has grown rapidly over the last decade, supported by a myriad of national and sub-national energy policies and facilitated by technology advancements and related cost reductions (IEA 2013; GWEC 2015; IRENA 2015; REN21 2015). Though the vast majority of this expansion has occurred onshore (>97%), offshore wind power deployment has also recently increased, especially in Europe. The rising maturity of wind power technology suggests that wind energy might play a significant future role in global electricity supply, perhaps especially in the context of efforts to reduce greenhouse gas emissions (Wiser et al. 2011; IPCC 2014; GWEC 2014; Luderer et al. 2014; IEA 2015).

The long-term contribution that wind energy makes to global 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. Those costs will be affected by technology advancements, as impacted by private and public research and development (R&D), among other factors. Yet there remains sizable uncertainty about both the degree to which costs will continue to decline and the conditions that might drive greater cost reduction (Wiser et al. 2011; Lantz et al. 2012; DOE 2015a).

This report summarizes the results of an expert elicitation survey on future wind energy costs and technology advancement possibilities. 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 future cost reduction and the enabling conditions needed to realize continued innovation and lower costs. An understanding of the potential for wind power costs to fall and the means by which future cost reductions could be delivered can inform policy and planning decisions affecting wind power deployment, R&D in the private and public sectors, and industry investment and strategy development. Enhanced insight into future cost-reduction opportunities also supports improved representation of wind energy technology in energy-sector modeling efforts.

Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory led the gathering of data and insights through an online elicitation survey of a large sample of the world's foremost wind energy experts, under the auspices of the International Energy Agency (IEA) Wind Implementing Agreement. The survey is global in scope—though with a focus on North America and Europe—and covers onshore (land-based), fixed-bottom offshore, and floating offshore wind technology. It emphasizes costs and associated drivers of cost changes in 2030, but with additional markers in 2020 and 2050. This report summarizes the 163 survey responses received, in what may be the largest single expert elicitation ever performed on an energy technology. Insights gained through this survey can complement other tools for evaluating cost-reduction potential, including the use of learning curves, engineering assessments, and less-formal means of synthesizing expert knowledge.

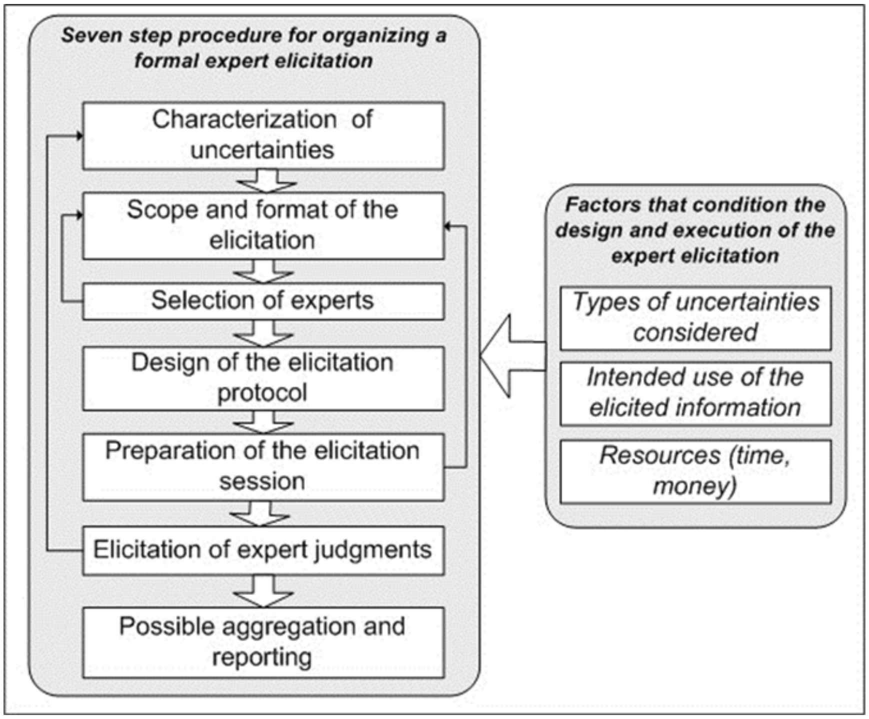
The remainder of this report is organized as follows. Chapter 2 introduces expert elicitation and discusses the scope, design, and implementation of our assessment. Chapter 3 summarizes our core results. Finally, Chapter 4 offers conclusions and discusses anticipated future work.

2. The Expert Elicitation Survey

2.1. Review of Expert Elicitation and other Methods to Assess Future Costs

Though multiple approaches have been used to assess the past and future cost of wind energy (discussed below), ours is one of the first publically available *formal* expert elicitation surveys with an explicit focus on future wind energy costs and related technology advancements.

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 (Morgan 2014). Several options are available to a researcher who wishes to make such estimates: make projections based on past data and trends, review existing literature and adopt projections made by others, develop detailed models based on experience in related fields and apply them to create forecasts, and so on. The expert elicitation approach is to carefully assess projections of the quantities of interest from relevant subject-matter experts. It is often considered the best—or perhaps the only—way to develop credible estimates when data are sparse or lacking, or when projections are sought for future conditions that are very different from past conditions (Kotra et al. 1996; Meyer and Booker 2001). Several formal protocols for organizing and conducting expert elicitations have been developed; all follow a very similar set of steps to those described by Knol et al. (2010) and summarized in Figure 1.



Source: Knol et al. (2010)

Figure 1. Steps in a Formal Expert Elicitation

Within this general protocol, a rich literature provides guidance on elicitation question design, the importance of clarity in what is being asked, how to avoid or minimize the effects of expert motivational and cognitive biases, and the importance of providing feedback to experts and providing opportunities for them to review and update their assessments (Hora 2007; Coppersmith et al. 2009; Morgan 2014). Section 2.3 below describes how we applied these principles in our expert elicitation.

Expert elicitations have been widely used to support decision making in the private sector (Sharpe and Keelin 1998) and in policy decisions (Hora and von Winterfeldt 1997). Their use is explicitly called for in a review of the Intergovernmental Panel on Climate Change (InterAcademy Council 2010) and implicitly called for in a National Academies review of the U.S. Department of Energy's Applied Energy R&D programs (NRC 2007). Within the energy community, expert elicitation is increasingly common as a tool for making estimates of the future costs of energy technologies under different possible future scenarios. Baker et al. (2015), for example, review nearly 20 such elicitations conducted over the past decade, including studies focused on carbon capture and storage, solar, nuclear, biomass, and storage technologies. Gillenwater (2013) uses expert elicitation to explore wind investment decisions, and Kempton et al. (2016) use elicitation to understand future offshore wind costs in one region of the United States, but formal elicitation procedures have not yet been widely applied to wind energy costs and related technology advancements. Verdolini et al. (2016) provide a comprehensive review of energy technology expert elicitation studies.

Expert elicitation is not without weaknesses—in general and when applied to wind energy. Expert responses may be affected by the design of the data-collection instrument, by the individuals selected to submit their views, by the behavior of the interviewers (for in-person elicitation), and by features of the questionnaire or web-based instrument. That said, when implemented well, insights gained through expert elicitations can complement other tools to assess cost-reduction potential, including learning curves, engineering assessments, and less-formal means of synthesizing expert knowledge (Lantz et al. 2012). These other methods have been used regularly—both individually and in combination—to assess potential future wind energy cost reductions:

- <u>Learning curves</u> have a long history within the wind sector (see Wiser et al. 2011; Lindman and Söderholm 2012; Rubin et al. 2015), but they have been criticized for simplifying the many causal mechanisms that lead to cost reduction (Ferioli et al. 2009; Mukora et al. 2009; Ek and Söderholm 2010; Junginger et al. 2010; Yeh and Rubin 2012; Witajewski-Baltvilks et al. 2015). Further, few published studies focus on the most important metric of wind energy costs, the levelized cost of energy (LCOE) (BNEF 2015a; Wiser et al. 2011; Rubin et al. 2015), with most research directed towards one component of LCOE: upfront capital costs (Ferioli et al. 2009; Dinica 2011; Rubin et al. 2015). 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 (Arrow 1962; Nordhaus 2009; Ferioli et al. 2009). For technologies with limited historical data, such as floating offshore wind, it is not even possible to compute technology-specific learning rates.

- <u>Engineering assessments</u> provide a bottom-up, technology-rich alternative or complement to learning curve analyses (Mukora et al. 2009). They involve detailed modeling of specific possible technology advancements (e.g., BVG 2015; Bywaters et al. 2005; Malcolm and Hansen 2002;

Fingersh et al. 2006; Crown Estate 2012; Sieros et al. 2012; Fitchner-Prognos 2013; Valpy and English 2014a,b). Because this approach often models both cost and performance, it inherently emphasizes expected reductions in LCOE. It requires a robust understanding of possible technology advancements, thus the opportunities captured by engineering studies are often incremental and generally realizable in the near to medium term (less than 15 years). This approach also generally requires sophisticated design and cost models to capture the full array of component- and system-level interactions, and rarely provides insight into the probability of different outcomes.

- Expert knowledge can be obtained through many means, not only through formal elicitation procedures. Through interviews, workshops, and other approaches, expert insight is a mainstay of many recent attempts to forecast future wind technology advancement and cost reduction. It can be paired with engineering assessment and learning curve tools to bolster the reliability of the overall estimates, garner a more detailed understanding of how cost reductions may be realized, and clarify the uncertainty in these estimates. The use of expert knowledge has proven especially valuable for emergent offshore wind technologies, for which historical data are often lacking (Junginger et al. 2004; Crown Estate 2012; Fitchner-Prognos 2013; Navigant 2013; TKI Wind op Zee 2015), but expert insight has also been used to assess onshore wind (Cohen et al. 2008; Neij 2008) and to compare onshore and offshore (Wüstemeyer et al. 2015). As with more-formal elicitation procedures, care is needed to avoid bias and overconfidence in expert responses.

2.2. Scope of Expert Assessment: What Were We Asking?

The scope of our assessment comprises three wind power applications: utility-scale onshore wind, fixed-bottom offshore wind, and floating offshore wind. Onshore (i.e., land-based) wind is relatively mature, and it already makes a significant contribution to energy supply in many countries. Fixed-bottom offshore wind can use multiple foundation types (e.g., monopile, jacket, gravity base). It is less mature than onshore wind, but it is being deployed at scale in Europe and, to a lesser degree, outside of Europe. Floating offshore wind (e.g., spar buoy, semi-submersible platform, tension-leg platform) is not yet fully commercialized, but it has been deployed in full scale demonstration projects.

Our analysis centers on potential changes in the LCOE of projects that use each of the three wind applications, in dollars or euros per megawatt-hour ($/MWh or €/MWh). The LCOE is the levelized cost per unit of generated electricity from a specific source over its project design life that allows recovery of all project expenses and meets investor return expectations.[1] The LCOE is regularly used to assess the unit costs of electric-generation technologies, and minimizing LCOE is a primary goal of the wind

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[1] We calculate LCOE in real 2014$ or 2014€ per MWh. This LCOE estimate equates to the minimum power price a project must obtain to cover all project costs, service debt, pay expected returns to equity shareholders, and cover income tax. LCOE is calculated at the plant boundary and excludes the valuation of public benefits (e.g., Renewable Energy Credits, carbon credits, Green Certificates) as well as ratepayer, taxpayer, or other forms of project-level government support (e.g., investment and production tax credits, feed-in-tariff premiums). The formula used to calculate LCOE and more details on its use in this survey can be found at: http://rincon.lbl.gov/lcoe_v2/background.html.

industry and of wind energy R&D.[2]

In surveying the experts, we sought insight on the LCOE of the three wind applications at four time points: a recent-cost baseline in 2014 (for which respondents could accept a predefined baseline or create their own) and then in 2020, 2030, and 2050.[3] Note that these dates are based on the year in which a new wind project is commissioned. We did not seek a baseline estimate for floating offshore wind, given the nascent present state of that technology and lack of current commercial applications.

For the baseline year, and for our focus year of 2030, we further requested details on five core input components of LCOE: (1) total upfront capital costs to build the project (CapEx, $ or €/kW); (2) levelized total annual operating expenditures over the project design life, including maintenance and all other ongoing costs, e.g., insurance and land payments (OpEx, $ or €/kW-yr); (3) average annual net project-level energy output (capacity factor, %); (4) project design life considered by investors (years); and (5) costs of financing, in terms of the after-tax, nominal weighted-average cost of capital (WACC, %).[4,5] For the other two time points (2020, 2050), we solicited only estimates of the LCOE.

For the 2014 and 2030 CapEx estimates, respondents were asked to include only costs within the plant boundary, which include costs for electrical cabling within the plant but exclude costs for any needed substations, transmission lines, or grid interconnection costs. As applied to offshore wind, this means that CapEx includes costs for within-plant array cabling but excludes the costs for offshore substations, any high-voltage direct-current collector stations and associated cables, and grid connection to land (e.g., subsea export cables, onshore substations, and onshore transmission cables). As defined in the

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[2] Though LCOE is useful for showing generation cost trends, simply comparing LCOEs among different electric-generation technologies is not sufficient to judge the relative value of those technologies. This is because electric system planners and modelers must consider not only levelized generation costs, but also system costs that include consideration of system peaking needs, transmission expenditure, and variable generation integration (Joskow 2011; Wiser et al. 2011; Edenhofer et al. 2013; Hirth 2013; Mills and Wiser 2013). Differences in taxation, incentives, and societal benefits and costs are also often considered.

[3] Inclusion of a 2014 baseline allows for any changes over time to be characterized in absolute ($ or €) and relative terms (% increase or decrease).

[4] This represents the average return required by the combination of equity and debt investors to make a project an attractive investment opportunity, where each category of capital is proportionately weighted. The WACC may be defined in after-tax or pre-tax terms. Owing to highly variable tax rules as well as the use of the tax code to incentivize wind energy in some countries, this survey relies exclusively on an after-tax WACC. Under these conditions, respective equity returns should reflect the annual average rate of return for equity positions after expenses and taxes, independent of how the rate of equity return is impacted by the applicable tax code. Similarly, debt interest rates should account for their status as a business tax deduction where applicable. In practice, after-tax WACCs may be considered either in real or nominal terms. Assuming an inflation rate of 2%, the following conversions between nominal and real apply: 4% nominal WACC = 2% real WACC; 8% nominal WACC = 5.9% real WACC; 12% nominal WACC = 9.8% real WACC.

[5] In calculating the LCOE, we use standardized taxation and inflation assumptions: standardized income tax rate (25%), depreciation schedule (20-year straight-line), and long-term inflation rate (2%); 100% of capital costs are assumed depreciable.

survey, OpEx excludes any costs associated with grid interconnection, substations, or transmission use; for offshore wind, transmission system use charges are also excluded.

Our survey emphasized the "typical" LCOE of wind projects in each respondent's primary region of expertise. We defined "typical" as the median project in terms of costs (Figure 2).

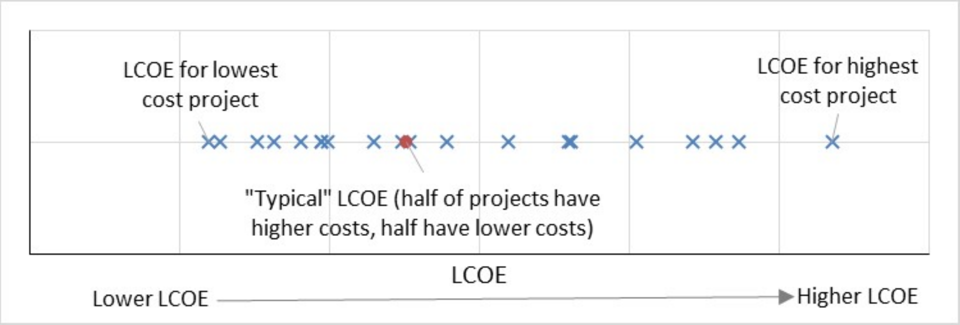

Figure 2. Definition of "Typical" LCOE in Expert Elicitation

Future wind LCOEs are uncertain. They can be affected by project-specific factors, such as the quality of the wind resource at a particular site, as well as by factors that affect the entire wind sector, such as changes in wind turbine technologies, markets, and policies. Technological changes may be induced by direct R&D or other advances. Market changes comprise, for example, systemic changes in the average wind speed of sites that remain for development as well as the amount of competition in the wind supply chain. Policy changes may directly or indirectly support or impede wind energy development and deployment.

In exploring future LCOE trends, we asked respondents to provide probabilistic estimates for three future scenarios: a low LCOE scenario (10th percentile), a high LCOE scenario (90th percentile), and a median LCOE scenario (50th percentile), considering only the broader, non-project-specific factors. We asked experts specifically to focus on changes in the typical LCOE (i.e., to ignore project-to-project variation) that might result from changes in factors that affect the industry as a whole (i.e., changes in wind energy technologies, markets, and policies). We also asked respondents to assume no changes in macroeconomic conditions (such as interest rates, inflation, and currency fluctuations), materials and commodity prices, and other factors not directly related to the wind energy business.[6]

In addition to asking about LCOE and the five core LCOE inputs, we asked about the market and technology characteristics and drivers most likely to impact LCOE trends in 2030. Specifically, we sought information on: (1) expected typical turbine characteristics for projects installed in 2030—nameplate capacity, hub height, and rotor diameter for all three wind applications; (2) the expected impact of each of a list of specific changes in wind development, technology, design, manufacturing, construction, operations, and markets on achieving reduced LCOE by 2030 for all three wind applications; and (3) broad drivers most likely to facilitate achieving "low" estimates of LCOE in 2030 as opposed to

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[6] For more detail, see: http://rincon.lbl.gov/lcoe_v2/typical_costs.html.

"median" estimates in that year, separately for onshore and fixed-bottom offshore wind.

2.3. Application of Expert Elicitation Principles

We applied many of the basic concepts, tools, and guidelines of a well-designed expert elicitation in order to minimize biases. Best elicitation practices include clearly defining the quantities that are being assessed, minimizing extra cognitive burden on the expert by asking questions using familiar terminology and units, and minimizing the need for "side" calculations. In addition, we sought to minimize the effects of anchoring and overconfidence biases (Kahneman et al. 1982) by asking for low- and high-scenario estimates *before* asking for a mid-point estimate, and providing experts with feedback and the opportunity to review and modify their responses (Coppersmith et al. 2009). Our online survey format created challenges (e.g., we had a limited ability to tailor questions to respondent preferences) but also provided benefits over traditional interview-based elicitations in terms of easily accessible calculation and graphical display tools that gave experts immediate feedback and context for their assessments.

We carefully and clearly defined each of the cost-related factors for which we elicited input, and we reinforced those definitions throughout the survey. In part we took extra care here because of differences across the industry in how each factor is defined—for example, whether a project's CapEx includes or excludes transmission and grid interconnection costs, or whether nominal or real WACC is used in calculating LCOE. Because we could not ask each expert how he or she defined each term, and because we wanted to compare answers across the experts, we needed to provide detailed definitions of each quantity.

Although the experts could not challenge the definitions of the quantities being assessed, we provided some flexibility in how they provided responses, and we reduced the need for extraneous calculations. Respondents could answer cost questions in real U.S. dollars or real euros (we used the average 2014 exchange rate of €1 = US $1.33). They were also asked to indicate which of the three wind applications they were comfortable discussing, and then they were asked questions only about those applications. They were provided with an in-survey, easy-to-use LCOE calculator to translate component estimates into an LCOE estimate.[7] Additionally, respondents had the opportunity to qualify their answers with additional written comments and could skip questions they did not feel comfortable answering.

A particular challenge in online elicitations is how to provide experts with feedback and context for their responses so they can consider their own internal consistency and modify their assessments as desired. Without personal interaction, the elicitation team cannot direct an expert's attention to particular questions and responses. We addressed this issue by including graphical elements in the survey instrument and by building useful feedback into the instrument based on the results of pretesting that identified feedback needs. Most critical was the use of a time-trend graphical interface that (1) displayed the experts' previous assessments of a 2014 baseline LCOE and their low, median, and high scenario LCOE values for 2030, and (2) asked for low, median, and high scenario LCOE

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[7] For an example, see http://rincon.lbl.gov/lcoe_v2/lcoe_calculator.html.

estimates for 2020 and 2050 on the same graph. This interface explicitly showed the experts all of their LCOE responses, encouraging them to think about the internal consistency of those estimates.

Though we followed expert elicitation principles and design guidelines in our assessment, three unique aspects of the present assessment deserve mention:

- Casting a Wide Net with an Online Survey: Many expert elicitations feature detailed and sometimes lengthy in-person interviews with fewer than 20 experts. In contrast, we distributed our survey online to a wide group of possible respondents. This necessitated a shorter, more focused survey than would be common in an in-person setting, with less follow-up and in-depth exploration of responses.[8] In part, this choice reflected the need for a greater number of overall respondents to address one goal of our effort: to compare responses by wind application, organizational type, location, expertise, and other respondent characteristics.[9]

- No Comprehensive Elicitation of Probability Distributions or Technical Parameters: Our assessment combined aspects of expert elicitation and an opinion survey. We focused the expert elicitation on LCOE and the five key inputs to LCOE under low, median, and high scenarios, and we limited consideration of the five key inputs to only two specific points in time. Our assessment of technical and market drivers mirrored an opinion survey—we did not seek detailed quantitative assessment of the LCOE effect of specific technical advancement possibilities. Instead we asked experts to identify which advancements they believe would be larger contributors to cost reductions.

- No Elicitation of Opinions Conditional on Specific R&D, Policy, Deployment, or Other Factors: We asked respondents to make low, high, and median scenario estimates of future LCOE, and we left it to them to define for themselves the future scenarios that might drive those cost changes. In contrast, many expert elicitations condition responses based on defined R&D expenditures and on specific market and policy scenarios, in order to more directly inform R&D and policy decisions. Our survey was designed to map the universe of possible future LCOEs but provides only limited information about specific contributions to lower or higher costs.

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[8] Some research shows that elicitations relying on self-administered, web-based surveys yield results different from those relying on in-person interviews (Verdolini et al. 2015; Nemet et al. 2016), whereas other research shows less evidence of such differences (Anadon et al. 2013; Baker et al. 2015); where differences exist, the relative accuracy of the two methods remains unclear, though it is generally believed that in-person interviews represent the "gold standard." On the other hand, Baker et al. (2015) and Nemet et al. (2016) also suggest there is value in including diverse and relatively large groups of experts when conducting elicitations, suggesting—all else being equal, and due to the resource intensity of in-person elicitation—that there is value to online elicitations.

[9] Our interest in assessing the effect of respondent type on elicitation results follows related work conducted by Anadon et al. (2013) on nuclear energy cost expectations, Verdolini et al. (2015) on solar photovoltaics, and Nemet et al. (2016) on a range of energy technologies.

2.4. Survey Design, Testing, and Implementation

We gathered data and insights through an online elicitation survey (via the Near Zero platform[10]) of a large sample of the world's foremost wind energy experts under the auspices of IEA Wind Task 26 on the "Cost of Wind Energy."

The survey was carefully designed over a number of months, including numerous rounds of review, testing, and revision. Reviewers included the core survey design team, IEA Wind Task 26 members, and a select group of external wind energy experts. An expert workshop was held early in the process to discuss the goals of the survey and to pilot test an early draft of the survey. A PDF version of the final survey can be found online at: https://emp.lbl.gov/iea-wind-expert-survey.

The survey was launched in October 2015 and closed in December 2015. During the intervening period, various steps were taken to maximize response rate and ensure respondent comprehension of the survey. In particular, we first "pre-announced" the survey to possible respondents, and we invited participation in a webinar during which we discussed the purpose, structure, and details of the elicitation: 33 people attended the webinar, the recording was viewed 19 times, and the slides were made available for download. The online survey was distributed with personalized web links, and six separate waves of reminders were sent before the survey finally closed—including personalized and less-personalized email reminders as well as some phone and in-person exhortations. Because of the depth and length of the online survey, respondents were allowed to complete it in multiple sittings as necessary. In some cases, several individuals within an organization collaborated on a single, collective survey response.

2.5. Selection and Response of Experts

The success of an expert elicitation depends on the expertise and commitment of the contributing experts. Given the focus of our elicitation on project-level LCOE, our ideal respondents included strategic, system-level thought leaders with wind technology, cost, and/or market expertise. Such individuals might come from the various strands of the private wind industry, public R&D institutes, academia, or a range of other organizations. We sought a relatively large number of respondents in part to ensure an adequate number of possible experts versed in each of the three wind applications. Though the survey was global in scope, we focused on experts from North America and Europe.

We received considerable assistance in identifying possible respondents from IEA Wind Task 26 members and their affiliated institutions, and we reached out to many other wind energy experts and organizations to ensure broad coverage. We allowed our initial set of potential respondents to suggest additional names, which yielded a small number of additional respondents.

In addition to the full survey sample, we identified a smaller group of "leading experts." These individuals were selected through an iterative, deliberative process by a core group of IEA Wind Task 26

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[10] See: http://www.nearzero.org/.

members and several leading external wind energy experts. The survey team believed this small group was uniquely qualified to complete the survey, and the group was created in part to enable comparison of survey results between the smaller leading-expert sub-sample (paralleling a more traditional elicitation) and the larger group (excluding the leading-expert sub-sample).

We successfully distributed surveys to 482 experts, including 42 in the leading-expert group. The total number of returned surveys was 163, of which 22 came from the leading-expert group and the remaining 141 fall within the larger group. This reflects a response rate of 34% across the full set and 52% among the smaller group.[11] Appendix A lists the individuals who submitted responses.

Responses came from a broad cross-section of the wind sector. Figure 3 summarizes the characteristics of the 163 respondents by wind application area addressed, region of the world with which experts are most familiar, organizational type, and type of expertise. Note that respondents were able to identify multiple wind applications, geographies, and types of expertise. The median respondent dedicated 49 minutes to completing the survey, with the 25th-to-75th percentile range from 29 to 99 minutes.

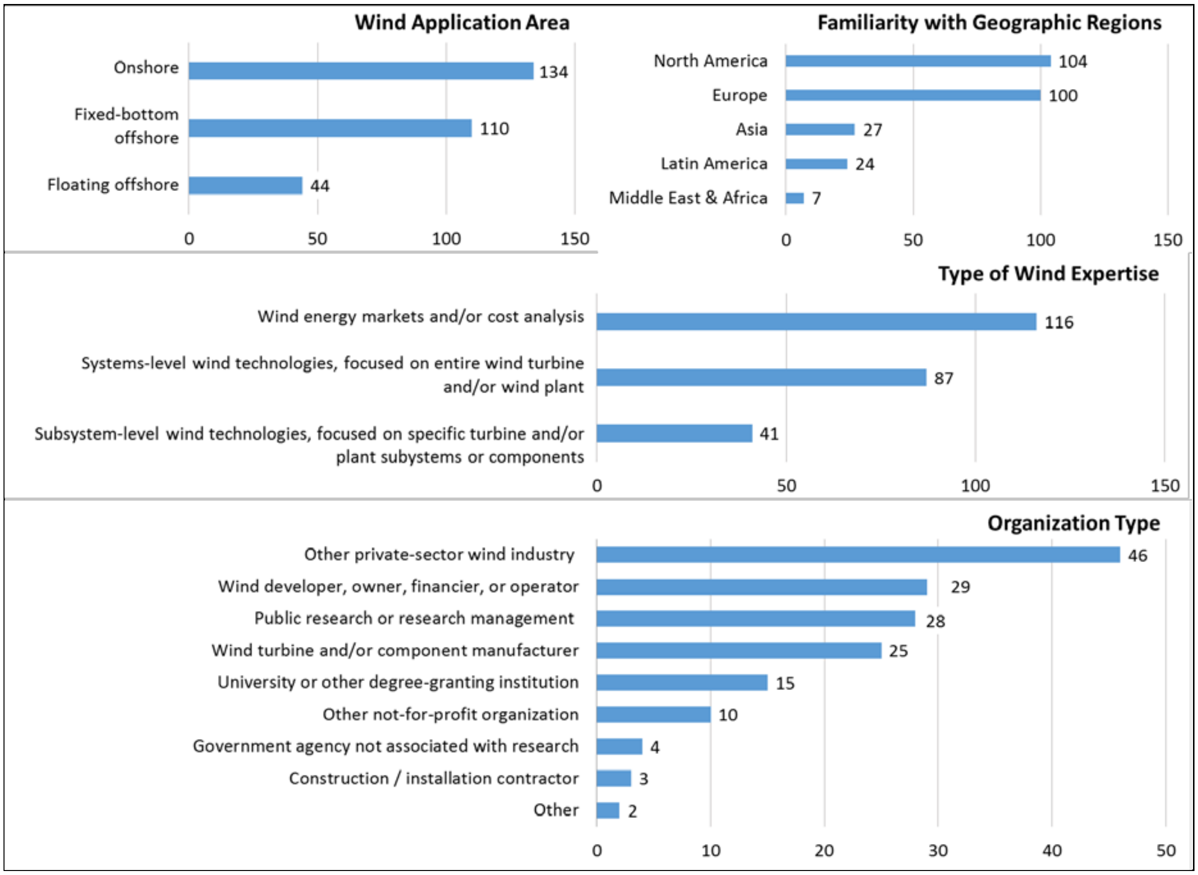

Figure 3. Characteristics of the 163 Expert Survey Respondents

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[11] In practice, there were some instances in which multiple individuals collaborated on a single survey response. Where we know of these instances, they are marked in Appendix A, and they result in a total response rate of 36% (by experts).

3. Summary of Elicitation Results

The analysis presented in this report summarizes the full set of 163 survey responses received. Additionally, in a number of text boxes, we highlight—on a cursory basis—notable differences in responses: (1) between the smaller leading-expert group vs. the full set of responses *less* that group; (2) by organizational type[12]; (3) between respondents who provided opinions on *only* onshore or offshore wind vs. those who provided responses to *both* onshore and offshore wind; (4) by type of expertise; and (5) by familiarity with different geographic regions.[13] Future work is planned to assess more thoroughly any systematic differences in survey responses by respondent characteristics.

3.1. Forecasts for LCOE Reduction

For each of the wind applications, experts provided a single estimate of LCOE for 2014 (the "baseline" value) and then provided low-, median-, and high-scenario estimates for the typical LCOE of wind projects in 2020, 2030, and 2050. In estimating the low-, median-, and high-scenario estimates, experts were asked to ignore project-to-project variation and instead to focus on factors that affect the industry as a whole, e.g., changes in wind energy technologies, markets, and policies. All dates are based on the year in which a new wind project is commissioned. Figure 4 shows the resulting changes in LCOE from 2014 through 2050 in percentage terms for (a) onshore, (b) fixed-bottom offshore, and (c) floating offshore wind. Expert-specific changes in LCOE are calculated using each expert's baseline and later values. Because a 2014 baseline was not established for floating offshore, the change is shown relative to the expert-specific baseline for fixed-bottom offshore wind. The figure shows the change from the baseline values for each of the three scenarios the experts were asked to provide: low, median, and high scenarios of typical LCOE. Expert opinions on these changes vary, and the figure also shows the range of those opinions. Lines and markers show the median value of expert responses, and the shaded regions around each line show the range (25th to 75th percentile) of expert responses. While the figure summarizes the full set of survey responses, Text Box 1 highlights key differences in LCOE estimates among various respondent groups.

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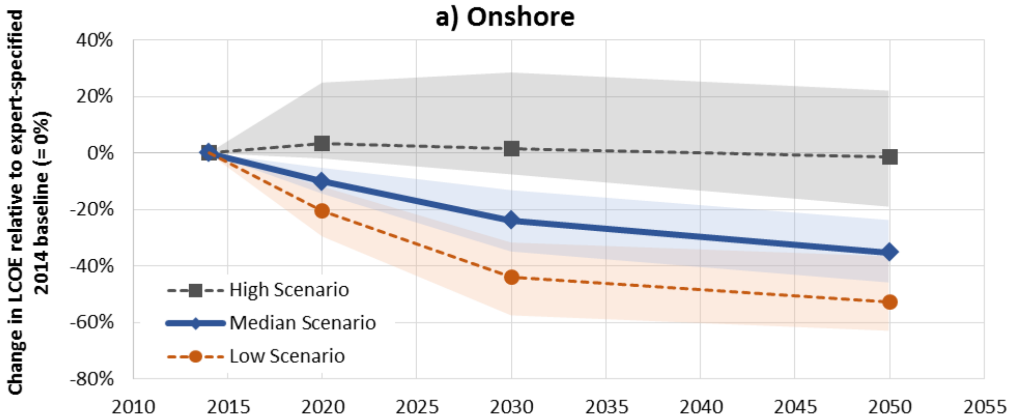
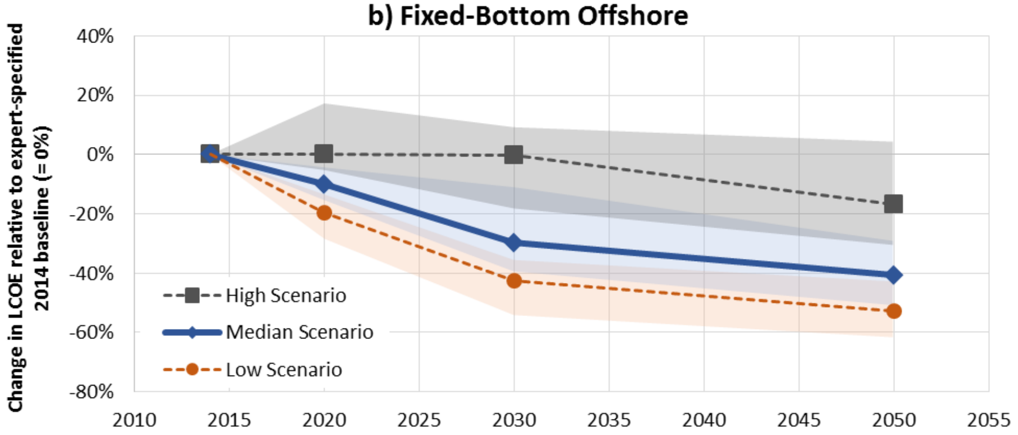
[12] We consolidated the nine organizational type categories presented in Figure 3 into five larger categories: (1) public R&D and academic (consolidating two of the original categories, and called the "research" group for the remainder of the report); (2) wind developer/owner/financier/operator and construction/installation contractor (consolidating two of the original categories, and called the "wind deployment" group); (3) wind turbine and/or component manufacturer (called the "equipment manufacturing" group); (4) other private-sector wind industry; and (5) other (consolidating three of the original categories—government agency not associated with research, other not-for-profit, and other).

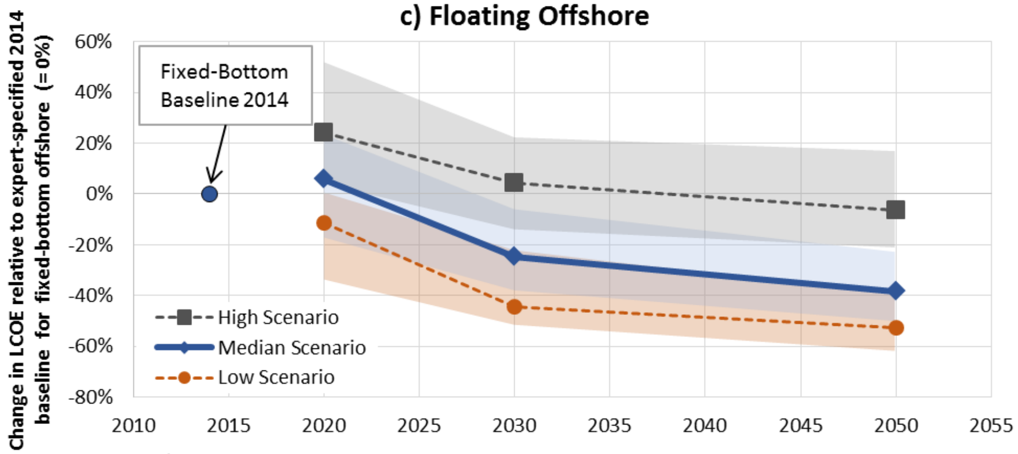
[13] Note that in many instances a single respondent may have identified multiple geographies (e.g., North America and Europe) or types of expertise (e.g., expertise on wind energy costs and on wind energy technologies). Such respondents may, therefore, fall within multiple categories when the survey responses are split by geography or expertise type. In these instances, careful interpretation is required. This issue is not present when culling results by organizational type; leading experts vs. larger group; or onshore, offshore, vs. both onshore and offshore—in each of the latter cases, the groupings are mutually exclusive.



Lines/markers indicate the **median** expert response
Shaded areas show the 1st-3rd quartile range of expert responses



Lines/markers indicate the **median** expert response
Shaded areas show the 1st-3rd quartile range of expert responses



Lines/markers indicate the **median** expert response
Shaded areas show the 1st-3rd quartile range of expert responses

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

Figure 4. Estimated Change in LCOE over Time for (a) Onshore, (b) Fixed-Bottom Offshore, and (c) Floating Offshore Wind Projects

Focusing first on the median (50th percentile) scenario for typical LCOE, experts clearly predict significant continued reductions in the cost of wind energy. Though onshore wind technology is already relatively mature, experts anticipate further advancements, with the median value of expert responses (also referred to as the median-expert response) showing LCOE reductions from baseline values of 10% in 2020, 24% in 2030, and 35% in 2050. Expert views on the long-term opportunities for fixed-bottom offshore wind are even more aggressive—perhaps not surprisingly, given the earlier state of the technology—with median LCOE reductions of 10% in 2020, 30% in 2030, and 41% in 2050. Floating offshore wind comes in at a 6% LCOE premium in 2020 relative to the 2014 fixed-bottom offshore baseline (reflective of the emerging state of the technology), but then it steeply declines to 25% below and then 38% below baseline values by 2030 and 2050, respectively.

There is also clearly a sizable range of uncertainty in future LCOEs, reflected both in the median-expert response for the low-scenario and high-scenario LCOE estimates as well as the range of expert views for all three scenarios shown by the shaded regions. For onshore wind, under the high scenario, the median-expert response shows effectively no change in LCOE from 2014 to 2050. Under the low scenario, however, the LCOE declines by 44% in 2030 and 53% in 2050. For fixed-bottom offshore wind, high-scenario LCOEs similarly remain at 2014 values, but only to 2030—in contrast with the onshore wind results, the high-scenario LCOE declines for fixed-bottom offshore after 2030, with a 17% reduction by 2050 for the median-expert response. High-scenario estimates for floating offshore wind show a somewhat different pattern: 25% higher than baseline values in 2020, 5% higher in 2030, and then 6% lower in 2050. Low-scenario estimates, at least in the long term, show a similar pattern for fixed-bottom and floating offshore wind (also bearing a strong similarity to onshore wind): a 43%–45% reduction in 2030 and a 53% reduction in 2050. Overall, the range in results among the high, median, and low scenarios demonstrates a sizable “opportunity space” for R&D- and deployment-related advancements.

Though percentage changes from the baseline are the most broadly applicable approach to presenting survey findings, depicting the relative absolute value for expert-specified LCOE (in $ or €/MWh) is also relevant. Figure 5 shows the estimated LCOE values for all three wind energy applications, over time, on a single plot, focusing only on the median scenario and depicting the median value of all expert responses as well as the range of expert responses. In reviewing this chart, emphasis should be placed on the relative positioning of and changes in LCOE, not on absolute magnitudes. This is because experts could accept a given 2014 baseline, or could create their own baseline. The median baseline shown in the figure therefore does not intend to represent any specific region of the world; for any specific region, the 2014 baseline figure and therefore expected absolute future LCOEs relative to that figure would vary. Additionally, because roughly 80% of experts chose to use the default 2014 baseline values for onshore and fixed-bottom offshore, the 1st and 3rd quartile as well and the median expert response for 2014 are all equivalent to those default baseline values. Appendix B includes two similar figures focused on the low-scenario (Figure A-1) and the high-scenario (Figure A-2) LCOE estimates.

Not surprisingly, experts clearly believe that onshore wind energy will remain lower cost than offshore, at least for typical projects. That being said, offshore wind energy is anticipated to see more-significant absolute reductions in LCOE over time, and so a narrowing occurs between the LCOEs of onshore and offshore wind applications. A similar trend is apparent for fixed-bottom and floating offshore wind: while the typical floating offshore wind project is expected to remain more costly than fixed-bottom wind over the entire period, the gap narrows over time, especially because of the sizable expected LCOE reductions for floating offshore wind between 2020 and 2030. Under the median scenario, of those experts who provided both fixed-bottom and floating LCOE figures, 23% see floating as less expensive than fixed-bottom by 2030, and 40% see it as less expensive by 2050.[14] These LCOE results—and comparisons—exclude costs of transmission interconnection to shore; differential interconnection costs between fixed-bottom and floating projects could therefore shift these relative LCOE results. Finally, there is clearly much higher uncertainty for the future LCOE of offshore wind energy than for onshore wind energy, depicted by the much larger 25th-to-75th percentile range for expert responses.

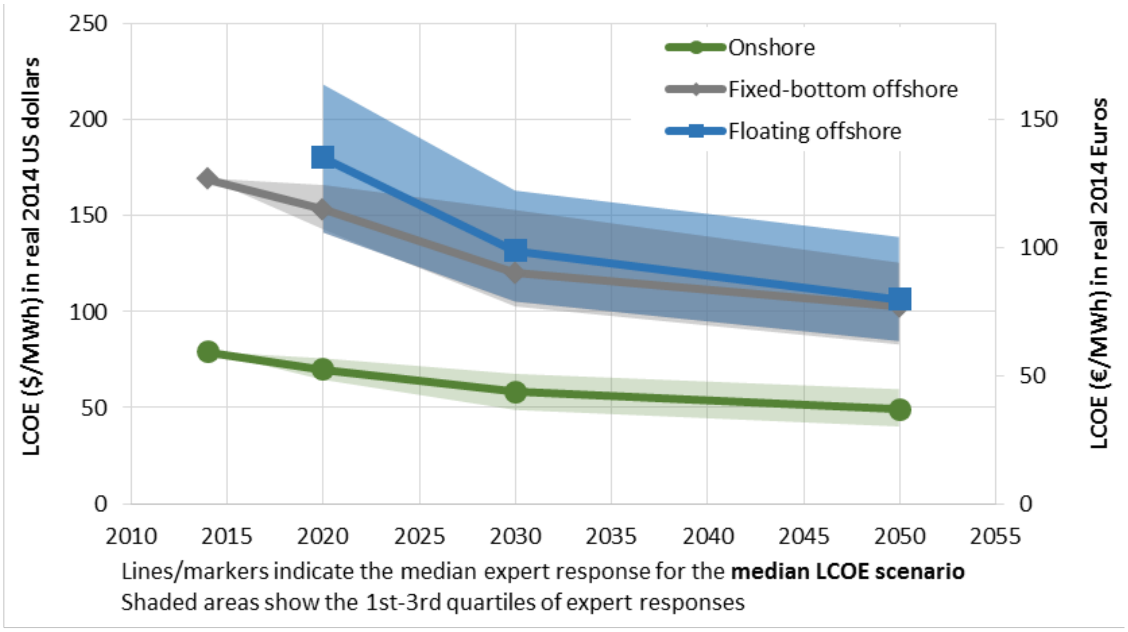


Figure 5. Expert Estimates of Median-Scenario LCOE for All Three Wind Applications

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[14] In the median scenario , the median-respondent LCOE of floating offshore wind is anticipated to remain slightly higher than that of fixed-bottom offshore wind through 2050, but the gap narrows and is very small by 2050 (Figure 5). In the low scenario, the median respondent expects an earlier LCOE convergence (see Appendix B). A deeper review shows that the leading-expert group is somewhat more optimistic for this convergence than the larger group of respondents (less the leading group). In the median LCOE scenario in 2050, for example, the small number of leading experts predicts a median LCOE reduction of 51% for fixed-bottom and 50% for floating offshore wind, whereas the larger respondent group predicts a 40% reduction for fixed-bottom and 31% for floating (see Figure 6, in Text Box 1). In the low-LCOE scenario, meanwhile, the leading experts predict median LCOE reductions of 62% for fixed-bottom and 64% for floating offshore wind (lower costs for floating offshore wind than fixed-bottom), whereas the larger respondent group expects a 53% reduction for fixed-bottom and 50% for floating (Appendix B).

Respondents were given the option of providing a textual discussion of the conditions that might produce low-, median-, or high-scenario LCOE estimates; these qualitative observations complement other survey results discussed later in this report that cover similar themes. For onshore wind, the experts identify a wide variety of factors as important to achieving low-scenario LCOE and, to a lesser extent, median-scenario LCOE estimates, including technical advancements (e.g., larger rotor and taller towers as well as improved and lighter materials, component reliability, turbine life, controls, and understanding of wind flow) and other market factors (e.g., learning through deployment volume and policy stability, transmission to access high-quality sites, lower-cost financing with industry maturation, and supply-chain efficiencies). Expert comments also reveal the tradeoff between CapEx and capacity factor, with some experts anticipating continued capacity factor improvements but only with stagnating CapEx value in order to pay for those performance increases. Conditions that might lead to high-scenario LCOE estimates often include weak demand for new wind power additions and/or a depletion of higher-quality wind resource sites (and/or lack of investment in new transmission to access those sites).

Expert-provided conditions for achieving low-, median-, or high-scenario LCOE for offshore wind energy—whether fixed-bottom or floating—are easier to summarize. The dominant themes relate to deployment volumes and market stability. Simply put, many experts believe that significant deployment is an essential precondition to the technical advancements, standardization, and supply-chain efficiencies in manufacturing, installation, and operations that would be required to achieve the low-scenario or even median-scenario LCOE estimate. Larger machine ratings are also especially important, according to the experts.

Text Box 1. LCOE-Reduction Expectations: Comparing Respondent Groups

We explored whether differences in LCOE expectations existed among respondent groups, namely between the leading-expert group vs. the full set of responses *less* that group; by organizational type (see Footnote 12 for definitions of the categories used); between respondents who provided opinions on only onshore or offshore wind vs. those who provided responses to both onshore and offshore; by type of expertise; and by familiarity with different geographic regions. Many respondents indicate familiarity with multiple geographies or have several types of expertise—such respondents may fall within multiple categories when responses are split by geography or expertise type, requiring careful interpretation. Expectations for LCOE reduction do not appear to differ substantially across many of the respondent groupings, including most regions. Though full results are presented in Appendix B (Tables A-9 through A-11), some of the more notable differences include:

- *Leading vs. Larger Group:* The leading-expert group expects greater LCOE reduction for **onshore** (27% in the median scenario in 2030 for the leading group vs. 24% for the larger group), **fixed-bottom** (35% vs. 29%), and **floating offshore** (38% vs. 15%, albeit with only six experts in the leading group). These differences persist or grow through 2050, as shown in Figure 6. Similar differences exist in the low- and high-LCOE scenarios as well.
- *Organization Type:* For **fixed-bottom offshore**, respondents in the “wind deployment” group anticipate larger LCOE reductions (e.g., median response of 36% reduction in the median scenario in 2030), whereas those in the “equipment manufacturer” group anticipate much smaller LCOE reductions in the median scenario in 2030 (9%). As shown in Figure 6, these differences narrow by 2050; similar patterns exist for the low and high LCOE scenarios. For **onshore** wind, expected LCOE reduction is largely consistent across all organizational types and, though sample size is limited, the same appears largely true for **floating offshore** wind (note, however, that no equipment manufacturers responded to questions on floating offshore LCOE).
- *Applications Considered:* Respondents who only expressed knowledge of offshore wind (i.e., did not answer the onshore questions) tend to be more aggressive about the LCOE reduction of offshore wind than those who expressed expertise in both onshore and offshore. For **fixed-bottom**, the median offshore-only respondent anticipates a 36% reduction in LCOE in 2030 in the median scenario, while those who also have expertise with **onshore** anticipate a 28% reduction. For **floating offshore** wind, the LCOE reductions are 25% and 20%, respectively. These differences persist to 2050 and also exist within the low and high LCOE scenarios.
- *Expertise Type:* Those who claimed expertise on “wind energy markets and/or cost analysis” are generally more aggressive about LCOE reduction than those with “systems-level” or “subsystems-level” technology expertise; those with “subsystems-level” expertise (i.e., those focused on specific turbine or plant subsystems or components) tend to be the most cautious. These trends exist for all three applications, but the differences are small except for **floating offshore** wind (for floating, median 2030 LCOE reductions are 31% for “wind energy markets and/or cost analysis,” 25% for “systems-level technology,” and 17% for “subsystems-level technology”).

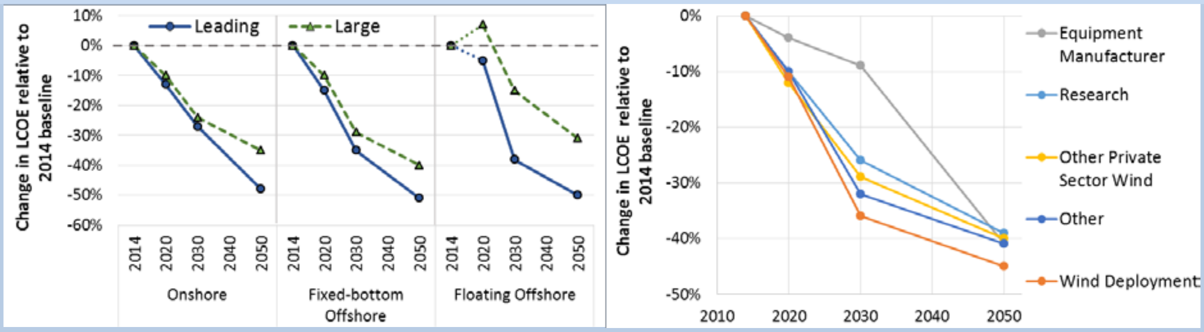

Figure 6. Impact of Leading-Expert vs. Larger Group on Median-Scenario LCOE of All Three Applications (left) and Organization Type on Median-Scenario LCOE of Fixed-Bottom Wind (right)

3.2. Baseline Values for 2014

To unpack the LCOE results presented earlier, it is first important to better understand the 2014 baseline values used by experts—not only for LCOE but also for the five key components that drive LCOE: CapEx, OpEx, capacity factor, project design life, and cost of financing. Rather than assume that all experts have the same internal "baseline" for the typical LCOE of recent projects, we offered a default option but allowed experts to provide their own estimates for onshore and fixed-bottom offshore wind; we did not provide or seek a baseline estimate for floating offshore wind, given the nascent state of that technology and lack of current commercial applications. The default baseline values offered for onshore wind were intended to reflect an average 2014 project installed in the United States or Europe, while the offshore baseline was intended to reflect European experience. Table 1 and Table 2 summarize both the default values and the range of other values provided by those experts who opted to provide their own.

The majority of experts accepted the default baseline values. For experts providing input on onshore wind projects, 103 of 134 respondents used the default baseline values shown in the tables. For experts providing input on offshore wind projects, 88 of 110 respondents used the baseline values.

Among experts modifying the 2014 baseline values for onshore wind projects, most estimated a lower LCOE, through lower CapEx and OpEx and through a longer project design life and higher capacity factor. Based on a review of open-ended responses to a question asking experts to describe their revised baseline, these revisions towards a lower LCOE came primarily from respondents who were seeking to reflect lower-cost projects in the United States, often through higher capacity factors, lower CapEx, or both. Those who revised the baseline figures to better reflect European costs did so less consistently in one direction or the other, given very different market and resource contexts from one European country to the next; a number of participants reduced the default capacity factor to better match European—and especially German—conditions, for example, while others left capacity factor at the default value but altered CapEx to better match conditions in certain windier European countries.[15]

In contrast to the onshore wind results, among those modifying the baseline values for offshore wind projects, most estimated a higher LCOE, in part through higher operating expenses. These upward revisions came from respondents seeking to better reflect European projects and, to a much lesser degree, hypothetical North American projects. In both cases, the revisions tended to result in higher 2014 baseline LCOEs; the upward revisions were particularly sizable in the few cases reflecting projects in the United States, perhaps due to the lack commercial offshore experience in that country.

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[15] As is apparent in some of the figures in Appendix B, some experts altered the default baseline values very significantly. In some cases, these revisions were made to reflect conditions that might be considered reasonably widespread, e.g., very high capacity factors in parts of the United States. In a few cases, however, respondents developed these "outlier" values considering relatively narrow project parameters, e.g., a small project in the Northeastern United States or in a difficult site in Switzerland.

Table 1. 2014 Baseline LCOE and Associated Components for Onshore Wind

	LCOE	Capital costs	Operating expenses	Capacity factor	Project design life	Cost of financing
Default baseline values (also the median response of all experts)	$79/MWh	$1,800/kW	$60/kW-yr	35%	20 years	8%
	€59/MWh	€1,353/kW	€45/kW-yr			
Mean baseline value across all experts	$77/MWh	$1,784/kW	$59/kW-yr	35%	20.7 years	7.9%
	€58/MWh	€1,341/kW	€44/kW-yr			
% of responding experts who defined their own baseline values (of 134 total respondents)	23%	21%	20%	19%	13%	14%
Median for respondents changing the baseline LCOE	$64/MWh	$1,650/kW	$55/kW-yr	36%	25 years	8%
	€48/MWh	€1,241/kW	€41/kW-yr			
% of self-defined values indicative of a lower LCOE than the default values	71%	71%	74%	52%	52%	45%

Table 2. 2014 Baseline LCOE and Associated Component for Fixed-Bottom Offshore Wind

	LCOE	Capital costs	Operating expenses	Capacity factor	Project design life	Cost of financing
Default baseline values (also the median response of all experts)	$169/MWh	$4,600/kW	$110/kW-yr	45%	20 years	10%
	€127/MWh	€3,459/kW	€83/kW-yr			
Mean baseline values across all experts	$171/MWh	$4,646/kW	$115/kW-yr	45%	20.3 years	10%
	€129/MWh	€3,493/kW	€86/kW-yr			
% of responding experts who defined their own baseline values (of 110 total respondents)	20%	19%	18%	12%	7%	5%
Median for respondents changing the baseline LCOE	$189/MWh	$4,600/kW	$123/kW-yr	45%	20 years	10%
	€142/MWh	€3,459/kW	€93/kW-yr			
% of self-defined values indicative of a lower LCOE than the default values	23%	32%	14%	14%	36%	14%

3.3. Sources of LCOE Reduction: CapEx, OpEx, Capacity Factor, Lifetime, WACC

With the baseline values now presented, the earlier LCOE results can be unpacked into five key components that impact LCOE. Due in part to the complexity of the relationships between the various LCOE components,[16] the elicitation focused on the distribution of LCOE, asking for a 10th (low scenario), 50th (median scenario), and 90th (high scenario) percentile estimate for the typical LCOE of wind projects, as presented earlier. Associated with each of these LCOE values, for 2030, the experts provided a set of LCOE component estimates that they felt would represent a project with that LCOE. With this focus, the component values themselves should not be directly interpreted as defining a specific probability range for each factor, but they do provide insight into which components experts believe are more likely to change, and by how much, as LCOE changes over time.

Appendix B provides detailed box-and-whisker charts showing the full range of expert opinions for LCOE and the five components for the 2014 baseline and for the low-, median-, and high-scenario 2030 estimates (Figures A-3 to A-5). To complement these results, Figure 7 focuses on *relative* changes in LCOE and LCOE components. For this analysis, each expert's responses for low-, median-, and high-scenario values in 2030 are compared to their 2014 baseline values, and the median result across all experts is shown in the figure. The change between the 2014 baseline and the estimates associated with the 2030 median scenario are shown with blue bars; markers also show the relative change associated with the low- and high-LCOE scenarios for 2030. Mean baseline values for each factor are shown in the x-axis labels for reference. Though the figure uses the full set of survey responses, Text Box 2 highlights key differences among various respondent groups.

Starting with the median scenario for onshore wind (LCOE reduction of 24%), experts anticipate that CapEx (-12%) and OpEx (-9%) will decline by 2030, while capacity factor (+10%) and project life (+10%) will increase; the median respondent anticipates no change in the cost of financing.[17] Under the low LCOE scenario, these directional trends become even stronger, while cost of financing declines.

Expectations for fixed-bottom offshore component trends from 2014 to 2030 differ from onshore. Under the median scenario (LCOE reduction of 30%), experts anticipate a slightly larger reduction in CapEx (-14%) than onshore, a smaller increase in capacity factors (+4%), and a sizable decline in the cost of financing (-10%). Results for OpEx (-9%) are consistent with onshore, in percentage terms, while experts are somewhat more optimistic on extended project lifetimes offshore (+15%). For floating offshore wind (LCOE reduction of 25%, relative to 2014 fixed-bottom baseline), experts anticipate a tradeoff between smaller CapEx improvements (-5%) and stronger capacity factor growth (+9%), relative to fixed-bottom wind; financing cost reductions (-5%), project life extensions (+25%), and OpEx

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[16] For example, there is a non-linear relationship between the components and LCOE, and a logical dependency among the components: e.g., a higher CapEx may lead to higher capacity factors (and possibly, lower LCOE).

[17] That the cost of financing does not change in the median scenario is—initially—somewhat surprising. Most respondents are most-familiar with the established markets in North America and Europe, however, where advancements in the cost of financing are less-likely than in less-developed wind regions. Results based on mean survey responses (Figure A – 3) do show a reduction in the cost of finance even in the median scenario.

reductions (-8%) also play a role in achieving the median-scenario LCOE estimated for 2030. Under the low LCOE scenario, these directional trends become stronger, for both fixed-bottom and floating offshore wind.

Figure 7. Relative Change in LCOE and LCOE Components from 2014 to 2030 for (a) Onshore, (b) Fixed-Bottom Offshore, and (c) Floating Offshore Wind Projects

Text Box 2. Sources of LCOE Reduction: Comparing Respondent Groups

Text Box 1 highlighted differences in LCOE reduction expectations by different respondent groups. Here we summarize some of the underlying drivers of those differences in terms of the five components that impact LCOE. See Appendix B (Tables A-12 to A-14) for data tables that underlie the text that follows.

- *Leading vs. Larger Group:* As noted earlier, the leading-experts group is more aggressive than the larger group in terms of LCOE reduction. As shown in Figure 8, for the median LCOE scenario for **onshore** wind in 2030 (relative to the 2014 baseline), the key contributors to these differences are CapEx (-17% for leading experts vs. -11% for the larger group) and OpEx (-17% for leading experts vs. -9% for larger group). For **fixed-bottom offshore**, major contributors are CapEx (-18% vs. -14%), capacity factor (+11% vs. +4%), and project design life (+25% vs. +15%). For **floating offshore** wind, primary contributions come from CapEx (-10% vs. -5%), capacity factor (+20% vs. +8%), and cost of finance (-15% vs. no change).

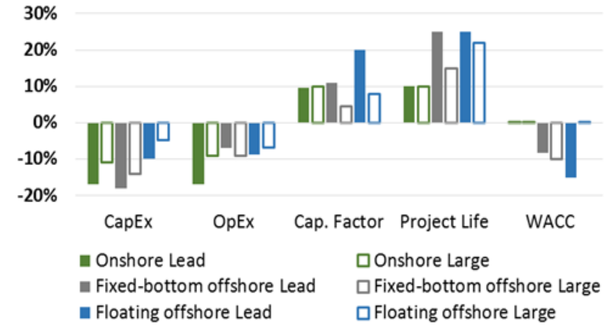

Figure 8. Sources of LCOE Reduction of Leading-Expert Group vs. Larger Group

- *Organization Type:* As noted earlier, organization type has an impact on the LCOE of **fixed-bottom** offshore wind but less-obvious impacts on the other two wind applications. In reviewing the five components of median-scenario LCOEs in 2030 (relative to the 2014 baseline), however, we observe a number of notable differences across all three applications. Starting with **onshore** wind and again focusing on the median value for each respondent group, the larger variations include: (a) lower CapEx and OpEx reductions, as well as lower capacity factor and project life improvements, for the "equipment manufacturing" group relative to all respondents (CapEx: -3% vs. -12% for all respondents; OpEx: -4% vs. -9%; capacity factor: +8% vs. +10%; project life: +5% vs. +10%); and (b) higher OpEx reductions, capacity factor improvements, and project life for the "research" group (OpEx: -14% vs. -9% for all respondents; capacity factor: +14% vs. +10%; project life: +25% vs. +10%). For **fixed-bottom** offshore wind, some of the same trends are apparent for the "equipment manufacturing" group: lower CapEx improvement (-4% vs. -14%), lower OpEx reduction (-2% vs. -9%), no capacity factor improvement (0% vs. +4%), no reduction in cost of finance (0% vs. -10%), and no change in project life (0% vs. +15%). Reflecting the lower LCOEs from the "wind deployment" group, this group is more aggressive on CapEx (-18% vs. -14% for all respondents), capacity factor (+9% vs. +4%), project life (+23% vs. +15%), and cost of finance (-20% vs. -10%). For both **onshore** and **offshore**, equipment manufacturers expect lower levels of improvement across many factors. Given the small sample for floating offshore, findings are less robust and so are not reported here.
- *Wind Application Coverage:* As noted earlier, respondents who only expressed knowledge of offshore wind tend to be more aggressive about the LCOE reduction potential of offshore wind than those who expressed expertise in both onshore and offshore applications. A review of these responses reveals that, for the median-LCOE scenario for **fixed-bottom** offshore in 2030 (relative to the 2014 baseline), the key contributors to LCOE differences are OpEx (-13% for offshore-only group vs. -9% for both), capacity factor (+7% vs. +4%), project design life (+20% vs. +13%), and especially cost of finance (-17% vs. -1%); CapEx reductions are actually lower for the offshore-only group (-11% vs. -16%). For **floating** offshore wind, key contributors are capacity factor (+11% vs. +7%) and, again, cost of finance (-15% vs. 0%). Particularly notable here is that the offshore-only group is actually less optimistic about CapEx reduction (0% vs. -8%), but offsets this with their greater optimism for other contributors to LCOE, and especially a reduced cost of finance.

A review of the percentage change in each component, as presented above, is an imperfect proxy for the *relative* importance of those changes in driving LCOE—because some components (e.g., CapEx) play a larger absolute role in LCOE than others (e.g., OpEx). To gain insight into the relative importance of changes in each component, we use a sensitivity analysis. In particular, we use each expert's baseline and 2030 component estimates to calculate what the change in LCOE *would be* for that expert if only one of the five components changed, relative to that expert's overall estimated change in LCOE. We do this for each of the five components for each expert and then normalize these "one-off" effects to sum to the overall LCOE percentage reduction. The resulting median values of expert responses are shown in Figure 9 for both the median scenario and the low scenario, for all three wind applications.[18]

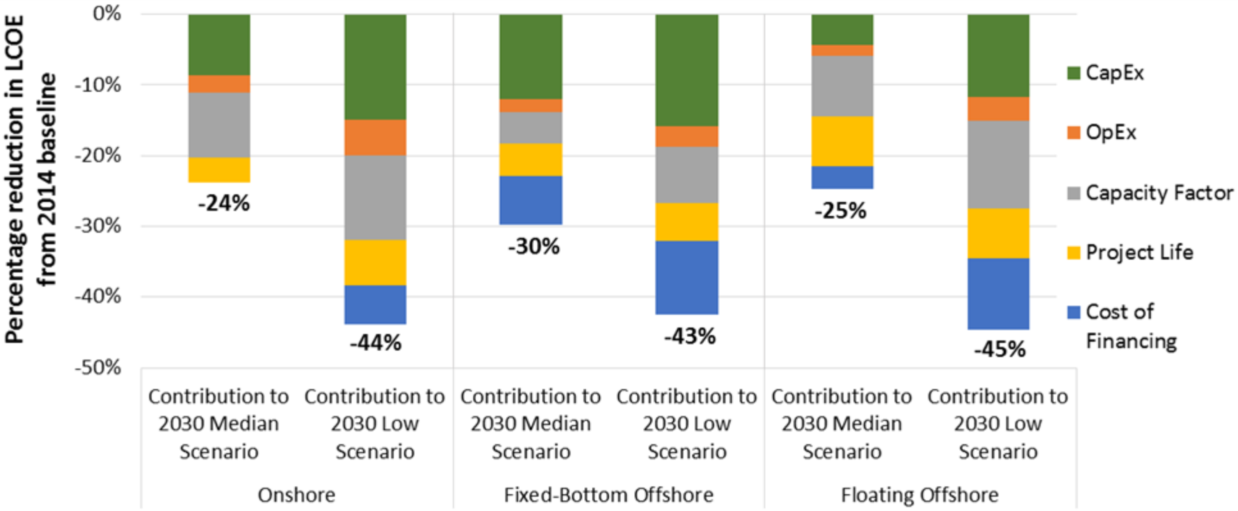

Figure 9. Relative Impact of Changes in Each Component on LCOE in 2030

For onshore wind energy, CapEx and capacity factor improvements are expected to constitute the largest drivers of LCOE reductions. Under the median scenario, 75% of the total LCOE reduction comes from these two components, with a slightly larger contribution of the capacity factor (39%) than CapEx (36%); under the low scenario, 61% of the total LCOE reduction comes from the two, with a somewhat greater impact from CapEx (34%) than capacity factor (27%). Under both the median and low scenarios, lower OpEx (~11% in both cases) and longer project life (~15% in both cases) play significant but far-smaller roles in driving LCOE changes. Lower-cost financing is not expected by experts to play a significant role for the median scenario, but it does have an impact (12%) in the low scenario.

The relative impact of the five factors differs for offshore wind. Focusing first on fixed-bottom offshore, CapEx reductions play the largest role, constituting 40% and 37% of total LCOE reduction under the median and low scenarios, respectively. Reductions in the cost of financing are also especially significant, at 23% in the median scenario and 25% in the low scenario, perhaps due to the still-early current state of commercial deployment and expectations of reduced risks over time. Capacity factor is

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[18] The high LCOE estimates for 2030 are close to the 2014 baselines, so the contribution of each component is of less interest.

the third most-impactful factor, at 15% and 19% for the low and median scenarios, respectively—lower in terms of contribution to LCOE reduction than for onshore wind. Closely following capacity factor improvements is project design life at 15% (median scenario) and 13% (low scenario). Improvements in OpEx are the least important driver for both the median (6%) and low (7%) scenarios.

The trends are different still for floating offshore wind, relative to the 2014 fixed-bottom baseline, with a notably more significant role for capacity factor improvements. This may reflect a belief that floating technology will tend to be deployed in windier sites as enabled by the ability to access deeper water locations. To achieve median-scenario 2030 LCOE estimates, the component rankings are: capacity factor (34%), project design life (29%), CapEx (18%), cost of financing (13%), and OpEx (6%). For low-scenario 2030 LCOE estimates, the component rankings are: capacity factor (28%), CapEx (26%), cost of financing (23%), project design life (16%), and OpEx (7%).

3.4. Expectations for Wind Turbine Size

Experts were asked to provide their estimates of wind turbine characteristics in 2030 for typical projects: turbine capacity, hub height, and rotor diameter. Because these characteristics may vary by region, experts identified the specific region of the world in which their estimates applied. Figure 10 summarizes the results by presenting the median of the responses,[19] split into three regional groupings: Europe, North America, and other. To provide a recent-year benchmark, the figure also includes 2014 onshore averages for the United States and Germany as well as 2014 offshore averages for Europe as a whole. Appendix B (Tables A-15 and A-16) summarizes North American and European turbine characteristic expectations among various respondent groups, which—as shown there—are reasonably consistent with the full set of responses summarized below.

It is clear that survey respondents anticipate pronounced upward scaling in wind turbine size, with some regional variations. Starting with nameplate capacity, experts believe that onshore turbines will continue to scale, with a typical size in 2030 of 3.75 MW in Europe and 3.25 MW in North America and elsewhere for the median expert response. Turbines deployed offshore are expected to grow even more dramatically, to 9 or 11 MW, depending on the region and technology. Growth in offshore wind represents another turbine design evolution beyond current commercial product development, which is generally focusing on turbines 8 MW and below.

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[19] Experts did not provide specific numeric estimates, but chose a range from a list (e.g., 2.5 to 3.0 MW for capacity). For simplicity of presentation, the figures and data included in this section show the median response as the mid-point of the range of the median category selected (e.g., 3.75).

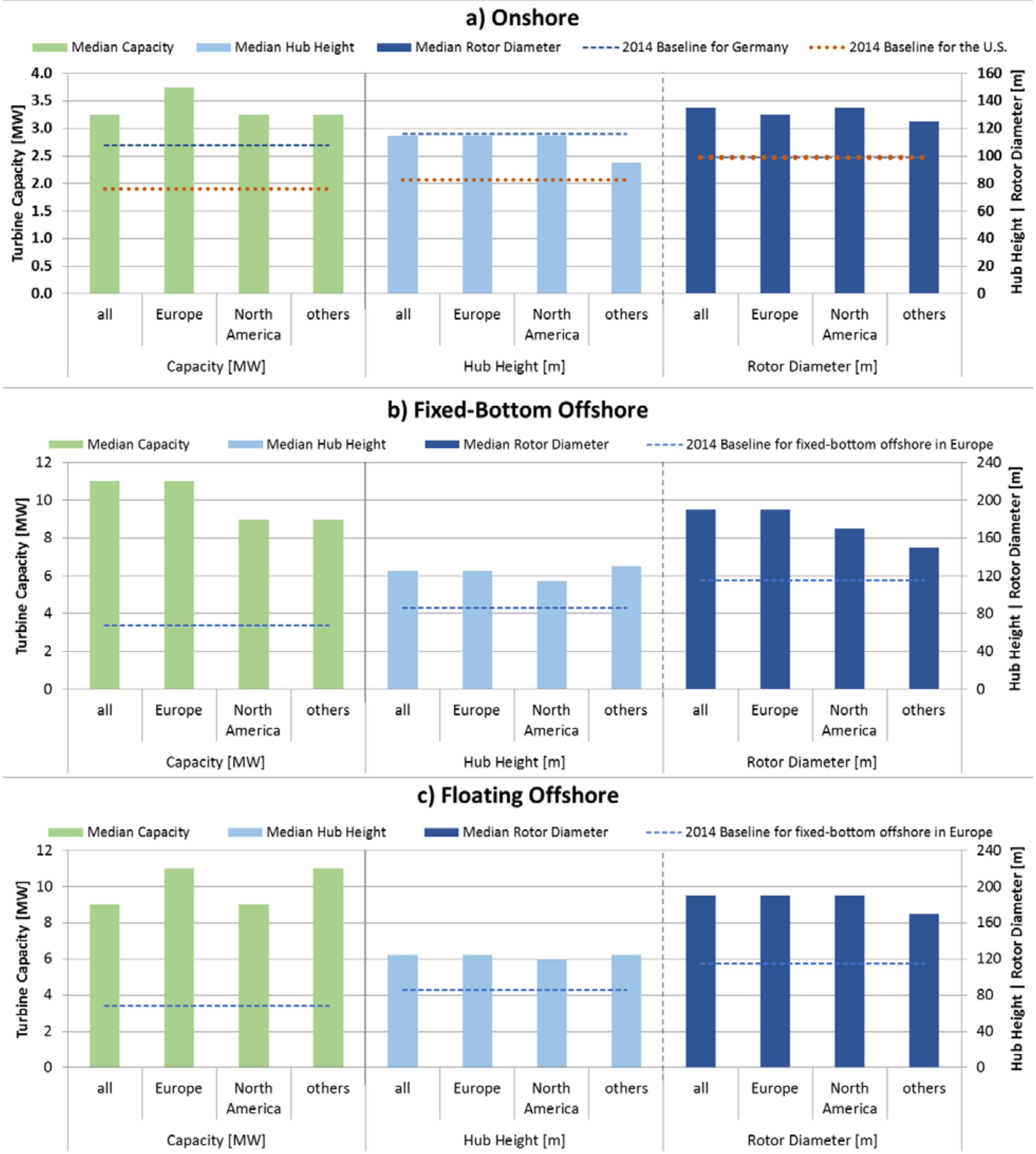

Figure 10. Wind Turbine Characteristics in 2030 for (a) Onshore, (b) Fixed-Bottom Offshore, and (c) Floating Offshore Wind Projects

This growth in nameplate capacity is matched by continued scaling in hub heights and rotor diameters. Hub heights onshore are expected—globally, in Europe, and in North America—to be roughly 115 m for typical wind projects, substantially higher than the 2014 benchmark average in the United States but equivalent to the 2014 average in Germany; typical hub heights are anticipated to be lower outside of

Europe and North America. Increased hub heights offshore are also expected, to roughly 125 m, though with some modest regional variation. Turning to rotor diameters, onshore averages are expected to reach roughly 135 m for typical projects, with some regional variations, while median offshore estimates equal 190 m, though again with some regional differences.

Overall, for offshore wind, expectations are for somewhat smaller turbines—capacity, hub height, and rotor diameters—in North America than in Europe. While the reasons for this modest divergence are unclear, it might be hypothesized that, as the leading offshore market globally, European projects may be expected to remain on the leading edge of technology deployment. Experts may simply believe that offshore development in North America, a lagging market, will emphasize somewhat smaller turbines for which greater commercial experience exists.

All of these results reflect expectations for typical wind projects deployed in 2030; in reality, turbines used in 2030 will—of course—span a wide range, depending on site characteristics. Moreover, the results presented here represent median expert responses, but experts have divergent views on the degree of future scaling; accordingly, Appendix B shows the distribution of expert responses in histogram form (Figure A-6), and it presents median responses based on different respondent groupings (Tables A-15 and A-16).

Finally, we calculated the implied 2030 turbine specific power[20] for each expert, with Figure 11 summarizing median responses for that metric. As shown, the median specific power estimate for onshore wind is roughly 260 W/m^2, with lower estimates for North America (250 W/m^2) and somewhat higher estimates in Europe and especially outside of Europe and North America. These specific power estimates are similar to 2014 averages from the United States, and they demonstrate that specific power is expected to decline globally by 2030, but only to the current averages already seen in the United States. In North America, continued reductions in average specific power are not anticipated, through 2030.

Turning to offshore wind, estimates of typical specific power in 2030 vary regionally, but with a rough average of 375 W/m^2 for fixed-bottom offshore and 390 W/m^2 for floating offshore installations, slightly higher than the 2014 European averages of 325 W/m^2 and considerably higher than the 2030 estimates for onshore wind. The higher specific power for offshore wind—whether fixed-bottom or floating—in concert with other survey findings suggests that experts are prioritizing turbine capacity scaling (with proportional rotor scaling) and associated CapEx reductions in reducing offshore LCOE, whereas, for onshore wind, the declining global specific power reflects a more significant role for capacity factor improvements in driving LCOE trends. Appendix B offers a closer look at the distribution of the experts' implicit estimates of specific power (Figure A-7).

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[20] Specific power was calculated by dividing the turbine capacity by the rotor swept area, a function of rotor diameter; because turbine characteristics were presented as ranges (e.g., 4–5 MW), we used midpoints of each range for turbine capacity and for turbine rotor diameter to estimate the specific power for each expert.

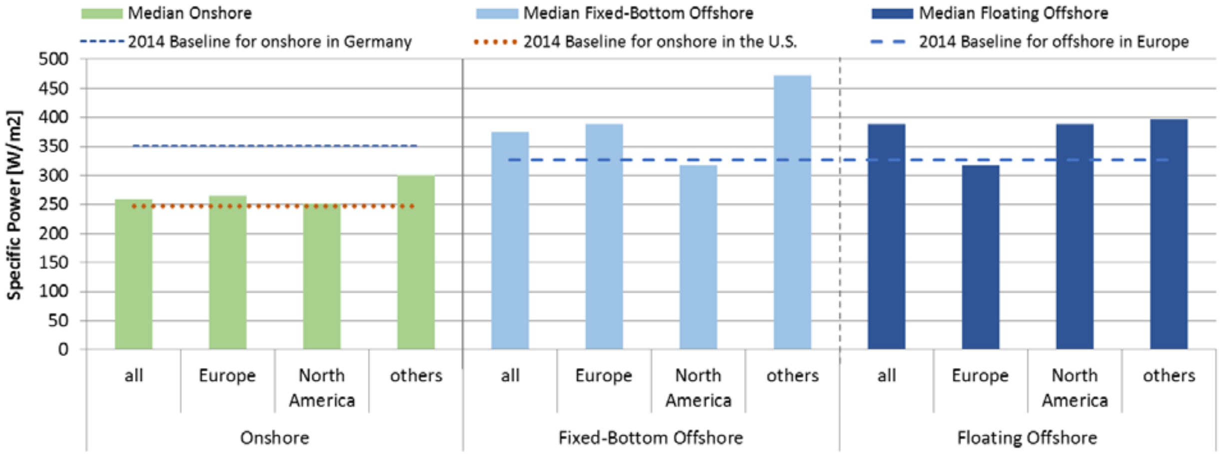

Figure 11. Wind Turbine Specific Power in 2030

3.5. Future Wind Technology, Market, and Other Changes Affecting Costs

A variety of wind development, technology, design, manufacturing, construction, operational, and market changes might contribute to reducing the LCOE for wind projects. To gauge the relative importance of the many possible drivers, we asked respondents to rate 28 different changes on a four-point scale based on their *expected* impact on *reducing* LCOE by 2030, for each of the three wind applications.[21] The 28 possible drivers were listed under seven broader categories: scaling in wind turbines; wind plant design; turbine and component design; foundation, support structure, and installation; supply-chain manufacturing; operating expenditures and performance; and competition, risk, development, and other opportunities. Respondents were allowed to add and rate "write-in" factors not otherwise specified in our list. The full set of results for all 28 listed items—across all three wind applications—is included in Appendix B (Table A-1 to A-3), while a listing of the write-in responses is also included in the appendix (Table A-4 to A-6).[22]

Figure 12 summarizes the findings at a superficial level, while Table 3 highlights the top-12 rated items for onshore, fixed-bottom offshore, and floating offshore wind. Specifically, the table summarizes the percentage of experts who said each item would have a "large expected impact" on LCOE in 2030, an "average" rating for each item based on converting the overall four-point scale to numerical scores, and the distribution of ratings (from left to right, the % of experts rating the item as having a large, medium, low, or no expected impact on LCOE). The table lists only the 12 highest-rated advancements—based on the percentage of experts who identified an item as having a "large expected impact"—for each of the three wind applications (see Appendix B for the results across all 28 items). Text Box 3 lists key

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[21] Respondents were also allowed to mark "no opinion," though few did so.

[22] A review of these write-in responses reveals that, in the majority of cases, experts listed: (a) detailed examples of advancements that were already captured in the 28 provided options; (b) items that might motivate an advancement but are not actually a direct advancement itself; or, in some cases, (c) options that do not obviously have a proximate impact on LCOE. Based on our review of these responses, we conclude that the 28 items originally listed do not obviously miss major advancement options.

differences in how the possible advancements were rated among various respondent groups.

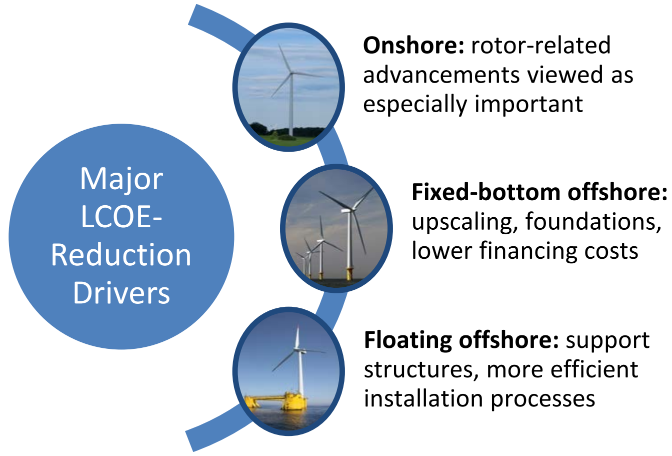


Figure 12. Top Advancement Opportunities

That the two leading drivers of LCOE reduction for onshore wind are related to rotors—increased rotor diameters and rotor design advancements—is consistent with the survey results presented earlier indicating capacity factor improvements as a major contributor to expected LCOE reduction, and with the anticipated global increase in rotor diameters (and declining specific power). Increased hub heights, coming in at number three on the ranked list, are also consistent with this theme and with previously presented results showing significant expected increases in hub height. After those three top-ranked items, a wide variety of technical and market advancements follows, from reduced financing costs and new transmission, to improved component durability and extended design lifetimes.

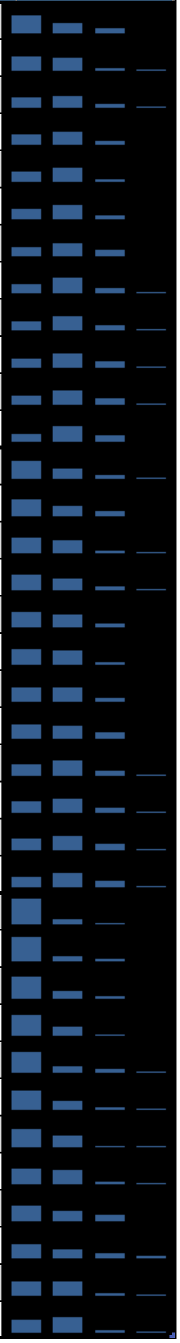
The relative ranking of the various drivers differs for offshore wind, and many more items were given higher ratings for offshore than for onshore. Starting with fixed-bottom offshore wind, the most highly rated advancements include increased turbine capacity ratings, design advancements for foundations and support structures, and reduced financing costs and project contingencies. Each of these is fully consistent with the findings noted earlier in terms of industry expectations for growth in turbine nameplate capacity ratings, and the relatively high importance of CapEx improvements and reducing financing costs, along with the relatively lower stated importance of capacity factor and OpEx improvements. Other highly rated items are also consistent with these themes, including larger project size and installation equipment and process advancements. Finally, turning to floating offshore wind, many of the themes here are similar to those for fixed-bottom technology, except with an even greater emphasis on foundations and support structures as well as turbine installation.

Five drivers show up in the top-12 for each of the three wind applications, though with different levels of prioritization within those lists: reduced financing costs and project contingencies; improved component durability and reliability; increased turbine capacity ratings; turbine and component manufacturing standardization, efficiencies, and volume; and integrated turbine-level system design optimization. Two other drivers are found within the top-12 for onshore and one of the top-12 offshore lists: rotor design advancements and extended turbine design lifetimes. The remaining items are more exclusive to either onshore or offshore wind, but not both. For example, increased rotor diameters and tower heights, new transmission, operating efficiencies, and improved plant layout are included in the top-12 list for onshore wind, but not for offshore. Similarly, a wide variety of foundation, support structure, installation, and transportation advancements as well as increased competition and project size are embedded in the top-12 lists for offshore wind, but not for onshore wind.

Experts identify some items as having no or negligible effect on reducing LCOE by 2030. As shown in Appendix B, for onshore wind, these include: lower decommissioning costs, reduced fixed operation and maintenance costs, installation process efficiencies, altered siting and permitting procedures, foundation design and manufacturing advancements, maintenance equipment advancements, and non-conventional turbine designs. For offshore wind, some of the same themes are evident, but added to those are site-specific turbine designs, non-conventional plant layouts, and increased tower height and tower design advancements.

Table 3. Expected Impact of Wind Technology, Market, and Other Changes on Reducing LCOE by 2030 for All Three Wind Applications

	Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating , Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact	
Onshore Wind	Increased rotor diameter such that specific power declines	58%	2.5	
	Rotor design advancements	45%	2.3	
	Increased tower height	33%	2.2	
	Reduced financing costs and project contingencies	32%	2.1	
	Improved component durability and reliability	31%	2.1	
	Increased energy production due to new transmission to higher wind speed sites	31%	2.0	
	Extended turbine design lifetime	29%	2.0	
	Operating efficiencies to increase plant performance	28%	2.0	
	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	28%	1.9	
	Turbine and component manufacturing standardization, efficiencies, and volume	27%	2.0	
	Improved plant layout via understanding of complex flow and high-resolution micro-siting	27%	2.0	
	Integrated turbine-level system design optimization	23%	2.0	
Fixed-Bottom Offshore Wind	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	55%	2.4	
	Foundation and support structure design advancements	53%	2.4	
	Reduced financing costs and project contingencies	49%	2.4	
	Economies of scale through increased project size	48%	2.3	
	Improved component durability and reliability	48%	2.3	
	Installation process efficiencies	46%	2.4	
	Installation and transportation equipment advancements	44%	2.3	
	Foundation/support structure manufacturing standardization, efficiencies, and volume	43%	2.2	
	Extended turbine design lifetime	36%	2.2	
	Turbine and component manufacturing standardization, efficiencies, and volume	36%	2.1	
	Increased competition among suppliers	35%	2.1	
	Integrated turbine-level system design optimization	33%	2.1	
Floating Offshore Wind	Foundation and support structure design advancements	80%	2.8	
	Installation process efficiencies	78%	2.7	
	Foundation/support structure manufacturing standardization, efficiencies, and volume	68%	2.6	
	Economies of scale through increased project size	65%	2.6	
	Installation and transportation equipment advancements	63%	2.5	
	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	59%	2.4	
	Improved component durability and reliability	58%	2.5	
	Reduced financing costs and project contingencies	46%	2.3	
	Increased competition among suppliers	46%	2.2	
	Rotor design advancements	45%	2.1	
	Integrated turbine-level system design optimization	44%	2.3	
	Turbine and component manufacturing standardization, efficiencies, and volume	40%	2.3	



Text Box 3. Technology, Market, and Other Changes Affecting LCOE: Comparing Respondent Groups

As presented in tabular form in Appendix B (Table A-17 to A-19), there is a substantial consistency across respondent groups in how the technology, market, and other changes are ranked based on expected impact on LCOE. There are, however some interesting differences, some of which are summarized below. Note that we focus on the leading-expert vs. larger-group distinction and on different organization types; we emphasize only items prioritized within the top-12 of at least one of the two groups being compared, and we only highlight those items that are at least five ranks different between the two comparison groups.

Onshore Wind*:* All respondent categories agree about the importance of increased rotor diameters and related rotor design advancements, and the various respondent categories agree—in broad terms—to the full ranking of items. The leading-expert group, however, places a number of items higher on its rank-ordered list in comparison to the larger group, notable examples of which include: improved plant-level layout; increased competition among suppliers; and installation and transportation equipment advancements. The leading-expert group places lower on its list—comparatively—items such as: turbine and component manufacturing standardization, efficiencies, and volume; increased turbine capacity; and reduced financing costs and contingencies.

Fixed-Bottom Offshore Wind*:* Again, the various respondent types agree—in broad terms—to the full ranking of items. The leading-expert group, however, places a number of items higher on its list in comparison to the larger group, including: improved component durability and reliability, extended turbine design lifetime, rotor design advancements, maintenance process efficiencies, operating efficiencies to increase plant performance, and increased energy production due to new transmission. The leading-expert group places lower on its list items such as: integrated turbine-level system design optimization; turbine and component manufacturing standardization, efficiencies, and volume; foundation and support structure manufacturing standardization, efficiencies, and volume; installation process efficiencies; and reduced financing costs and contingencies.

Floating Offshore Wind*:* Notwithstanding the smaller respondent sample for floating offshore wind, many of the respondent categories again generally agree to the full ranking of items. The leading-expert group places a number of items higher on its list, including: increased turbine capacity, integrated turbine-level system design optimization, innovative non-conventional turbine designs, tower design advancements, nacelle components design advancements, operating efficiencies to increase plant performance, and improved plant-level layout. The leading-expert group places lower on its list items such as: extended turbine design lifetime; turbine and component manufacturing standardization, efficiencies, and volume; and increased competition among suppliers.

Differences by organization type match expectations. The research group, for example, tends to rank emerging areas of research as more important. For onshore wind, this means comparatively higher rankings for: improved plant-level layout, integrated turbine-level system design optimization, and innovative non-conventional plant-level layouts. For floating offshore wind, integrated turbine-level system design optimization, innovative non-conventional turbine designs, and tower design advancements all rank comparatively higher. Equipment manufacturers, on the other hand, tend to focus on issues related to component and equipment design, manufacturing, and installation. As one example, for onshore wind, this means higher rankings for: turbine and component manufacturing standardization, efficiencies, and volume; large variety of alternative turbine designs to suit site-specific conditions; and innovative non-conventional turbine designs. Finally, the wind deployment group tends to place additional emphasis on matters related to development and operations. For fixed-bottom offshore wind, as one example, this means comparatively higher rankings for: extended turbine design lifetime; increased competition among suppliers; and reduced fixed operating costs, excluding maintenance.

3.6. Broad Market, Policy, and R&D Conditions Enabling Low LCOE

Whether future LCOE trends generally follow the low-, median-, or high-scenario estimates is—in part—under the control of public and private decision makers. As such, in a final question, we asked experts to rank four broad drivers that might enable achieving *low-scenario* LCOE (as opposed to median-scenario LCOE) in 2030 for onshore and fixed-bottom offshore wind separately (we did not ask a similar question for floating offshore wind). The four drivers were defined as:

- Research and Development: Breakthrough discoveries and technological innovation resulting from public- and private-sector research and development
- Learning with Market Growth: Incremental technical, manufacturing, process, and/or workforce-efficiency improvements resulting from learning with market growth
- Increased Competition and Decreased Risk: Lower contingencies and greater competition within the supply chain resulting from market maturity and reduced technology and construction risk
- Eased Wind Project and Transmission Siting: Reduced development costs and/or increased access to higher wind resources resulting from conditions that ease wind project and transmission siting

Table 4 shows the overall expert rankings of these four drivers. In particular, the table shows the percentage of experts who ranked each item as the most important, an “average” rank for each item, and the distribution of rankings (from left to right, the % of experts ranking each driver as 1, 2, 3, 4, or lower than 4). Respondents were allowed to add and rank additional “write-in” items—a listing of those write-in responses is included in Appendix B (Table A-7 and A-8).[23] Text Box 4 highlights key differences in how these broad drivers were rated among various respondent groups.

Overall, respondents ranked “learning with market growth,” followed closely by “research and development,” as the two leading drivers for achieving low LCOE estimates, and they did so for both onshore and offshore wind. Experts clearly view these two items as the highest priority items for achieving low-scenario LCOE estimates. For onshore wind, “increased competition and decreased risk” and then “eased wind project and transmission siting” followed. For offshore wind, these last two items were switched in order. Somewhat surprising is the low ranking of “increased competition and decreased risk” for offshore wind energy, given the current state of the offshore wind sector.[24]

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[23] A review of write-in responses reveals that most are consistent in tone and detail with the question and results discussed in Section 3.6: no obvious major “broad driver” was missed in our question formulation.

[24] Note that the question asked respondents to rank these drivers based on their expected impact in achieving the *low-scenario* LCOE estimates in 2030 as opposed to *median-scenario* estimates in 2030. Presuming that this careful wording was understood by respondents, experts might believe that “increased competition and decreased risk” is important in driving LCOE towards median-scenario values in 2030, but that there is relatively limited *incremental* opportunity for that driver to motivate even-lower LCOE.

Table 4. Ranking of Broad Drivers for Lower Onshore and Fixed-Bottom Offshore LCOE in 2030

	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	

Text Box 4. Broad Market, Policy, and R&D Enablers to Low LCOE: Comparing Respondent Groups

As presented in tabular form in Appendix B (Tables A-20 and A-21), there are various differences among respondent groups in how the four broad drivers are ranked based on their ability to enable the low-scenario 2030 LCOE estimates:

For **onshore** wind, the leading-experts group places “learning with market growth” squarely at the top of the list, followed—at some distance—by “research and development.” By organization type, the most notable difference is that equipment manufacturers identify “learning with market growth” as the least important driver, listing “research and development” as the leading driver. The other group, on the other hand, rates “research and development” considerably below “learning with market growth” and on par with the other two options. Interpretations for geography and expertise type are complicated by the large number of experts that fall within multiple respondent groups. Nonetheless, experts who expressed familiarity with North America—at least in comparison to those with familiarity with Europe—tend to emphasize to a greater degree “research and development” and “eased wind project siting,” while respondents with familiarity with Europe place greater focus on “learning with market growth” and “increased competition and decreased risk.” Respondents with expertise outside of Europe and North America tend to place a great deal of emphasis on “learning with market growth.” Finally, those with systems- and subsystems-level wind technologies expertise tend to rank “research and development” above “learning with market growth,” while the opposite is true for those with wind markets and/or cost analysis expertise.

For **fixed-bottom offshore** wind, the leading-experts group ranks “research and development,” “eased wind project and transmission siting,” and “learning with market growth” largely equivalently. By organization type, notable differences include a comparatively higher rating for “research and development” by the research group and a higher rating for “learning with market growth” by the other private-sector wind group. The other organizational group rates “eased wind project and transmission siting” comparatively higher. Respondents who expressed familiarity with Europe rate “eased wind project and transmission siting” somewhat higher than other respondents, while respondents with knowledge of markets outside of Europe and North America again tend to emphasize “learning with market growth” and, in some cases, “eased wind project and transmission siting.”

3.7. Comparison of Expert-Specified LCOE Reduction to Broader Literature

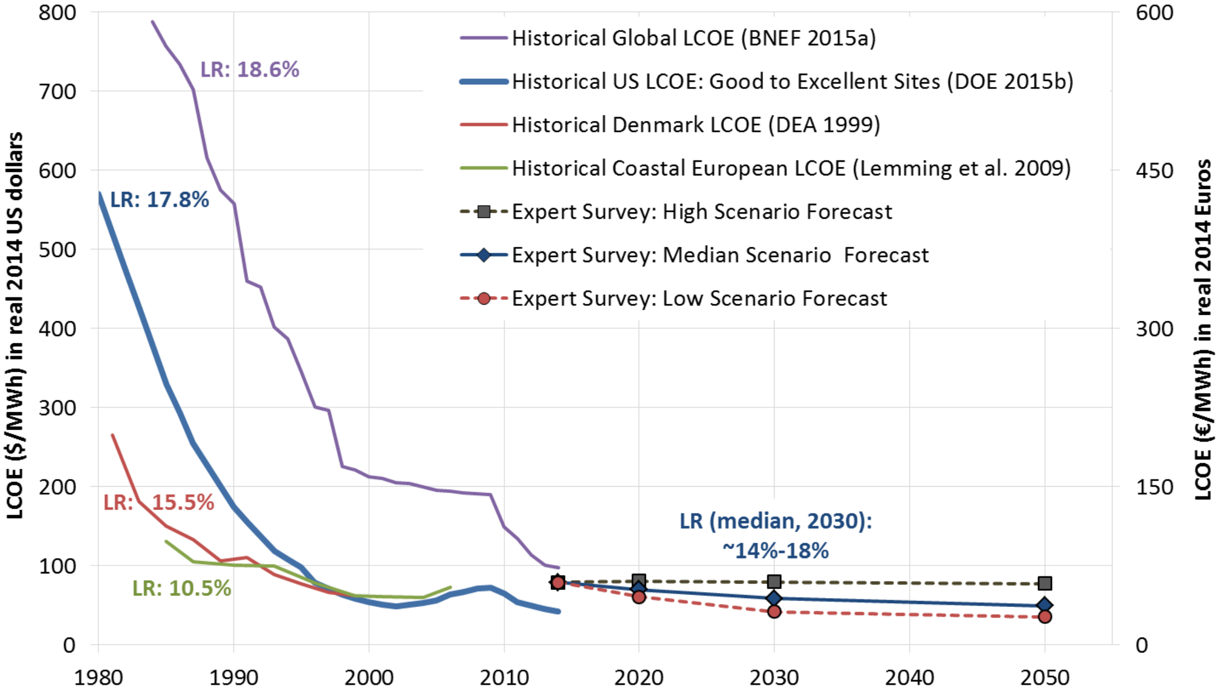
As indicated earlier, a considerable amount of literature has sought to track and understand historical wind energy cost trends and/or estimate future costs—using learning curves, engineering analysis, and/or various forms of expert knowledge. Here we compare expert survey results on LCOE expectations with: (1) past LCOE trends, and (2) other forecasts of future LCOE. Notwithstanding the sizable range in LCOE estimates reflected in the expert survey results, those results are found to be broadly consistent with historical LCOE trends—at least for onshore wind. Results are also broadly consistent with many other wind energy cost forecasts, though with some notable caveats.

3.7.1. Historical LCOE and Learning Estimates

A substantial literature has sought to estimate historical learning rates for onshore wind energy. Summaries of that literature are available in Wiser et al. (2011), Lindman and Söderholm (2012), and Rubin et al. (2015). Estimated learning rates (LRs) span an enormous range, from a 33% cost decline with each doubling of cumulative production (LR = 33%) to a cost increase of 11% for each doubling (LR = -11%). The wide variation can be partly explained by differences in learning model specification (e.g., whether cumulative production is the only driver considered), assumed geographic scope of learning (e.g., whether global or country-level cumulative installations are used), and the period of the analysis (Wiser et al. 2011). Additionally, Rubin et al. (2015) shows that, with few exceptions, learning rates have been estimated based on turbine- or project-level CapEx, and have rarely focused on the more decision-relevant metric of LCOE. Recent CapEx learning rates have been estimated at 6-9% (BNEF 2015a; Criqui et al. 2015; Wiser and Bolinger 2015), but the use of learning rates solely based on individual factors that influence LCOE can be misleading.

To compare properly expert survey results with historical LCOE and LCOE learning rates, Figure 13 depicts four published estimates of historical onshore wind energy LCOE. Each of those estimates is derived differently, and each covers distinct geographies. Also included in the graphic are the implicit single-factor learning rates associated with the four historical LCOE trajectories, each based on historical growth in cumulative global wind capacity. The absolute values of the LCOE estimates span a considerable range—reflecting the different methods, periods, assumptions, and geographies involved—with effective onshore wind LCOE learning rates ranging from 10.5% to 18.6%.

Our expert survey did not ask respondents for their estimates of cumulative wind deployment in the low-, median-, or high-LCOE scenarios. However, a reasonable range of projections for cumulative wind capacity from IEA (2015), BNEF (2015b), and GWEC (2014) can be applied to estimate an implicit onshore LCOE learning rate from the expert survey results of about 14%–18% when focused on median-scenario LCOE in 2030[25]; 2050 learning rate estimates are broadly consistent with this range. As indicated earlier, learning rates are an imperfect tool for understanding the drivers of past cost reduction or forecasting future costs. Moreover, elicitation results show that both deployment growth and R&D are expected to exert downward pressure on LCOE, implying that a two-factor learning curve would be a more appropriate specification. Nonetheless, the implicit single-factor learning rate embedded in the median-scenario LCOE forecast from our experts is highly consistent with past learning trends for onshore LCOE.



Note: For the expert survey results, emphasis should be placed on the relative positioning of and changes in LCOE, not on absolute magnitudes. Because the 2014 baselines shown in the figure are the median of expert responses, they do not represent any specific region of the world. For any specific region, the 2014 baselines and future absolute LCOE values would vary. For similar reasons, it is not appropriate to compare expert-survey results in terms of absolute LCOE magnitudes with the historical LCOE estimates shown on the chart for specific regions. Finally, learning rates are calculated based on a log-log relationship between LCOE and cumulative wind installations; as such, while historical learning rates closely match expected future learning predicted by the expert elicitation, visual inspection of the figure does not immediately convey that result.

Figure 13. Historical and Forecasted Onshore Wind LCOE and Learning Rates

The expert survey results for onshore wind LCOE in the low scenario, on the other hand, are a bit of a departure from historical trends. Experts presumably based their low-scenario LCOE estimates, in part, on a strong forecast for wind energy growth. Even under the GWEC (2014) “advanced” scenario for

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[25] To best reflect median-scenario LCOE estimates from wind energy experts, we apply a range of projections for cumulative global wind capacity that includes the IEA (2015) “New Policies” scenario (1,046 GW in 2030), the BNEF (2015b) base scenario (1,300 GW in 2030), and the GWEC (2014) “moderate” scenario (1,480 GW). Forecasts that are higher or lower than this range would result in lower or higher learning rate estimates, respectively. Note also that we use total wind installations here, including both onshore and offshore, which implicitly presumes that onshore LCOE benefits from experience with both onshore and offshore wind deployment.

wind deployment (1,900 GW in 2030; 4,040 GW in 2050), however, resulting implicit learning rates are 23% (2030) and 21% (2050)—higher than estimated historical rates of LCOE learning. Under the lower GWEC "moderate" scenario for future wind capacity, implicit learning rates are even higher: 27% (2030) and 25% (2050). To be sure, these implicit learning rates (as well as the ones calculated earlier) may overstate the actual rate of expected learning. Specifically, these rates do not account for the fact that aging wind turbines would need to be replaced over the duration of the forecast period to 2030 and—especially—2050. Were those replacement turbines considered in the cumulative wind capacity forecasts, estimated learning rates would be lower. As one example, if one assumes full repowering after a 20-year project life, then the GWEC (2014) "advanced" scenario would require a total wind turbine installation level of roughly 2,130 GW in 2030 and 5,980 GW in 2050, yielding implicit learning rates for onshore wind under the low-LCOE scenario of 22% (2030) and 18% (2050)—closer to historical learning rates, at least in the 2050 timeframe.

Turning to offshore wind, historical cost trends are mixed, with an initial reduction in costs for the first fixed-bottom offshore wind installations in the 1990s, following by steeply increasing costs in the 2000s and, most recently, some indication of cost reductions (IRENA 2015; Smith et al. 2015; Voormolen et al. 2016; Willow and Valpy 2015). Given this history—and the limited amount of total deployment—there have been few attempts to fit a learning curve to offshore data. van der Zwaan (2012) finds a learning rate of 3%–5% when focused on CapEx, whereas Dismukes and Upton (2015) find little evidence of learning thus far. Others conclude that a simple learning curve cannot readily be used to explain historical cost developments (Voormolen et al. 2016). It is also unclear what learning specification might best be used to understand past trends or to forecast future ones. Offshore wind technology is distinct from onshore, and so cumulative offshore installed capacity might be reasonably viewed as the primary driver for LCOE reduction in a single-factor learning estimate. There is obvious overlap in onshore and offshore turbine-related learning, however, such that continued future onshore wind deployment might also contribute to future offshore LCOE reductions.

As with onshore wind, the expert survey did not ask respondents for their estimate of cumulative offshore wind deployment. However, when applying an *offshore-only* forecast of cumulative wind power capacity from BNEF (2016) of 123 GW by 2030, an implicit fixed-bottom offshore learning rate of 8% is estimated for the median-scenario 2030 LCOE estimates and 13% for low-scenario 2030 estimates.[26] These rates are considerably lower than those estimated previously for onshore wind. In contrast, if one applies a range of projections for cumulative *total (onshore and offshore)* wind capacity from IEA (2015), BNEF (2015b), and GWEC (2014) (which, while much greater in total capacity terms, leads to fewer total "doublings" of capacity given the higher starting point in 2014), then implicit LCOE learning rates from the expert survey range from about 16%–20% when focused on median LCOE in 2030. This learning rate range is somewhat higher than but closer to the range for onshore wind. Overall, these results for offshore wind suggest that experts either anticipate lower offshore-only learning (relative to learning for onshore wind) or expect learning spillovers from onshore to offshore.

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[26] We do not calculate implicit learning rates for floating offshore wind.

3.7.2. Forecasts for Future LCOE Reduction

It is also relevant to compare the expert elicitation results to other forecasts of LCOE change over time. Figure 14 does just that, for onshore wind and for fixed-bottom offshore wind (see Appendix C for a listing of the references from which the other forecasts were obtained).[27]

The expert survey results for onshore wind are generally within the range of other forecasts, but elicitation results tend to show greater expectations for LCOE reductions for onshore wind in the median scenario than the majority of other forecasts. The reasons for this somewhat-more aggressive set of onshore LCOE estimates from wind energy experts in the median scenario is not known. However, other forecasts are sometimes informed by published learning rates that, as noted earlier, have been primarily based on CapEx (Criqui et al. 2015). Learning rates based on CapEx alone, however, will understate LCOE-based learning given concomitant advances in capacity factor, OpEx, and other factors impacting LCOE (BNEF 2015a). Recent estimates of CapEx-based learning (LR = 6-9%) cited earlier, for example, are well below the historical LCOE-based learning rates shown in Figure 13. As such, at least some of the broader literature might be biased low in terms of onshore wind energy LCOE forecasts due to inappropriate use of CapEx-based learning estimates (Criqui et al. 2015). Alternatively, our expert survey results could be biased in some way, or other forecasters might have tended to err on the side of conservatism for other reasons, such as a presumed decline in the learning rate over time.

The expert survey results for fixed-bottom offshore wind, meanwhile, tend to be more conservative than the broader literature, both for the median and low scenarios. Specifically, a sizable number of other forecasts anticipate steeper LCOE reductions than even the low-scenario expert survey results. As indicated earlier, offshore wind energy costs have not experienced the sizable historical reductions witnessed onshore. Those historical data points may be encouraging some conservatism among the experts, at least relative to the broader literature.

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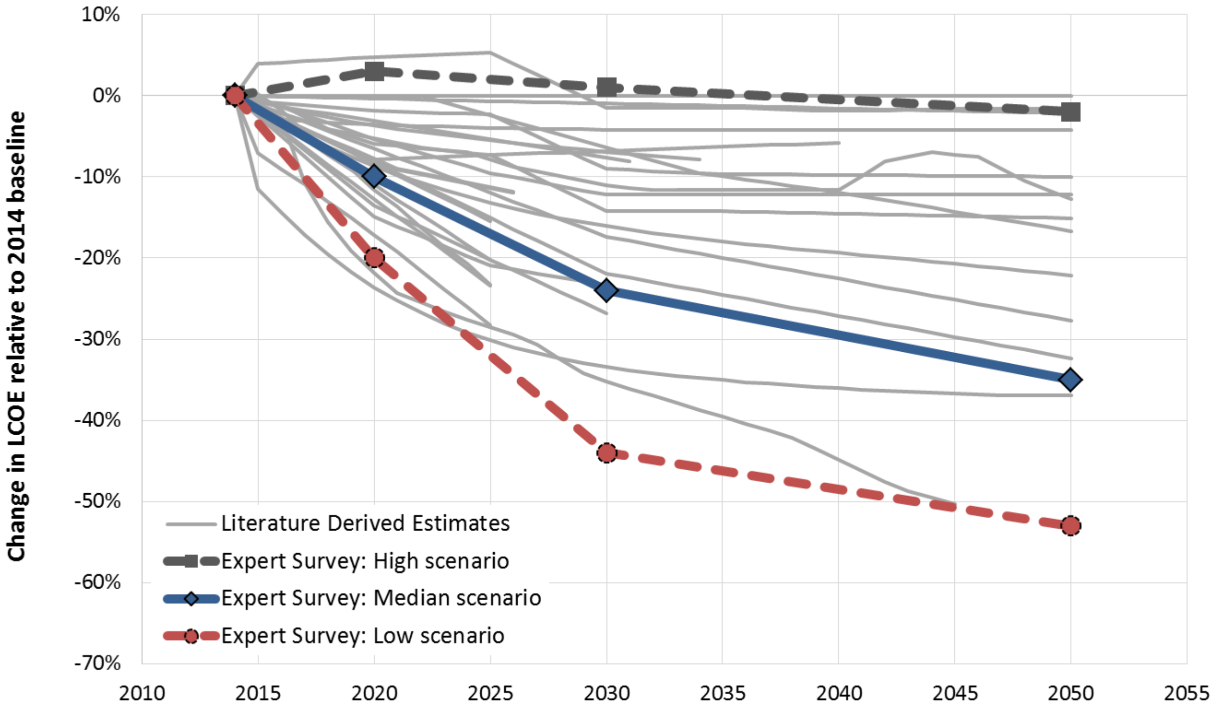
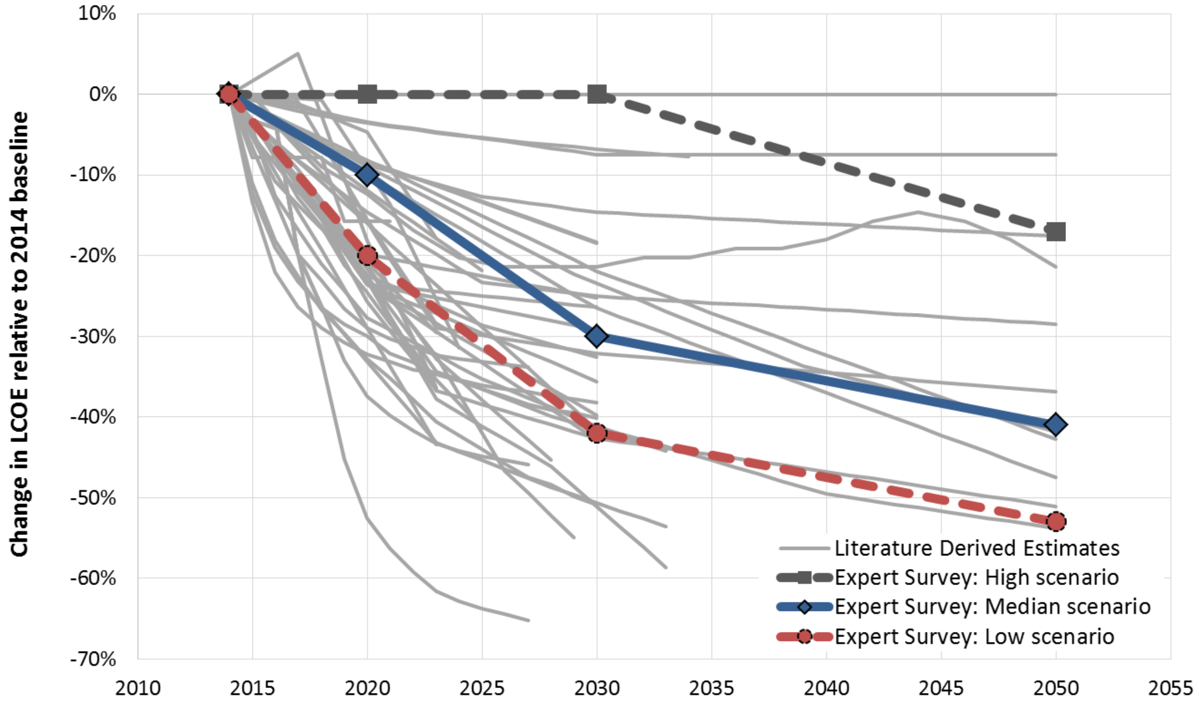
[27] We do not include a similar chart for floating offshore wind because of the limited number of unique estimates for the future cost of this technology, relative to a 2014 fixed-bottom baseline.

a) Onshore



b) Fixed-Bottom Offshore



Note: See Appendix C for a listing of the references from which the literature-derived estimates were sourced.

Figure 14. Estimated Change in LCOE over Time for (a) Onshore and (b) Fixed-Bottom Offshore Wind Projects: Expert Survey Results vs. Other Forecasts

4. Conclusions

The wind energy industry has matured substantially since its beginnings in the 1970s, as has wind power technology. Sizable reductions in the cost of onshore wind energy have accompanied that maturation, with the hope that those reductions will also be witnessed offshore. But how much additional cost reduction is possible, both onshore and offshore? What technological and market factors are the most likely contributors to those reductions? And what broad trends might drive even greater technological advancements and cost reductions?

This study has sought to help answer these questions, leveraging the unique insights of 163 of the world's foremost wind energy experts. Specifically, we have summarized the core results of an expert elicitation survey on future wind energy costs and technology advancement possibilities, in what may be the largest single elicitation ever performed on an energy technology in terms of expert participation. Insights gained through this survey can complement other tools for evaluating cost-reduction potential, including the use of learning curves, engineering assessments, and less-formal means of synthesizing expert knowledge. Ultimately, we hope this work informs policy and planning decisions, R&D decisions, and industry investment and strategy development while improving the representation of wind energy in energy-sector planning models.

Notwithstanding the growing maturity of onshore wind and the limited evidence of historical cost reductions for offshore wind, we find that experts anticipate significant additional reductions in the levelized cost of wind energy across all three applications. As summarized in Figure 15, under the median scenario, experts anticipate 24%–30% reductions by 2030 and 35%–41% reductions by 2050. 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. Though onshore wind is anticipated to remain less expensive than offshore—and fixed-bottom less expensive than floating—there are greater absolute reductions (and more uncertainty) in the long-term LCOE of offshore wind compared with onshore wind.

For onshore wind, CapEx and capacity factor improvements are expected to constitute the largest drivers of LCOE reduction. The importance of higher capacity factors is consistent with expert views on turbine characteristics, with scaling expected not only in turbine capacity ratings but also rotor diameters and hub heights. For fixed-bottom offshore wind, on the other hand, CapEx reductions and improvements in financing costs are the largest expected contributors to LCOE reduction. The relatively higher importance of CapEx and lower importance of capacity factor is consistent with expert opinions on future offshore turbine size: expected turbine capacity ratings (and hub heights) grow significantly in order to minimize CapEx, but specific power is expected to remain roughly at recent levels. Capacity factor improvements play a larger role for floating offshore wind (relative to the 2014 baseline for fixed-bottom), perhaps reflecting a belief that floating technology will tend to be deployed in windier sites as enabled by the ability to access deeper water locations. Some of the specific technology, market, and other changes expected to drive down LCOE are listed in Figure 15 and detailed earlier.

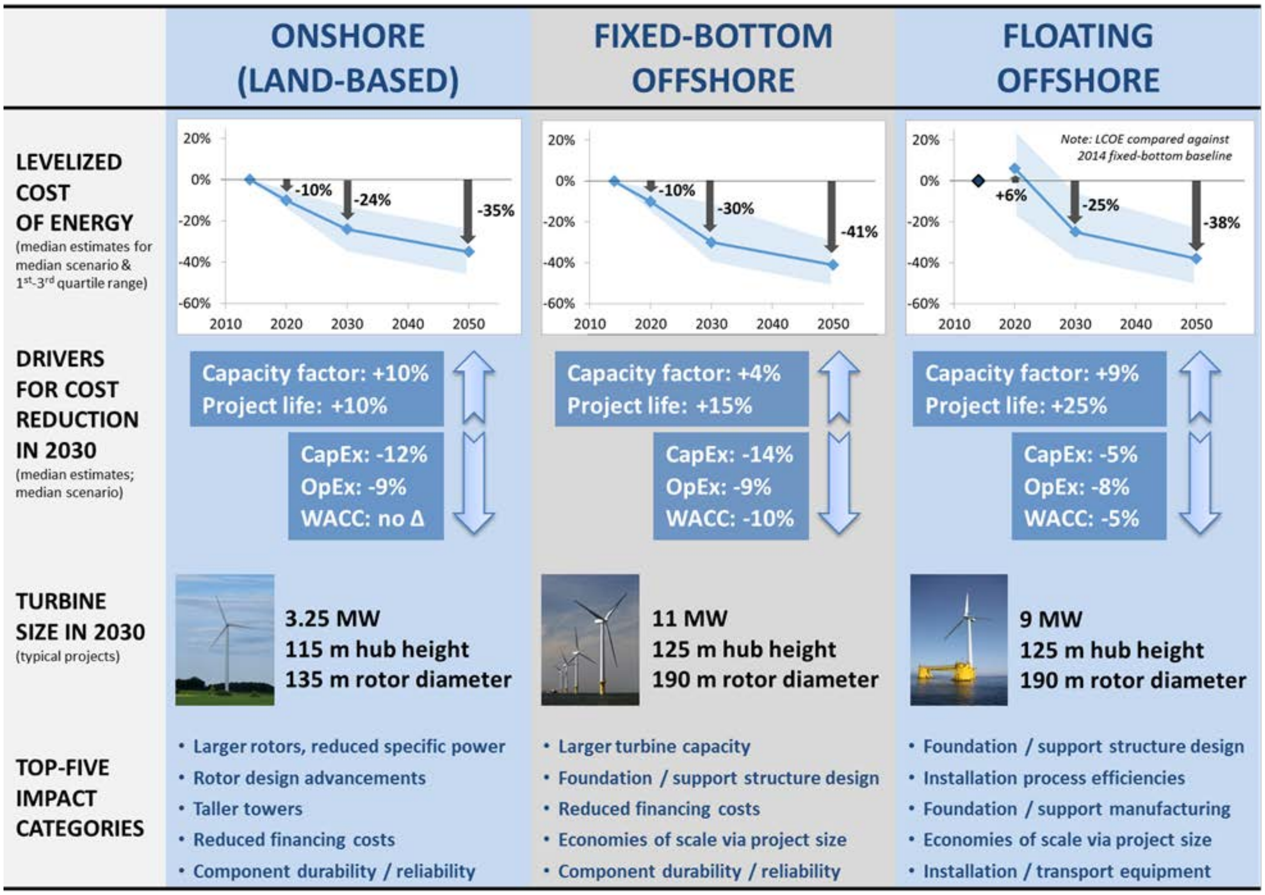


Figure 15. Summary of Expert Survey Findings

Elicitation results for onshore wind are consistent with historical LCOE learning, suggesting that properly constructed learning rates may be reasonably used to forecast future costs in more mature applications. However, the majority of the literature assessing historical learning rates for wind have emphasized only upfront capital costs, and some energy-sector and integrated-assessment models rely on those learning estimates when forecasting future costs (Criqui et al. 2015). Expert elicitation findings demonstrate that capital-cost improvements are only one means of achieving LCOE reductions, and not always the dominant one. Extrapolation of past capital-cost-based learning models therefore likely understates the opportunities for future LCOE reduction by ignoring major drivers for that reduction. This is illustrated by the fact that the elicitation-based forward-looking LCOE learning rates are twice as high as recently estimated CapEx-based learning rates for onshore wind of 6-9%, and may explain why onshore cost reduction estimates from wind experts are more aggressive than many past forecasts.

Expert survey results further illustrate the considerable uncertainty that exists across all of these variables and factors. This uncertainty is, in part, reflected in the range among expert-specified low-, median-, and high-scenario LCOE estimates. And, to some degree, managing this uncertainty is within the control of public and private decision makers: learning with market growth along with R&D, for example, are the two most significant factors in enabling the low-LCOE scenario. Differences are also found when reviewing the range in expert-specific responses (rather than median responses). Some of the variation in expert-specific responses, meanwhile, can be explained by segmenting respondents into various categories. As presented in various text boxes earlier, for example, we find that the smaller "leading-expert" group generally expects greater wind energy cost reductions than the larger set of other respondents, whereas equipment manufacturers are sometimes more cautious about nearer-term advancement possibilities. Future work is planned to assess more thoroughly these differences in survey responses by respondent characteristics.

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Appendix A. Survey Respondents

Respondents to the survey are listed below. If it is known that multiple individuals within an organization collaborated on a single survey response, that is noted by listing multiple names in one row of the table. Prior to survey release, a select group of "top experts" were identified. Survey participants among that group are identified with an asterisk (*) after their name.

Name(s)	Organization
John Dalsgaard Sørensen	Aalborg University
Scott Baron	Acciona
Thomas Donoghue	Acciona
Michaela O'Donohoe	Adwen
Alberto Ceña	AEE
Wallace Ebner	AIG
David Blittersdorf	All Earth Renewables
Michael Goggin	American Wind Energy Association
Bruce Bailey	AWS Truepower
Ryan Pletka	Black and Veatch
John Reilly	Bord na Mona
Sandy Butterfield	Boulder Wind Consulting
Mike Blanch, Charlie Nordstrom, Alun Roberts, Bruce Valpy*	BVG Associates
Nancy Rader	California Wind Energy Association
Denja Lekou	Center for Renewable Energy Sources
Rashid Abdul	CG Holdings
Ignacio Cruz	CIEMAT
Michael Skelly	Clean Line Energy Partners
Matt McCabe	Clear Wind
Andy Paliszewski	Consultant
Bernard Chabot	Consultant
David Milborrow	Consultant
Eize de Vries	Consultant
John Brereton	Consultant
Paul Gipe	Consultant
Edgar DeMeo	Consultant
Per Vøland	COWI
Flemming Rasmussen	Denmark Technical University
Kenneth Thomsen	Denmark Technical University
Klaus Skytte	Denmark Technical University
Lena Kitzing	Denmark Technical University
Peter Hjuler Jensen	Denmark Technical University
Poul Erik Morthorst*	Denmark Technical University
Thomas Buhl*	Denmark Technical University
Carl Sixtensson	DNV GL
Carlos Albero Fuyola	DNV GL

Name(s)	Organization
Clint Johnson	DNV GL
Johan Sandberg	DNV GL
Karen Conover	DNV GL
Peter Frohbose	DNV GL
Robert Poore*	DNV GL
Mats Vikholm*	DONG energy
Sune Strom	DONG energy
Aidan Duffy	Dublin Institute of Technology
Aisma Vitina	EA Energy Analyses
Robert Brueckmann	Eclareon
Sander Lensink	ECN
Bob Prinsen	Ecofys
David de Jager	Ecofys
James Walker*	EDF
Jeffery Ghilardi	EDF
Francisco Galván González	EDPR
Mike Finger	EDPR
Christopher Namovicz	Energy Information Agency
Andrew Scott	Energy Technologies Institute
Jasper Voormolen	Energyprofs
Kevin Standish	Envision Energy
Roberto Lacal Arantegui	European Commission Joint Research Centre
Andrew Ho	European Wind Energy Association
Joe Phillips	Everoze Partners
Mark Jonkhof	EWT
Randall Swisher	formerly American Wind Energy Association
Jorgen Lemming	formerly Denmark Technical University
Birger Madsen	formerly Navigant
Per Krogsgaard	formerly Navigant
Henrik Stiesdal*	formerly Siemens
Volker Berkhout	Fraunhofer IWES
Jochen Giebhardt	Fraunhofer IWES
Aris Karcanis	FTI
Feng Zhao	FTI
Juan Diego Diaz Vega	Gamesa
Henk-Jan Kooijman	General Electric
Seth Dunn	General Electric
Thomas Fischetti*	General Electric
Steve Sawyer	Global Wind Energy Council
Weiping Pan	Goldwind
Fort Felker	Google
Jérôme Guillet*	Green Giraffe Energy Bankers
Carlos Casco	Iberdrola
Richard Glick, Scott Haynes, Wayne Mays, Kevin Walker, Scott Winneguth	Iberdrola

Name(s)	Organization
Thomas Choisnet	Ideol
Matt Daprato	IHS
Maxwell Cohen	IHS
Philip Heptonstall*	Imperial College
Heymi Bahar, Cedric Philibert	International Energy Agency
Christian Kjaer	International Renewable Energy Agency
Michael Taylor	International Renewable Energy Agency
Gadi Hareli	Israeli Wind Energy Association
Carsten Ploug Jensen	K2 Management
Albert Jochems	Laidlaw Capital Management
Mark Bolinger	Lawrence Berkeley National Lab
Lorry Wagner	LEEDCo
Lena Neij	Lund University
Jeffrey Kehne	Magellanwind
Jim Lanard	Magellanwind
Aaron Barr	MAKE
Dan Shreve*	MAKE
Aaron Zubaty	MAP
Sam Enfield*	MAP
Jorg Kubitza	MHI Vestas
Brian Smith	National Renewable Energy Lab
Christopher Mone	National Renewable Energy Lab
Daniel Laird	National Renewable Energy Lab
Paul Veers	National Renewable Energy Lab
Rick Damiani	National Renewable Energy Lab
Robert Thresher*	National Renewable Energy Lab
Senu Sirnivas	National Renewable Energy Lab
Walt Musial	National Renewable Energy Lab
Bruce Hamilton	Navigant
Dan Brake	NextEra
Mike O'Sullivan*	NextEra
Leif Husabo	Norwegian Water Resources and Energy Directorate
Jim Lyons	NOVUS Energy Partners
Gavin Smart	Offshore Renewable Energy Catapult
Ignacio Marti Perez	Offshore Renewable Energy Catapult
Andreas Wagner	Offshore Wind Energy Foundation
John Calaway	Pattern
Joshua Weinstein	Principal Power Inc
Brian Healer	RES
Rob Morgan	RES
Brian Naughton	Sandia National Lab
Steve Dayney	Senvion
Henning Kruse	Siemens
Jason Folsom	Siemens
John Amos*	Siemens

Name(s)	Organization
Lanny Kirkpatrick	Siemens
Liz Salerno	Siemens
Morten Rasmussen	Siemens
Peder Nickelsen	Siemens
Iver Bakken Sperstad	SINTEF Energy Research
Jan Schelling	Statkraft
Eirik Byklum	Statoil
Finn Gunnar Nielsen	Statoil
Jan-Fredrik Stadaas*	Statoil
Duncan Koerbel*	Suzlon
Reto Rigassi	Swiss Wind Energy Association
Jim O'sullivan	Technip
Andy Swift	Texas Tech University
Jurgen Weiss	The Brattle Group
Alastair Dutton*	The Crown Estate
Craig Christenson	Turbine Technology Partners
Doug Pfeister	TUV-SUD PMSS
Daniel Beals	U.S. Department of Energy
Greg Matzat	U.S. Department of Energy
Jim Ahlgrimm	U.S. Department of Energy
Mike Derby	U.S. Department of Energy
Mike Robinson*	U.S. Department of Energy
Nick Johnson	U.S. Department of Energy
Patrick Gilman	U.S. Department of Energy
Rich Tusing	U.S. Department of Energy
Case Van Dam	UC Davis
Steve Clemmer	Union of Concerned Scientists
Jimmy Murphy	University College Cork
Stephanie McClellan	University of Delaware
Barry Butler	University of Iowa
Robert de Bruin, Dolf Elsevier van Griethuysen	Van Oord
Johannes Kammer*	Vattenfall
Anurag Gupta	Vestas
Chris Brown	Vestas
Jorge Magalhaes	Vestas
Margaret Montanez*	Vestas
Mark Ahlstrom*	WindLogics
Bob Gates	Windstream Properties

Appendix B. Additional Survey Results

This appendix includes a number of additional figures and tables based on the survey results:

- **Absolute LCOE, 2014-2050:** The main report includes a figure (Figure 5) depicting estimated absolute LCOE values for all three wind energy applications, over time, on a single plot, focusing only on median-scenario LCOE estimates, and showing the median and range of expert responses. This appendix includes two similar figures, one focused on the low-scenario LCOE and the other one on the high-scenario LCOE.

- **LCOE and LCOE Components, 2014 and 2030:** This appendix includes three detailed figures for LCOE and the five components of LCOE for the baseline year of 2014 and 2030, one for each of the wind applications. These figures show the mean, median, and range of expert estimates in box-and-whiskers plots. In these plots, shaded grey boxes show the 1st to 3rd quartile values, and the "whiskers" generally show the minimum to maximum assessed values, except where there are outlier values, which appears as small circles. Outliers are defined as values that are less than the 1st quartile or greater than the 3rd quartile by more than 1.5 times the inter-quartile difference. Most experts endorsed the default 2014 baseline values—as a result, the median values for 2014 as well as the 25th and 75th percentiles are all equal to the default baseline values, and all cases where experts defined baseline values different from the default values appear as outliers.

- **Turbine Characteristics, 2030:** This appendix includes histograms of respondent assessments of turbine nameplate capacity, hub height, and rotor diameter, for all three wind energy applications. Implied specific power is also presented, in the form of a box-and-whiskers plot; unlike in (2), above, however, outlier values are not presented in this chart, and so the whiskers do not necessarily represent absolute maximum or minimum respondent values.

- **Wind Technology, Market, and Other Changes:** This appendix provides survey results for all 28 wind technology, market, and other changes that might impact LCOE by 2030, for each of the three wind applications. It also lists the expert-provided "write-in" responses to the question, separately for onshore, fixed-bottom offshore, and floating offshore wind.

- **Broad Drivers for Lower LCOE:** This appendix lists the expert-provided "write-in" responses to the question about broad drivers for achieving low LCOE estimates in 2030, for onshore and fixed-bottom offshore wind projects.

- **Differences among Respondent Groups:** This appendix includes a series of color coded tables that provide additional detail on the results found in text boxes and elsewhere throughout the main body of the report, summarizing key differences in expert responses based on various respondent groupings.

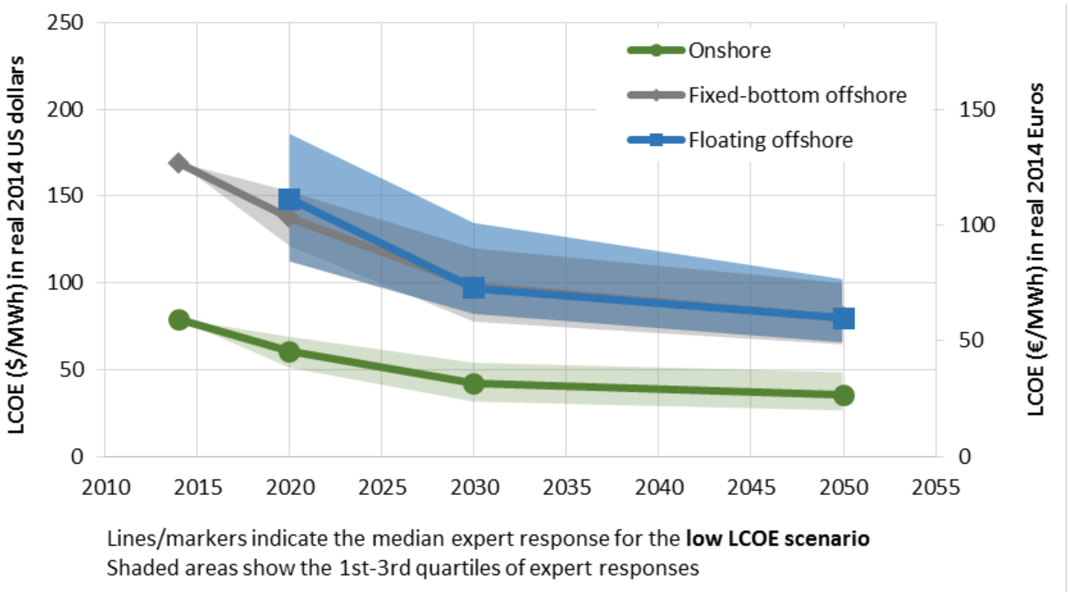


Figure A –1. Expert Estimates of Low-Scenario LCOE for All Three Wind Applications

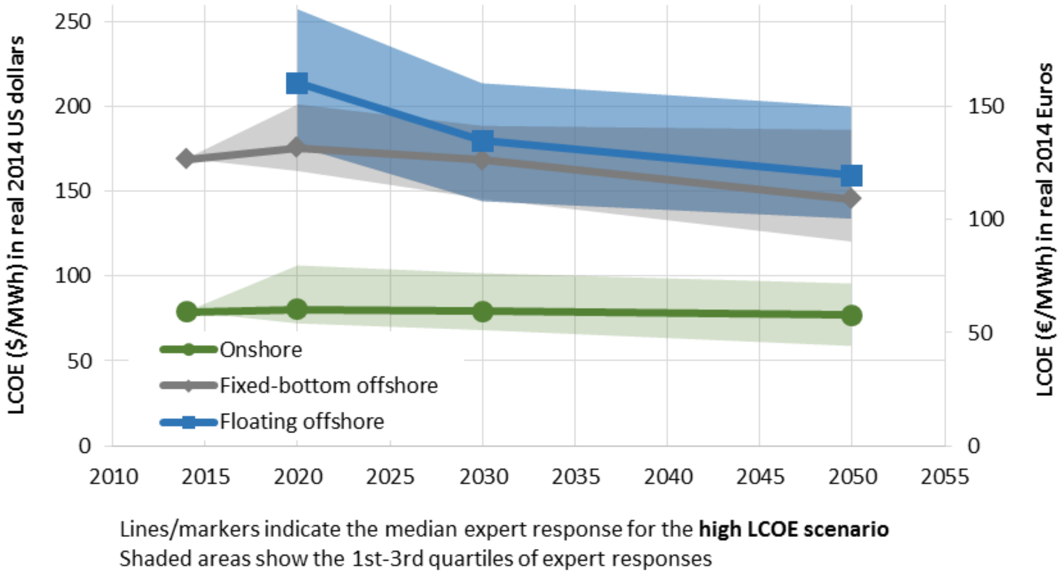
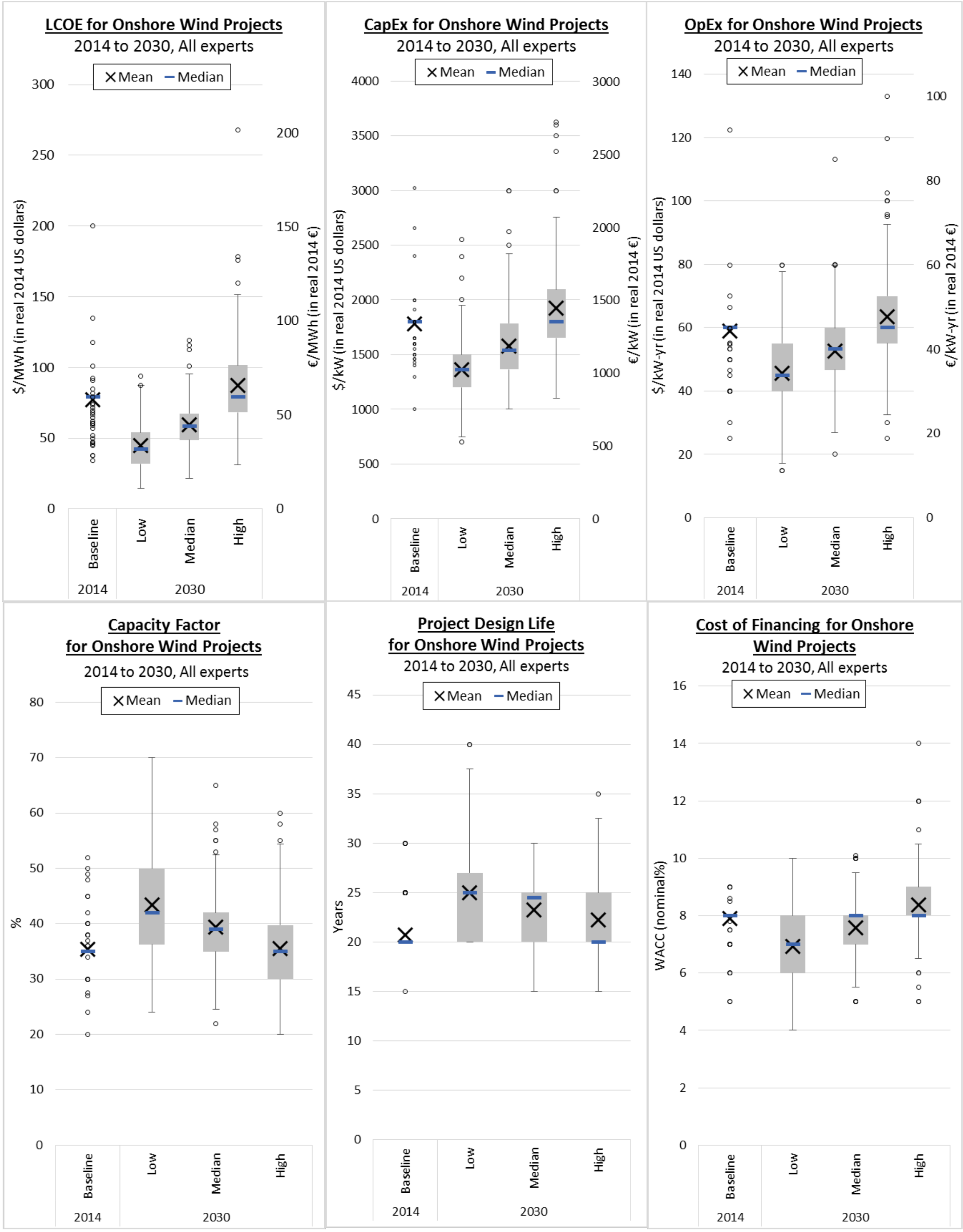


Figure A – 2. Expert Estimates of High-Scenario LCOE for All Three Wind Applications



LCOE for Onshore Wind Projects
2014 to 2030, All experts

CapEx for Onshore Wind Projects
2014 to 2030, All experts

OpEx for Onshore Wind Projects
2014 to 2030, All experts

Capacity Factor for Onshore Wind Projects
2014 to 2030, All experts

Project Design Life for Onshore Wind Projects
2014 to 2030, All experts

Cost of Financing for Onshore Wind Projects
2014 to 2030, All experts

Figure A – 3. Expert Estimates of LCOE and LCOE Components for Onshore Wind in 2014 and 2030

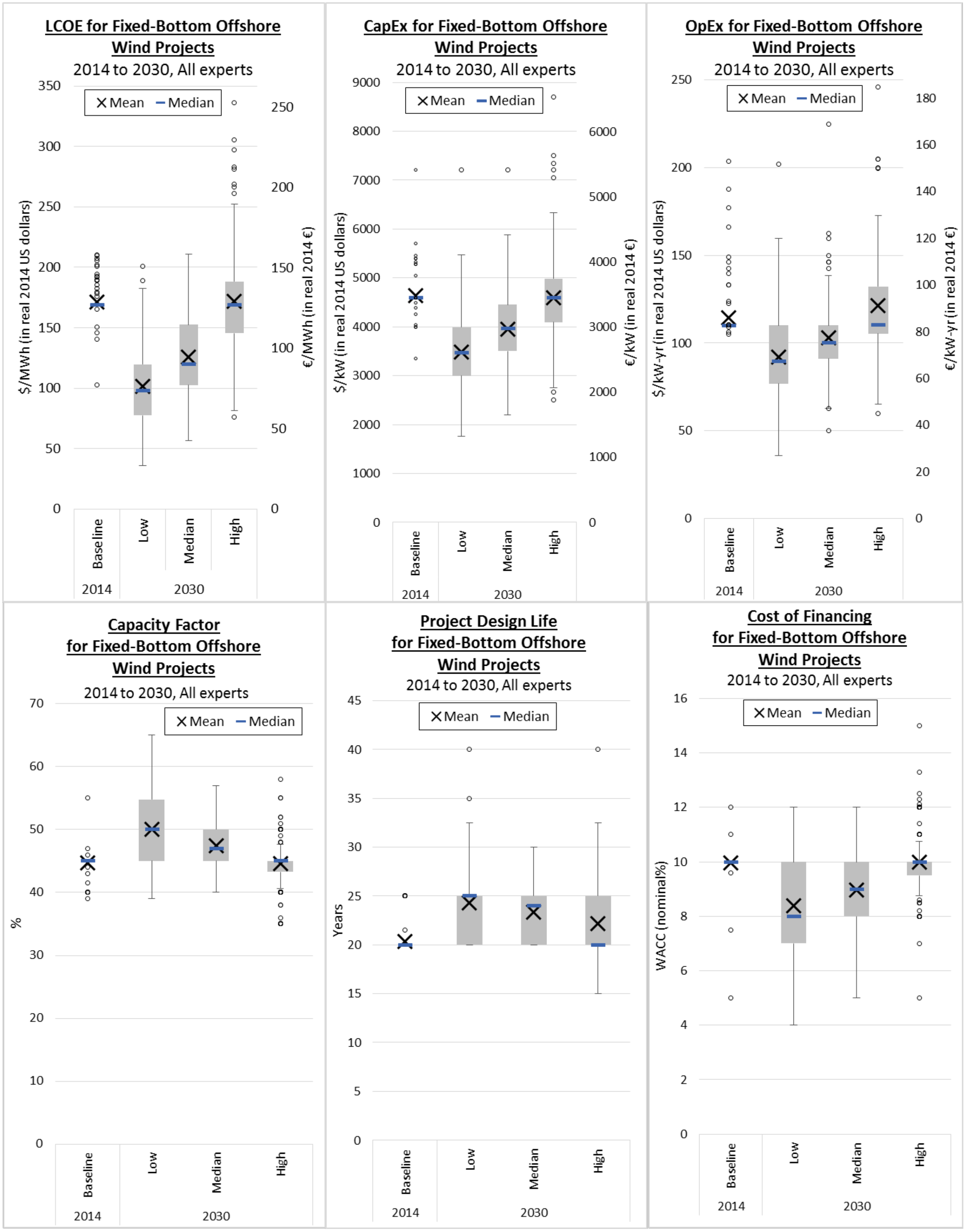


Figure A – 4. Expert Estimates of LCOE and LCOE Components for Fixed-Bottom Offshore Wind in 2014 and 2030

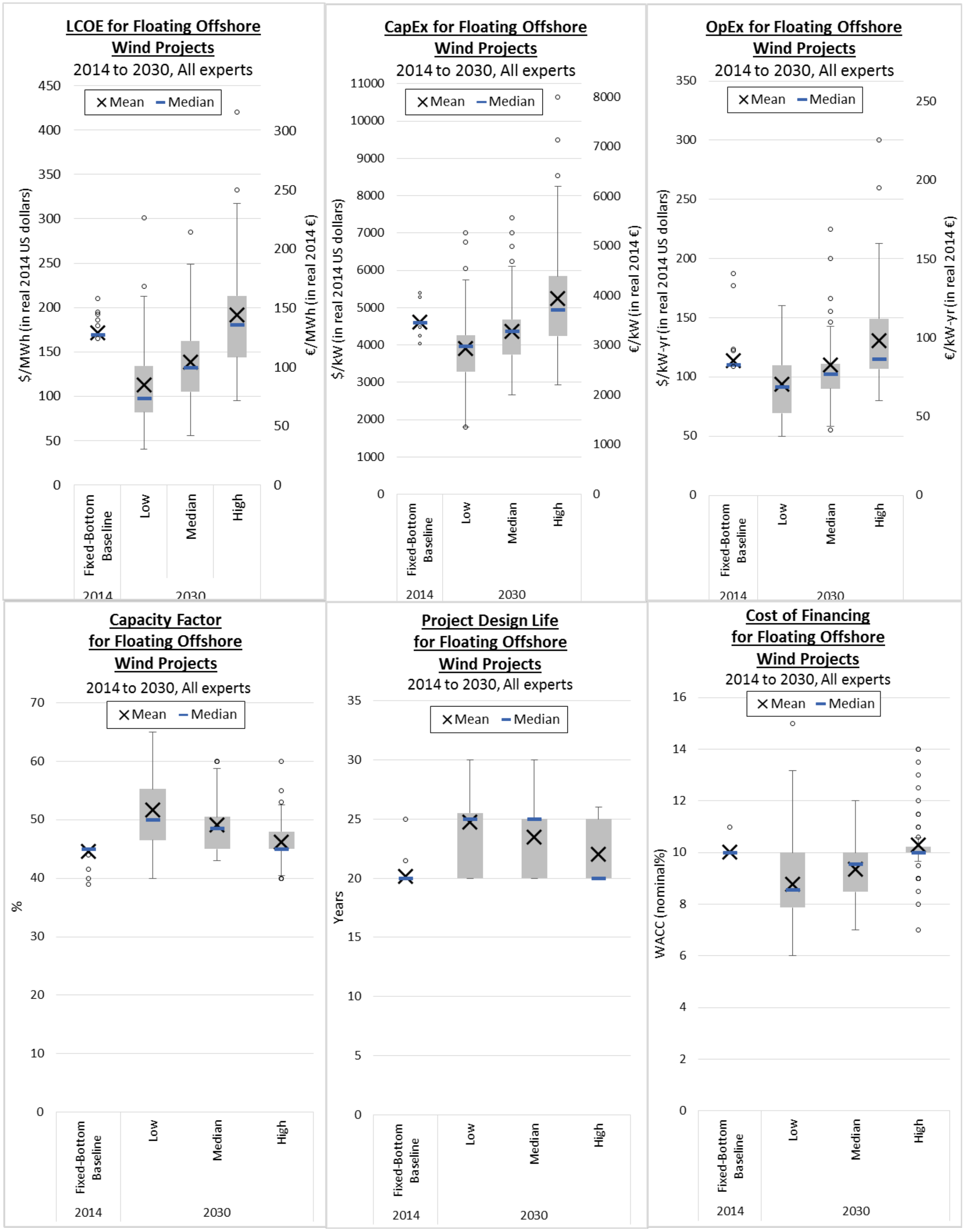


Figure A – 5. Expert Estimates of LCOE and LCOE Components for Floating Offshore Wind in 2030, Compared to Fixed-Bottom 2014 Baseline

Note: The values for the "Fixed-bottom Baseline" are derived only from the expert sub-sample that also answered floating offshore questions and is thus different from the 2014 baseline on the preceding page.

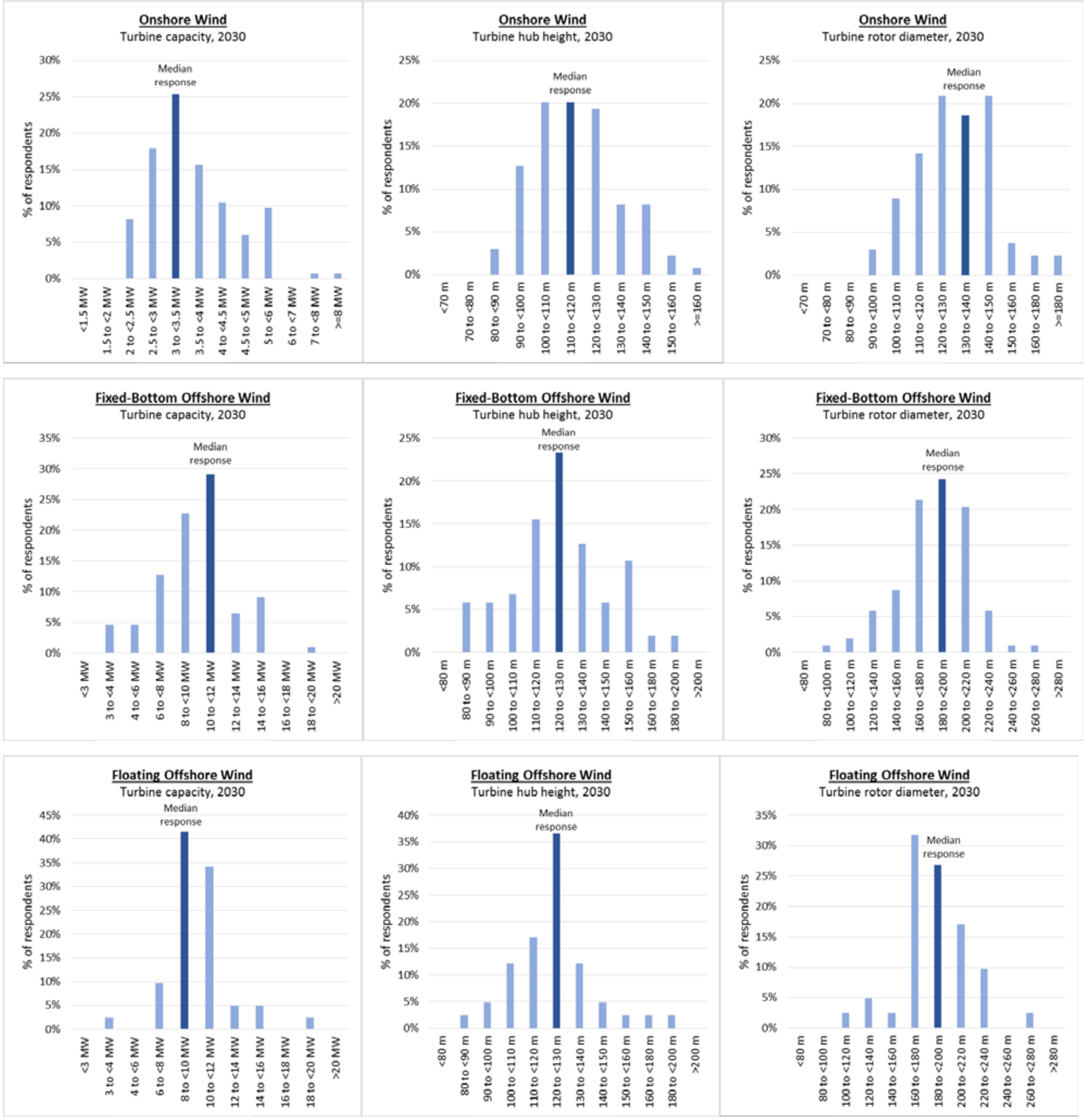


Figure A – 6. Wind Turbine Characteristics in 2030 for Onshore, Fixed-Bottom Offshore, and Floating Offshore Wind Projects

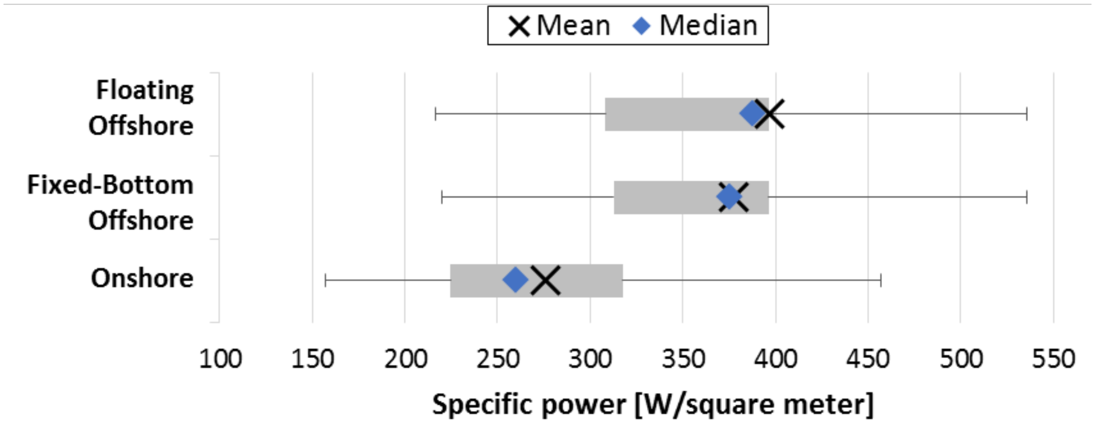


Figure A – 7. Wind Turbine Specific Power in 2030 for Onshore, Fixed-Bottom Offshore, and Floating Offshore Wind Projects

Table A – 1. Expected Impact of Wind Technology, Market, and Other Changes on Reducing LCOE of Onshore Wind Projects by 2030

Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating , Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact	
Increased rotor diameter such that specific power declines	58%	2.5	
Rotor design advancements	45%	2.3	
Increased tower height	33%	2.2	
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	32%	2.1	
Improved component durability and reliability	31%	2.1	
Increased energy production due to new transmission to higher wind speed sites	31%	2.0	
Extended turbine design lifetime	29%	2.0	
Operating efficiencies to increase plant performance	28%	2.0	
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	28%	1.9	
Turbine and component manufacturing standardization, efficiencies, and volume	27%	2.0	
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	27%	2.0	
Integrated turbine-level system design optimization	23%	2.0	
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	21%	1.8	
Large variety of alternative turbine designs to suit site-specific conditions	17%	1.7	
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	17%	1.6	
Maintenance process efficiencies	17%	1.8	
Tower design advancements	14%	1.8	
Economies of scale through increased project size	12%	1.6	
Installation and transportation equipment advancements	12%	1.7	
Nacelle components design advancements	12%	1.6	
Innovative non-conventional turbine designs	12%	1.2	
Maintenance equipment advancements	10%	1.6	
Foundation and support structure manufacturing standardization, efficiencies, and volume	10%	1.5	
Foundation and support structure design advancements	10%	1.3	
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	9%	1.5	
Installation process efficiencies	9%	1.4	
Reduced fixed operating costs, excluding maintenance	5%	1.3	
Lower decommissioning costs	1%	0.8	

Table A – 2. Expected Impact of Wind Technology, Market, and Other Changes on Reducing LCOE of Fixed-Bottom Offshore Wind Projects by 2030

Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating , Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact	
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	55%	2.4	
Foundation and support structure design advancements	53%	2.4	
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	49%	2.4	
Economies of scale through increased project size	48%	2.3	
Improved component durability and reliability	48%	2.3	
Installation process efficiencies	46%	2.4	
Installation and transportation equipment advancements	44%	2.3	
Foundation and support structure manufacturing standardization, efficiencies, and volume	43%	2.2	
Extended turbine design lifetime	36%	2.2	
Turbine and component manufacturing standardization, efficiencies, and volume	36%	2.1	
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	35%	2.1	
Integrated turbine-level system design optimization	33%	2.1	
Rotor design advancements	32%	2.1	
Maintenance process efficiencies	32%	2.2	
Maintenance equipment advancements	30%	2.0	
Operating efficiencies to increase plant performance	29%	2.1	
Increased rotor diameter such that specific power declines	27%	2.0	
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	25%	1.9	
Increased energy production due to new transmission to higher wind speed sites	21%	1.7	
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	21%	1.8	
Nacelle components design advancements	19%	1.9	
Innovative non-conventional turbine designs	17%	1.5	
Tower design advancements	12%	1.5	
Reduced fixed operating costs, excluding maintenance	10%	1.5	
Increased tower height	6%	1.3	
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	5%	1.1	
Large variety of alternative turbine designs to suit site-specific conditions	5%	1.2	
Lower decommissioning costs	2%	0.9	

Table A – 3. Expected Impact of Wind Technology, Market, and Other Changes on Reducing LCOE of Floating Offshore Wind Projects by 2030

Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating , Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact	
Foundation and support structure design advancements	80%	2.8	
Installation process efficiencies	78%	2.7	
Foundation and support structure manufacturing standardization, efficiencies, and volume	68%	2.6	
Economies of scale through increased project size	65%	2.6	
Installation and transportation equipment advancements	63%	2.5	
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	59%	2.4	
Improved component durability and reliability	58%	2.5	
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	46%	2.3	
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	46%	2.2	
Rotor design advancements	45%	2.1	
Integrated turbine-level system design optimization	44%	2.3	
Turbine and component manufacturing standardization, efficiencies, and volume	40%	2.3	
Extended turbine design lifetime	39%	2.2	
Maintenance process efficiencies	35%	2.2	
Innovative non-conventional turbine designs	34%	1.9	
Increased rotor diameter such that specific power declines	32%	2.1	
Increased energy production due to new transmission to higher wind speed sites	29%	1.7	
Tower design advancements	28%	1.9	
Nacelle components design advancements	28%	1.8	
Maintenance equipment advancements	25%	2.0	
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	20%	1.9	
Operating efficiencies to increase plant performance	18%	2.0	
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	15%	1.8	
Increased tower height	15%	1.4	
Large variety of alternative turbine designs to suit site-specific conditions	12%	1.2	
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	12%	1.2	
Reduced fixed operating costs, excluding maintenance	8%	1.4	
Lower decommissioning costs	3%	0.8	

Table A – 4. Expert-Added Wind Technology, Market, and Other Changes that Are Expected to Reduce LCOE of Onshore Wind Projects by 2030

Access to high wind class due to taller towers and larger rotors	Hybrid projects, mainly PV, better use of electrical infrastructure
Advanced controls with smart rotors	Improved control strategy
Advanced feed-in tariffs adapted to the quality of sites and giving incentives to use wind turbines with high specific area Su (m2/kW) values	Improved operational forecasts
Advanced storage systems	Increased lifetime of wind turbine generators
Advanced wind plant control	Lighter structures, less material
Better wind feedback from i.e. lidar measuring in front of the turbine	Lower financing costs
Carbon blades	Modularity in electric generators and power electronics
Carbon tax	Modularization
Continuing increase in specific area Su ratio (m2/kW)	New climate change agreement
Cross border infrastructure	New electricity demand
Cross-country alignment of regulations	Optimization of blade design
Dispersed energy solutions and comprehensive wind farm controls balancing annual energy productions, grid quality, loads, and noise	Plant control systems
Disruptive new airborne wind energy systems	Reduced energy storage costs
Electrical system efficiency improvements	Reduced tax credits , lower cost of capital
Energy storage technologies combined with wind power to provide more stability to the grid	Regulation
Enhanced power-system flexibility that reduces curtailment	Regulatory stability
Farm control strategies	Segmented blades to reduce transportation cost
Full transparency, public access, and good data based on actual projects' performances and costs	Smarter modularized tower designs to ease transport logistics
Global energy market reform	Tailored gearbox designs for wind turbines
Hardware reliability improvements	Wind plant control to enable new plant layout options and efficiencies
High altitude kite turbine technology	Wind plant control to optimize production and minimize losses

Table A – 5. Expert-Added Wind Technology, Market, and Other Changes that Are Expected to Reduce LCOE of Fixed-Bottom Offshore Wind Projects by 2030

Advanced wind plant control	Improvements in electrical collection systems
Carbon rotors at low cost	Inland Sea developments
Coastal State energy policies	Integrated Logistics
Cross-border alignment of regulation for greater development flexibility	Large vessel strategy
Departure from onshore technology with emphasis on reducing offshore installation and maintenance	Less complex sites
Design of turbines for offshore installation	Market introduction of floating systems
Development of foundations for rocky seabeds	Nearshore, shallow, good wind, good geology sites
Development of interest rates	New business models
Disruptive new airborne wind energy systems	New custom design procedures for wind turbine gearboxes
Electricity demand	Smarter foundation design i.e. jackets with suction-buckets
Far-shore site development	Stable energy policy framework in support of offshore wind
Higher transmission voltage	Tailored installation vessels

Table A – 6. Expert-Added Wind Technology, Market, and Other Changes that Are Expected to Reduce LCOE of Floating Offshore Wind Projects by 2030

Advanced wind plant control with dynamic turbine positioning	Float out installation
Aggressive GHG reduction policies	Integration with fishing industry
Aggressive GHG reduction policies in Pacific Rim jurisdictions opening new markets for large-scale development	Integration with Oil & Gas industry (e.g. the WIn WIn project)
Carbon rotors at low cost	Large scale energy storage technology providing grid stability
Coastal State energy policies	Mooring components qualification
Creating public support through information campaigns and demonstrating that floating wind can be built beyond the horizon	Nearshore, good wind sites
Departure from onshore and fixed offshore technologies to take advantage of unique system opportunities available to pre-fabricated floating units	New customized design procedures for wind turbine gearboxes
Dry dock fabrication	Rational federal tax policy
Electricity demand	

Table A – 7. Expert-Added Broad Drivers to Move from Median to Low LCOE Scenario for Onshore Wind in 2030

A carbon fiber cost reduction breakthrough will enable lighter weight and very large rotor turbines	Larger rotors compared to generator
Availability of IEC3 and IEC2 wind turbines with increasing high and very high specific area ratios Su (m2/kW), delivering high and very high capacity factors on IEC3 and IEC2 sites (or from 55 to 85 m/s average at hub height)	Low natural gas prices and possible withdrawal of subsidies force turbine vendors and purchasers to lower installed costs
Cheaper financing: stable regulatory frameworks and increasing familiarity with risks allow for cheaper types of capital, with longer term horizon	Lower cost of financing as offshore wind becomes more like other utility projects
Common components and systems and modules	R&D incremental improvements leading to efficiency in O&M
Cost reduction of longer blades and taller towers	Reduced hurdle rates
Increased economic life of projects	Robust, stable policy driving markets for wind
Increased net capacity factor through technology and manufacturing innovation	Standardization and modularization
Integrated design of wind farms with holistic approach and system optimization, and continuous improvement of wind detection and capture as well as improved reliability of wind farm plants	

Table A – 8. Expert-Added Broad Drivers to Move from Median to Low LCOE Scenario for Fixed-Bottom Offshore Wind in 2030

A carbon fiber cost reduction breakthrough will enable lighter weight and very large rotor turbines	Increased turbine rating (yield)
Cheaper financing: stable regulatory frameworks and increasing familiarity with risks allow for cheaper types of capital, with longer term horizon	Lower costs of capital as per previous
Gigawatts of development	Realistic project pipeline with appropriate support at the state and federal level
Increase of project design life over 30 years	Site selection: nearshore, shallow, good wind, good geology

Table A – 9. Estimated Change in LCOE over Time for Onshore Wind Projects, by Respondent Group

Onshore wind (LCOE relative to expert-specific 2014 baseline)											
Respondent Group		Number of respondents	Median scenario for typical LCOE (median expert response)			Low scenario for typical LCOE (median expert response)			High scenario for typical LCOE (median expert response)		
			2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
All		134	**-10%**	**-24%**	**-35%**	**-20%**	**-44%**	**-53%**	**3%**	**1%**	**-2%**
By Lead / Larger group	Leading	17	-13%	-27%	-48%	-26%	-57%	-66%	0%	0%	-7%
	Larger	117	-10%	-24%	-35%	-19%	-44%	-52%	3%	2%	-1%
By type of organization	Research	38	-9%	-25%	-31%	-21%	-44%	-50%	7%	10%	1%
	Wind deployment	22	-10%	-22%	-34%	-21%	-43%	-50%	0%	1%	-1%
	Equipment manufacturer	22	-12%	-23%	-36%	-21%	-40%	-53%	-3%	0%	-10%
	Other private sector	39	-10%	-26%	-37%	-18%	-48%	-54%	5%	7%	0%
	Other	13	-10%	-24%	-34%	-20%	-42%	-47%	0%	0%	-2%
By applications evaluated	Onshore only	52	-9%	-24%	-36%	-19%	-43%	-52%	4%	2%	3%
	Both onshore and offshore	82	-11%	-24%	-35%	-21%	-44%	-54%	3%	1%	-5%
By type of expertise	Wind energy markets	94	-10%	-27%	-38%	-21%	-46%	-54%	1%	0%	-2%
	Systems level	74	-11%	-26%	-38%	-21%	-44%	-53%	1%	0%	-6%
	Subsystem level	36	-8%	-24%	-34%	-21%	-44%	-53%	5%	0%	-4%
By familiarity with region	North American	93	-10%	-25%	-38%	-22%	-46%	-55%	2%	0%	-2%
	Europe	77	-10%	-23%	-32%	-21%	-44%	-53%	5%	5%	-2%
	Asia	22	-12%	-27%	-40%	-27%	-49%	-55%	33%	4%	9%
	Latin America	24	-8%	-19%	-34%	-22%	-37%	-54%	1%	0%	0%
	Middle East and Africa	6	-11%	-24%	-30%	-24%	-54%	-50%	17%	-5%	-6%

Note: Colors refer to whether and the degree to which the LCOE estimate is lower (green) or higher (red) than for "all" respondents

Table A – 10. Estimated Change in LCOE over Time for Fixed-Bottom Offshore Wind Projects, by Respondent Group

Fixed-Bottom Offshore wind (LCOE relative to expert-specific 2014 baseline)											
Respondent Group		Number of respondents	Median scenario for typical LCOE (median expert response)			Low scenario for typical LCOE (median expert response)			High scenario for typical LCOE (median expert response)		
			2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
All		110	**-10%**	**-30%**	**-41%**	**-20%**	**-43%**	**-53%**	**0%**	**0%**	**-17%**
By Lead / Larger group	Leading	15	-15%	-35%	-51%	-29%	-53%	-62%	8%	-3%	-21%
	Larger	95	-10%	-29%	-40%	-19%	-42%	-53%	0%	0%	-15%
By type of organization	Research	38	-10%	-26%	-39%	-20%	-43%	-51%	6%	0%	-12%
	Wind deployment	16	-11%	-36%	-45%	-23%	-53%	-58%	-4%	-12%	-25%
	Equipment manufacturer	12	-4%	-9%	-41%	-7%	-32%	-51%	3%	0%	-11%
	Other private sector	32	-12%	-29%	-40%	-20%	-43%	-55%	0%	0%	-16%
	Other	12	-10%	-32%	-41%	-17%	-43%	-54%	-3%	-4%	-22%
By applications evaluated	Offshore only	28	-11%	-36%	-44%	-24%	-49%	-56%	-2%	-12%	-22%
	Both onshore and offshore	82	-10%	-28%	-39%	-18%	-42%	-53%	2%	0%	-14%
By type of expertise	Wind energy markets	77	-12%	-31%	-41%	-21%	-45%	-55%	-1%	0%	-19%
	Systems level	59	-10%	-31%	-41%	-19%	-43%	-54%	0%	0%	-17%
	Subsystem level	30	-10%	-29%	-39%	-18%	-43%	-53%	2%	1%	-13%
By familiarity with region	North American	65	-8%	-27%	-39%	-18%	-42%	-53%	0%	0%	-15%
	Europe	79	-11%	-32%	-42%	-20%	-43%	-53%	1%	0%	-16%
	Asia	21	-14%	-29%	-44%	-26%	-47%	-56%	-1%	-4%	-23%
	Latin America	11	-11%	-28%	-39%	-15%	-42%	-52%	-1%	0%	-28%
	Middle East and Africa	6	-6%	-25%	-38%	-10%	-37%	-53%	-1%	-3%	-17%

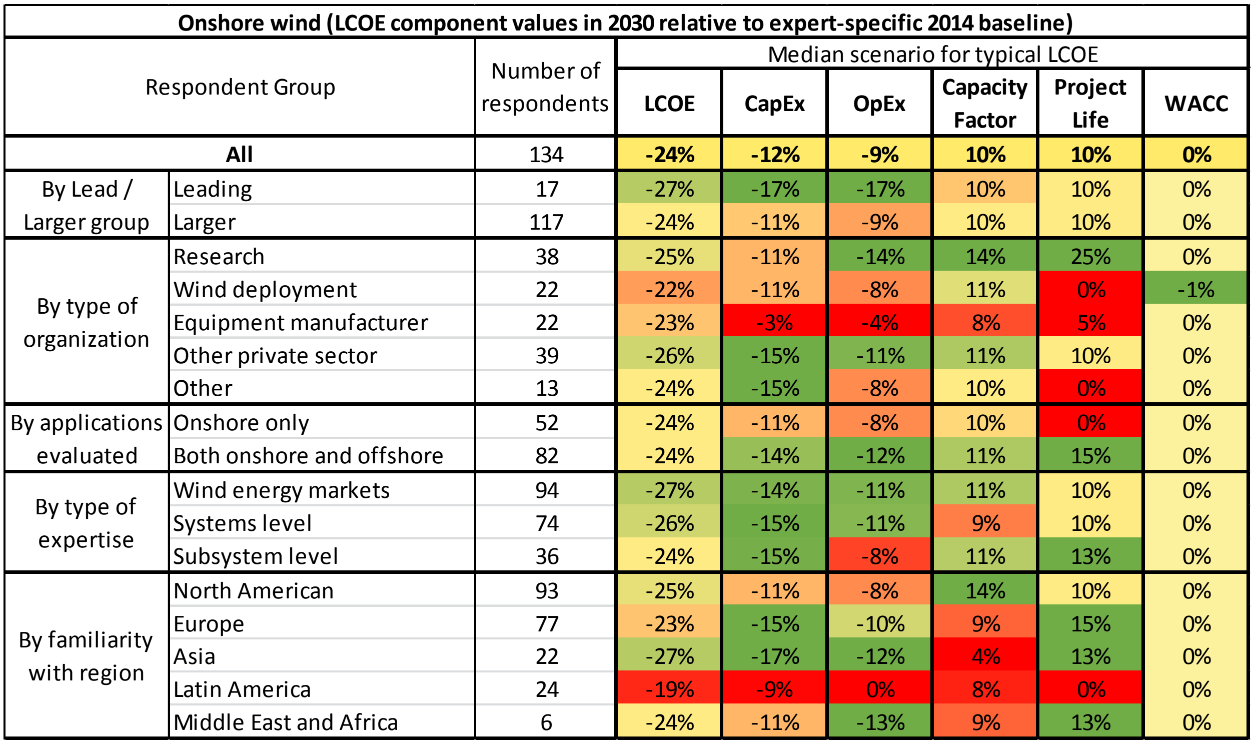
Note: Colors refer to whether and the degree to which the LCOE estimate is lower (green) or higher (red) than for "all" respondents

Table A – 11. Estimated Change in LCOE over Time for Floating Offshore Wind Projects, by Respondent Group

Floating Offshore wind (LCOE relative to expert-specific 2014 baseline)											
Respondent Group		Number of respondents	Median scenario for typical LCOE (median expert response)			Low scenario for typical LCOE (median expert response)			High scenario for typical LCOE (median expert response)		
			2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
All		44	**6%**	**-25%**	**-38%**	**-11%**	**-45%**	**-53%**	**25%**	**5%**	**-6%**
By Lead / Larger group	Leading	6	-5%	-38%	-50%	-23%	-54%	-64%	28%	2%	-13%
	Larger	38	7%	-15%	-31%	-11%	-40%	-50%	23%	5%	-5%
By type of organization	Research	17	7%	-26%	-31%	-11%	-45%	-48%	18%	8%	-4%
	Wind deployment	7	5%	-25%	-38%	-13%	-47%	-55%	28%	5%	-9%
	Equipment manufacturer	0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Other private sector	15	5%	-20%	-39%	-14%	-44%	-53%	19%	0%	-5%
	Other	5	13%	-15%	-44%	-9%	-39%	-55%	29%	9%	-6%
By applications evaluated	Offshore only	13	8%	-25%	-39%	-11%	-45%	-56%	25%	5%	-9%
	Both onshore and offshore	31	5%	-20%	-31%	-11%	-44%	-52%	24%	4%	-5%
By type of expertise	Wind energy markets	29	5%	-31%	-42%	-20%	-45%	-53%	19%	0%	-12%
	Systems level	31	6%	-25%	-38%	-10%	-45%	-53%	26%	5%	-6%
	Subsystem level	16	0%	-17%	-31%	-11%	-43%	-48%	13%	4%	-4%
By familiarity with region	North American	27	5%	-20%	-31%	-11%	-45%	-53%	22%	4%	-5%
	Europe	31	8%	-15%	-38%	-11%	-40%	-53%	28%	13%	-5%
	Asia	9	7%	-15%	-31%	-12%	-34%	-44%	27%	13%	-1%
	Latin America	4	13%	-4%	-23%	-8%	-4%	-36%	26%	13%	2%
	Middle East and Africa	2	-4%	-22%	-31%	-23%	-34%	-42%	13%	-3%	-9%

Note: Colors refer to whether and the degree to which the LCOE estimate is lower (green) or higher (red) than for “all” respondents

Table A – 12. Relative Change in LCOE and LCOE Components from 2014 to 2030 for Onshore Wind Projects, by Respondent Group



Onshore wind (LCOE component values in 2030 relative to expert-specific 2014 baseline)								
Respondent Group		Number of respondents	Median scenario for typical LCOE					
			LCOE	CapEx	OpEx	Capacity Factor	Project Life	WACC
All		134	**-24%**	**-12%**	**-9%**	**10%**	**10%**	**0%**
By Lead / Larger group	Leading	17	-27%	-17%	-17%	10%	10%	0%
	Larger	117	-24%	-11%	-9%	10%	10%	0%
By type of organization	Research	38	-25%	-11%	-14%	14%	25%	0%
	Wind deployment	22	-22%	-11%	-8%	11%	0%	-1%
	Equipment manufacturer	22	-23%	-3%	-4%	8%	5%	0%
	Other private sector	39	-26%	-15%	-11%	11%	10%	0%
	Other	13	-24%	-15%	-8%	10%	0%	0%
By applications evaluated	Onshore only	52	-24%	-11%	-8%	10%	0%	0%
	Both onshore and offshore	82	-24%	-14%	-12%	11%	15%	0%
By type of expertise	Wind energy markets	94	-27%	-14%	-11%	11%	10%	0%
	Systems level	74	-26%	-15%	-11%	9%	10%	0%
	Subsystem level	36	-24%	-15%	-8%	11%	13%	0%
By familiarity with region	North American	93	-25%	-11%	-8%	14%	10%	0%
	Europe	77	-23%	-15%	-10%	9%	15%	0%
	Asia	22	-27%	-17%	-12%	4%	13%	0%
	Latin America	24	-19%	-9%	0%	8%	0%	0%
	Middle East and Africa	6	-24%	-11%	-13%	9%	13%	0%

Note: Colors refer to whether and the degree to which the factor change will result in LCOE estimates that are lower (green) or higher (red) than for “all” respondents

Table A – 13. Relative Change in LCOE and LCOE Components from 2014 to 2030 for Fixed-Bottom Offshore Wind Projects, by Respondent Group

Fixed-Bottom Offshore wind (LCOE component values in 2030 relative to expert-specific 2014 baseline)								
Respondent Group		Number of respondents	Median scenario for typical LCOE					
			LCOE	**CapEx**	**OpEx**	**Capacity Factor**	**Project Life**	**WACC**
All		110	**-30%**	**-14%**	**-9%**	**4%**	**15%**	**-10%**
By Lead / Larger group	Leading	15	-35%	-18%	-7%	11%	25%	-8%
	Larger	95	-29%	-14%	-9%	4%	15%	-10%
By type of organization	Research	38	-26%	-17%	-9%	7%	0%	-5%
	Wind deployment	16	-36%	-18%	-8%	9%	23%	-20%
	Equipment manufacturer	12	-9%	-4%	-2%	0%	0%	0%
	Other private sector	32	-29%	-15%	-13%	4%	20%	-10%
	Other	12	-32%	-10%	-4%	4%	13%	-20%
By applications evaluated	Offshore only	28	-36%	-11%	-13%	7%	20%	-17%
	Both onshore and offshore	82	-28%	-16%	-9%	4%	13%	-1%
By type of expertise	Wind energy markets	77	-31%	-14%	-9%	7%	20%	-10%
	Systems level	59	-31%	-17%	-9%	7%	15%	-9%
	Subsystem level	30	-29%	-17%	-13%	3%	25%	0%
By familiarity with region	North American	65	-27%	-13%	-9%	4%	10%	-5%
	Europe	79	-32%	-17%	-12%	7%	20%	-10%
	Asia	21	-29%	-18%	-13%	4%	20%	-10%
	Latin America	11	-28%	-11%	-9%	4%	20%	0%
	Middle East and Africa	6	-25%	-10%	0%	4%	23%	-13%

Note: Colors refer to whether and the degree to which the factor change will result in LCOE estimates that are lower (green) or higher (red) than for “all” respondents

Table A – 14. Relative Change in LCOE and LCOE Components from 2014 to 2030 for Floating Offshore Wind Projects, by Respondent Group

Floating Offshore wind (LCOE component values in 2030 relative to expert-specific 2014 baseline)

Respondent Group		Number of respondents	Median scenario for typical LCOE					
			LCOE	**CapEx**	**OpEx**	**Capacity Factor**	**Project Life**	**WACC**
All		44	**-25%**	**-5%**	**-8%**	**9%**	**25%**	**-5%**
By Lead / Larger group	Leading	6	-38%	-10%	-9%	20%	25%	-15%
	Larger	38	-15%	-5%	-7%	8%	23%	0%
By type of organization	Research	17	-26%	-7%	-9%	9%	25%	0%
	Wind deployment	7	-25%	-3%	5%	2%	25%	-20%
	Equipment manufacturer	0	NA	NA	NA	NA	NA	NA
	Other private sector	15	-20%	-8%	-7%	7%	16%	-3%
	Other	5	-15%	0%	-7%	11%	0%	-5%
By applications evaluated	Offshore only	13	-25%	0%	-9%	11%	25%	-15%
	Both onshore and offshore	31	-20%	-8%	-7%	7%	25%	0%
By type of expertise	Wind energy markets	29	-31%	-12%	-9%	9%	25%	-5%
	Systems level	31	-25%	-3%	-7%	11%	25%	-4%
	Subsystem level	16	-17%	-4%	-8%	4%	25%	0%
By familiarity with region	North American	27	-20%	-2%	-9%	7%	25%	-7%
	Europe	31	-15%	0%	-5%	9%	25%	-3%
	Asia	9	-15%	-7%	0%	10%	25%	0%
	Latin America	4	-4%	-6%	0%	3%	0%	10%
	Middle East and Africa	2	-22%	-10%	-6%	22%	8%	8%

Note: Colors refer to whether and the degree to which the factor change will result in LCOE estimates that are lower (green) or higher (red) than for “all” respondents

Table A – 15. Wind Turbine Characteristics in 2030 for North American Wind Projects, by Respondent Group

North America														
Number of all respondents	Respondent Group		Onshore				Fixed-Bottom Offshore				Floating Offshore			
			n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)	n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)	n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)
77	**All North America**		71	3.25	115	135	37	9	115	170	18	9	120	190
69	By Lead / Larger group	Larger	63	3.25	115	135	31	9	125	170	16	9	115	180
8		Leading	8	3.5	115	125	6	8	115	190	2	10	125	210
52	By type of expertise	Wind energy markets	47	3.25	115	125	24	9	125	190	11	11	125	190
46		Systems level	44	3.25	115	135	22	9	115	170	4	9	120	180
23		Subsystem level	23	3.25	115	135	12	9	120	190	8	9	120	190
35	By applications evaluated	Onshore only	34	3.25	115	135		NA	NA	NA		NA	NA	NA
5		Offshore only		NA	NA	NA	4	11	125	200	3	11	125	210
37		Both onshore and offshore	37	3.25	115	125	33	9	115	170	15	9	115	170
22	By type of organization	Research	20	3.25	115	125	17	9	115	190	11	9	125	190
16		Wind deployment	14	3.5	130	140	2	12	130	210	2	12	130	210
14		Equipment manufacturer	14	3.25	125	145	4	12	155	200	0	NA	NA	NA
21		Other private sector	19	2.75	105	125	13	7	100	170	4	9	95	170
4		Other	4	3	115	115	1	7	155	150	1	9	170	170

Note: Colors refer to whether turbine size is larger (green) or smaller (red) than for “all” respondents

Table A – 16. Wind Turbine Characteristics in 2030 for European Wind Projects, by Respondent Group

Europe														
Number of all respondents	Respondent Group		Onshore				Fixed-Bottom Offshore				Floating Offshore			
			n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)	n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)	n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)
73	**All Europe**		49	3.75	115	130	58	11	125	190	20	11	125	190
61	By Lead / Larger group	Larger	41	3.75	120	135	50	11	125	190	18	10	125	190
12		Leading	8	3.25	115	110	8	10	130	150	2	11	125	200
53	By type of expertise	Wind energy markets	34	3.5	115	125	42	11	125	190	14	10	125	190
34		Systems level	23	4.25	115	135	9	11	125	190	13	11	125	190
13		Subsystem level	9	3.25	125	130	13	11	125	190	5	9	115	170
12	By applications evaluated	Onshore only	10	3.75	115	115		NA	NA	NA		NA	NA	NA
22		Offshore only		NA	NA	NA	20	11	125	190	8	11	125	190
39		Both onshore and offshore	39	3.75	125	135	38	11	135	190	12	9	125	180
20	By type of organization	Research	17	3.75	115	135	17	11	125	170	4	10	125	190
14		Wind deployment	7	4.75	125	135	12	11	125	210	5	9	115	190
9		Equipment manufacturer	6	3.75	130	145	7	11	135	190	0	NA	NA	NA
20		Other private sector	12	3.5	115	125	15	11	125	190	8	11	125	190
10		Other	7	3.25	115	125	7	11	135	190	3	11	135	190

Note: Colors refer to whether turbine size is larger (green) or smaller (red) than for “all” respondents

Table A – 17. Expected Impact of Wind Technology, Market, and Other Changes on Reducing LCOE for Onshore Wind Projects by 2030, by Respondent Group

Onshore																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Wind technology, market, or other change	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Number of respondents	129	112	17	37	22	22	36	12	89	75	21	24	6	90	74	35
Increased rotor diameter such that specific power declines	58%	62%	39%	68%	68%	60%	51%	33%	60%	56%	50%	52%	50%	58%	61%	62%
Rotor design advancements	45%	46%	38%	47%	45%	64%	35%	33%	43%	49%	48%	54%	60%	40%	52%	46%
Increased tower height	33%	33%	33%	31%	32%	45%	30%	33%	36%	28%	33%	54%	17%	36%	28%	36%
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	32%	35%	17%	47%	24%	27%	21%	46%	29%	39%	36%	21%	33%	31%	32%	35%
Improved component durability and reliability	31%	31%	31%	39%	19%	23%	31%	42%	26%	39%	48%	29%	60%	31%	32%	28%
Increased energy production due to new transmission to higher wind speed sites	31%	32%	22%	22%	38%	33%	31%	38%	36%	25%	32%	35%	33%	35%	31%	35%
Extended turbine design lifetime	29%	29%	25%	31%	27%	32%	24%	33%	24%	40%	38%	25%	20%	28%	29%	31%
Operating efficiencies to increase plant performance	28%	29%	24%	31%	14%	27%	32%	33%	24%	32%	43%	21%	67%	30%	26%	25%
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	28%	30%	12%	19%	45%	36%	28%	8%	31%	24%	24%	46%	0%	31%	34%	26%
Turbine and component manufacturing standardization, efficiencies, and volume	27%	30%	12%	21%	14%	48%	32%	17%	20%	36%	43%	29%	60%	24%	34%	29%
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	27%	27%	29%	32%	18%	32%	24%	27%	29%	28%	33%	38%	17%	26%	34%	31%
Integrated turbine-level system design optimization	23%	23%	21%	36%	10%	32%	15%	10%	20%	28%	20%	17%	0%	20%	30%	26%
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	21%	20%	24%	17%	14%	14%	26%	38%	16%	32%	32%	29%	50%	23%	20%	23%
Large variety of alternative turbine designs to suit site-specific conditions	17%	18%	12%	19%	10%	33%	8%	25%	16%	15%	24%	13%	17%	18%	15%	20%
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	17%	19%	0%	22%	14%	27%	8%	11%	16%	17%	24%	25%	0%	16%	19%	17%
Maintenance process efficiencies	17%	16%	18%	22%	10%	9%	14%	36%	10%	22%	14%	8%	0%	18%	12%	11%
Tower design advancements	14%	16%	6%	12%	19%	14%	14%	17%	15%	13%	5%	22%	20%	14%	17%	18%
Economies of scale through increased project size	12%	12%	17%	5%	14%	14%	19%	8%	8%	15%	15%	13%	0%	13%	18%	17%
Nacelle components design advancements	12%	12%	14%	12%	14%	9%	15%	8%	10%	12%	15%	13%	0%	11%	17%	15%
Installation and transportation equipment advancements	12%	11%	19%	18%	5%	14%	11%	8%	14%	9%	10%	21%	20%	13%	16%	26%
Innovative non-conventional turbine designs	12%	13%	0%	12%	14%	22%	8%	0%	14%	13%	21%	10%	0%	11%	16%	20%
Maintenance equipment advancements	10%	10%	12%	9%	10%	5%	11%	30%	8%	13%	14%	8%	0%	12%	8%	9%
Foundation and support structure manufacturing standardization, efficiencies, and volume	10%	11%	0%	18%	5%	15%	6%	0%	6%	14%	10%	13%	0%	6%	15%	12%
Foundation and support structure design advancements	10%	11%	0%	18%	10%	0%	8%	9%	6%	11%	5%	4%	0%	8%	11%	11%
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	9%	9%	11%	14%	5%	5%	5%	23%	7%	14%	9%	8%	17%	10%	13%	12%
Installation process efficiencies	9%	9%	6%	15%	10%	0%	11%	0%	6%	11%	10%	13%	20%	8%	14%	11%
Reduced fixed operating costs, excluding maintenance	5%	4%	12%	3%	0%	5%	5%	17%	1%	6%	5%	0%	0%	3%	1%	3%
Lower decommissioning costs	1%	1%	0%	0%	5%	0%	0%	0%	1%	1%	0%	4%	0%	1%	0%	0%

Note: Colors refer to the relative rating of each advancement possibility within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated advancement and red a lower-rated advancement)

Table A – 18. Expected Impact of Wind Technology, Market, and Other Changes on Reducing LCOE for Fixed-Bottom Offshore Wind Projects by 2030, by Respondent Group

Fixed-Bottom Offshore																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Wind technology, market, or other change	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Number of respondents	98	83	15	33	15	9	30	11	56	74	20	11	6	70	6	29
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	55%	57%	47%	55%	67%	44%	50%	64%	50%	58%	45%	73%	50%	61%	54%	52%
Foundation and support structure design advancements	53%	55%	36%	44%	60%	67%	47%	73%	53%	51%	50%	73%	80%	53%	51%	45%
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	49%	51%	33%	46%	56%	44%	42%	67%	44%	49%	45%	55%	33%	53%	47%	38%
Economies of scale through increased project size	48%	49%	40%	46%	50%	44%	57%	30%	46%	47%	40%	64%	60%	51%	44%	38%
Improved component durability and reliability	48%	48%	50%	56%	53%	33%	41%	45%	46%	49%	50%	73%	40%	45%	56%	52%
Installation process efficiencies	46%	49%	29%	41%	56%	22%	47%	70%	47%	45%	50%	73%	50%	46%	46%	55%
Installation and transportation equipment advancements	44%	46%	36%	39%	44%	44%	50%	45%	46%	45%	55%	64%	20%	43%	43%	48%
Foundation and support structure manufacturing standardization, efficiencies, and volume	43%	48%	8%	42%	38%	44%	45%	45%	39%	45%	42%	55%	20%	46%	42%	43%
Extended turbine design lifetime	36%	35%	43%	24%	56%	33%	33%	55%	26%	42%	45%	55%	40%	41%	37%	34%
Turbine and component manufacturing standardization, efficiencies, and volume	36%	40%	8%	30%	50%	22%	38%	40%	30%	37%	26%	45%	20%	36%	35%	32%
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	35%	38%	20%	31%	56%	22%	32%	33%	31%	38%	25%	36%	17%	39%	30%	24%
Integrated turbine-level system design optimization	33%	37%	7%	39%	23%	38%	33%	20%	30%	40%	33%	40%	25%	32%	38%	36%
Rotor design advancements	32%	32%	36%	33%	27%	33%	36%	27%	33%	35%	42%	55%	20%	26%	38%	39%
Maintenance process efficiencies	32%	32%	33%	28%	27%	33%	33%	45%	25%	34%	30%	36%	17%	32%	32%	34%
Maintenance equipment advancements	30%	30%	27%	31%	40%	11%	27%	36%	19%	32%	25%	36%	17%	31%	26%	34%
Operating efficiencies to increase plant performance	29%	28%	33%	31%	27%	33%	24%	36%	23%	32%	25%	45%	17%	26%	25%	24%
Increased rotor diameter such that specific power declines	27%	29%	14%	28%	27%	33%	28%	13%	26%	30%	35%	45%	0%	26%	33%	32%
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	25%	28%	7%	20%	20%	44%	29%	17%	24%	30%	37%	45%	17%	22%	23%	34%
Increased energy production due to new transmission to higher wind speed sites	21%	20%	27%	21%	20%	33%	19%	20%	21%	22%	20%	36%	40%	22%	20%	11%
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	21%	23%	7%	24%	15%	33%	17%	18%	27%	21%	26%	45%	20%	14%	24%	24%
Nacelle components design advancements	19%	20%	14%	16%	21%	13%	28%	9%	26%	16%	26%	40%	20%	19%	20%	31%
Innovative non-conventional turbine designs	17%	20%	0%	16%	14%	33%	17%	10%	20%	17%	26%	10%	25%	15%	21%	24%
Tower design advancements	12%	11%	14%	16%	7%	11%	10%	9%	9%	13%	10%	9%	20%	9%	13%	10%
Reduced fixed operating costs, excluding maintenance	10%	10%	7%	3%	29%	11%	7%	10%	7%	12%	11%	18%	0%	10%	9%	17%
Increased tower height	6%	6%	7%	6%	0%	11%	7%	9%	11%	5%	10%	18%	0%	8%	9%	14%
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	5%	6%	0%	9%	0%	0%	7%	0%	5%	6%	5%	0%	25%	1%	9%	10%
Large variety of alternative turbine designs to suit site-specific conditions	5%	6%	0%	3%	6%	0%	0%	30%	7%	5%	10%	18%	50%	6%	4%	3%
Lower decommissioning costs	2%	3%	0%	0%	14%	0%	0%	0%	2%	1%	0%	0%	0%	3%	2%	4%

Note: Colors refer to the relative rating of each advancement possibility within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated advancement and red a lower-rated advancement)

Table A – 19. Expected Impact of Wind Technology, Market, and Other Changes on Reducing LCOE for Floating Offshore Wind Projects by 2030, by Respondent Group

Floating Offshore																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Wind technology, market, or other change	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Number of respondents	41	37	4	15	7	0	14	5	26	29	8	3	2	28	29	14
Foundation and support structure design advancements	80%	78%	100%	80%	86%	NA	79%	80%	77%	76%	63%	33%	0%	79%	83%	79%
Installation process efficiencies	78%	76%	100%	80%	57%	NA	86%	80%	88%	69%	75%	100%	50%	79%	72%	79%
Foundation and support structure manufacturing standardization, efficiencies, and volume	68%	69%	50%	43%	86%	NA	79%	80%	54%	75%	75%	67%	0%	70%	57%	43%
Economies of scale through increased project size	65%	64%	75%	71%	71%	NA	64%	40%	72%	61%	75%	100%	50%	61%	64%	69%
Installation and transportation equipment advancements	63%	65%	50%	60%	43%	NA	79%	60%	77%	59%	75%	100%	50%	64%	62%	71%
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	59%	54%	100%	47%	71%	NA	57%	80%	62%	55%	63%	100%	50%	61%	59%	57%
Improved component durability and reliability	58%	56%	75%	50%	86%	NA	50%	60%	54%	57%	75%	67%	100%	67%	64%	71%
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	46%	49%	25%	33%	57%	NA	43%	80%	42%	48%	50%	100%	50%	57%	41%	21%
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	46%	46%	50%	40%	43%	NA	50%	60%	42%	45%	50%	67%	50%	46%	38%	36%
Rotor design advancements	45%	44%	50%	53%	57%	NA	31%	40%	52%	43%	63%	67%	50%	39%	50%	64%
Integrated turbine-level system design optimization	44%	41%	75%	60%	14%	NA	43%	40%	42%	48%	50%	67%	50%	43%	45%	57%
Turbine and component manufacturing standardization, efficiencies, and volume	40%	44%	0%	21%	57%	NA	43%	60%	38%	43%	38%	100%	50%	44%	36%	21%
Extended turbine design lifetime	39%	41%	25%	33%	57%	NA	36%	40%	38%	38%	50%	67%	50%	43%	41%	50%
Maintenance process efficiencies	35%	36%	25%	29%	14%	NA	50%	40%	38%	36%	63%	67%	100%	41%	32%	50%
Innovative non-conventional turbine designs	34%	32%	50%	47%	0%	NA	43%	20%	38%	31%	50%	33%	100%	32%	41%	57%
Increased rotor diameter such that specific power declines	32%	31%	33%	36%	14%	NA	38%	25%	29%	38%	38%	33%	0%	27%	41%	46%
Increased energy production due to new transmission to higher wind speed sites	29%	30%	25%	27%	57%	NA	14%	40%	35%	24%	38%	67%	50%	32%	28%	21%
Tower design advancements	28%	25%	50%	40%	14%	NA	31%	0%	28%	29%	50%	33%	0%	18%	32%	50%
Nacelle components design advancements	28%	25%	50%	27%	29%	NA	31%	20%	40%	18%	38%	33%	0%	29%	29%	50%
Maintenance equipment advancements	25%	25%	25%	7%	14%	NA	36%	60%	23%	29%	38%	67%	100%	30%	21%	14%
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	20%	22%	0%	20%	0%	NA	29%	20%	23%	25%	57%	67%	50%	21%	14%	29%
Operating efficiencies to increase plant performance	18%	14%	50%	7%	0%	NA	23%	60%	16%	22%	38%	67%	50%	22%	15%	21%
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	15%	11%	50%	20%	0%	NA	8%	40%	12%	11%	0%	0%	0%	18%	15%	14%
Increased tower height	15%	14%	25%	13%	0%	NA	15%	40%	16%	14%	13%	33%	0%	21%	18%	21%
Large variety of alternative turbine designs to suit site-specific conditions	12%	14%	0%	13%	0%	NA	7%	40%	8%	14%	13%	33%	50%	11%	7%	0%
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	12%	14%	0%	20%	0%	NA	7%	20%	8%	17%	13%	33%	50%	7%	10%	7%
Reduced fixed operating costs, excluding maintenance	8%	9%	0%	0%	0%	NA	15%	20%	4%	12%	14%	0%	0%	7%	8%	7%
Lower decommissioning costs	3%	3%	0%	0%	0%	NA	7%	0%	0%	4%	14%	0%	50%	4%	4%	8%

Note: Colors refer to the relative rating of each advancement possibility within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated advancement and red a lower-rated advancement)

Table A – 20. Ranking of Broad Drivers for Lower Onshore LCOE in 2030, by Respondent Group

Ranking of Broad Drivers for Lower Onshore LCOE in 2030																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Driver	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Learning with market growth	33%	30%	47%	39%	30%	10%	32%	54%	31%	35%	48%	32%	67%	34%	24%	25%
Research and development	32%	32%	25%	32%	33%	48%	26%	17%	38%	24%	19%	26%	0%	28%	36%	42%
Increased competion and decreased risk	16%	16%	19%	16%	15%	14%	19%	17%	9%	24%	14%	22%	17%	16%	21%	17%
Eased wind project and transmisison siting	14%	15%	7%	11%	14%	14%	16%	17%	15%	11%	10%	13%	17%	15%	14%	17%

Note: Colors refer to the relative rating of each broad driver within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated driver and red a lower-rated driver)

Table A – 21. Ranking of Broad Drivers for Lower Fixed-Bottom Offshore LCOE in 2030, by Respondent Group

Ranking of Broad Drivers for Lower Offshore LCOE in 2030																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Driver	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Learning with market growth	33%	34%	27%	27%	31%	33%	42%	33%	32%	35%	52%	36%	50%	30%	33%	27%
Research and development	32%	33%	29%	41%	31%	36%	23%	27%	31%	26%	15%	18%	33%	32%	31%	37%
Eased wind project and transmisison siting	25%	25%	29%	19%	25%	27%	29%	36%	24%	29%	33%	45%	0%	30%	25%	30%
Increased competion and decreased risk	5%	3%	14%	8%	6%	0%	3%	0%	7%	4%	0%	0%	17%	4%	7%	7%

Note: Colors refer to the relative rating of each broad driver within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated driver and red a lower-rated driver)

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