


Expert Predictions about the Future of Onshore and Offshore Wind Energy

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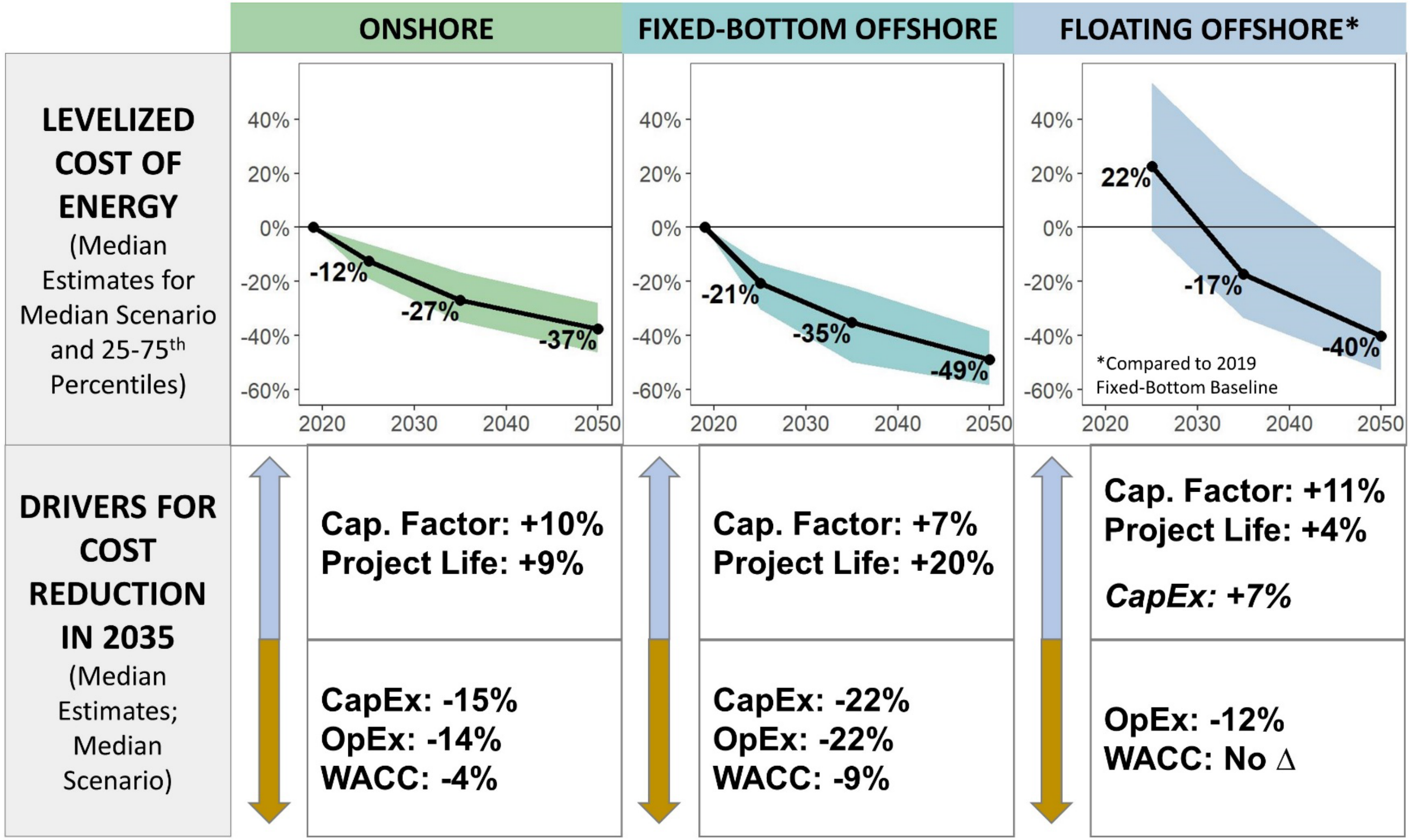


Overview

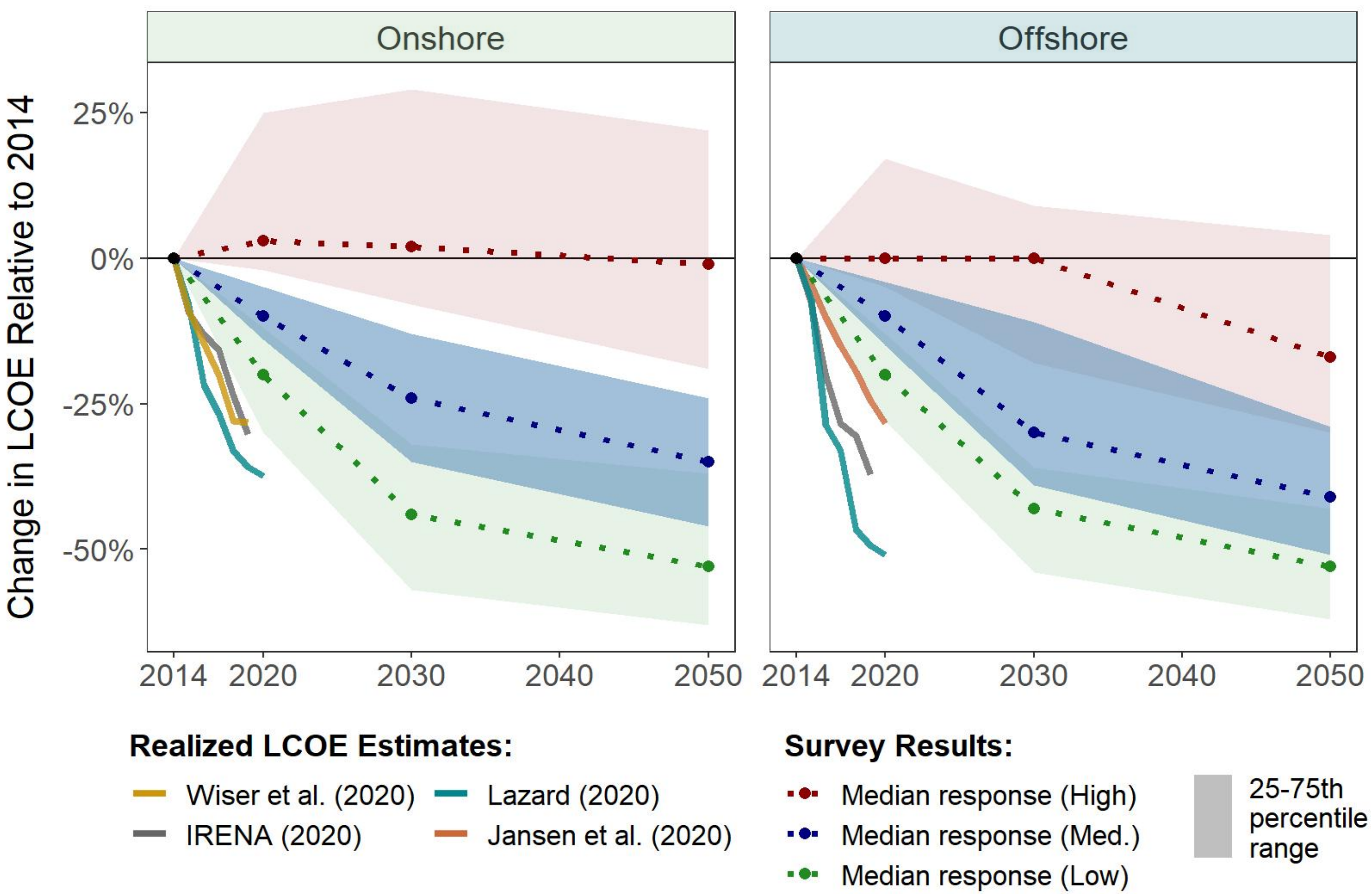
Project motivation

Long-term contribution of wind in energy supply depends, in part, on future costs

Uncertainty about the extent of future cost reduction, technology choices, value options

Accelerated cost reduction in recent years makes earlier forecasts obsolete

2015 Expert Cost Forecasts vs. Actual Costs



Objectives and scope: conduct expert survey to solicit perspectives on future wind costs, updating 2015 effort

What

Expert survey to gain insight on possible magnitude of future cost reductions, underlying drivers, and anticipated wind technology trends and trade-offs

Covering commercial-scale onshore, and fixed-bottom and floating offshore wind

Who

Among largest energy-technology expert elicitations performed in terms of participants: 140 of world's foremost wind experts

Led by LBNL w/ contributions from NREL and Univ. of Massachusetts, under the auspices of IEA Wind

Why

Inform policy & planning, R&D, industry investment & strategy development; improve treatment of wind in energy-sector models

Complement other tools for evaluating cost reduction: learning curves and engineering assessments

Survey focus is primarily on changes in the levelized cost of energy (LCOE) from 2019 to 2025, 2035 and 2050 under low/median/high scenarios, and on LCOE composition in 2019 and 2035

Acknowledgements

BERKELEY LAB

This global survey of wind experts would not have been possible without the support of many individuals and organizations:

IEA Wind Contributors: This study was conducted under the auspices of the IEA Wind Implementing Agreement for Cooperation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). We especially thank our IEA Wind Task 26 collaborators: Volker Berkhout (Fraunhofer), Greg Bohan (IWEA), János Hethey (Ea Energy Analyses), Shadi Kalash (Sustainable Energy Authority Of Ireland), Lena Kitzing (DTU), Yuka Kikuchi (University of Tokyo), Silke Lüers (Deutsche WindGuard), Fiona Devoy McAuliffe (University College Cork), Miriam Noonan (ORE Catapult), Ann Myhrer Østenby (NVE), Alberto Dalla Riva (Ea Energy Analyses), Tyler Stehly (NREL), Maria Stenkvist (Swedish Energy Agency), Thomas Telsnig (European Commission JRC), and Magnus Wold (NVE). These collaborators and contributors were involved from the outset of this project, offering crucial feedback on overall objectives, survey design and specific questions, piloting draft versions of the survey, and suggesting experts to include in the sample.

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Survey Execution: Ultimately, the survey was implemented online via the Qualtrics survey software but required considerable customization. We greatly appreciate Walker for assistance in survey implementation and execution, with special thanks to Ryne Fanning, John Connolly, and Jeff Wiggington.

Survey Respondents: Of course, the findings presented in the pages that follow would not have been possible without the gracious contributions of the experts who chose to participate in the survey—we list those individuals and their affiliated organizations in a separate document. Thank you for your time and insights!

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Methods and Sample

Summary of survey focus and approach

Global expert survey on the cost of wind energy, building on earlier survey from 2015

- Includes onshore (land-based) wind as well as fixed-bottom and floating offshore wind
- Focuses on the future levelized cost of wind energy (LCOE), excluding both subsidies and grid interconnection costs outside plant boundary*
- Explores influence of CapEx, OpEx, capacity factor, project life & WACC on LCOE in 2019 & 2035, with additional LCOE estimates for 2025 & 2050
- Investigates median estimates as well as low (10^{th} percentile) and high (90^{th}) cost scenarios
- Elicits site conditions and technology expectations, drivers and constraints
- Additional questions explore options to enhance grid-system value

Expert elicitation survey, custom designed in Qualtrics software

- Expert elicitation is a tool—with established protocols—to develop estimates of uncertain quantities based on careful assessment of the knowledge and beliefs of subject-matter experts
- Rich literature provides guidance on question design, importance of clarity in what is being asked, how to minimize expert motivational and cognitive biases, and importance of providing feedback to experts and providing opportunities for them to review and update their assessments
- Relative to other elicitations, we cast a wide net for a large number of possible participants via an online survey, inclusive of a smaller set of pre-identified 'leading experts'

* Cost estimates include electrical cabling within the plant, but exclude any needed substations, transmission lines, or grid interconnection costs. For offshore wind, within-plant array cabling is included, but offshore substation, any HVDC collector stations and associated cables, and costs for grid connection to land are all excluded.

Diverse set of 140 survey participants yields a 22% response rate (55 leading experts, 30% response rate)

Response Rate			
Survey sample: total	645		
Survey respondents: total	140		
Response rate: total	22%		
Leading expert sample	184		
Leading expert respondents	55		
Response rate: leading experts	30%		
Respondents by Wind Application			
Onshore wind	97		
Fixed-bottom offshore wind	71		
Floating offshore wind	37		
Respondents by Organization Type			
Wind power developer, owners, financier, operator, and/or construction contractor	31		
Other private-sector company (e.g., consultant)	31		
Wind turbine and/or component manufacturer	24		
Public research or research management institution	22		
University of other degree-granting academic institution	14		
Other not-for-profit organization (e.g., NGO, international organizations)	11		
Government agency not associated with research management	7		
Respondents by Type of Expertise			
Wind energy markets and/or cost analysis	72		
Systems-level wind technologies	58		
Subsystems-level wind technologies	9		
Geographic Region	**Onshore**	**Fixed-Bottom Offshore**	**Floating Offshore**
North America	46	18	5
Europe	39	44	29
Asia	6	5	1
Central & South America	1	0	0
Global Average	3	4	2

- Extensive effort to identify a broad and diverse set of 645 global wind experts
- Also pre-identified a smaller group of 184 “leading experts” as uniquely qualified
- Survey was open from July to September 2020, with multiple reminders
- Respondents cover all three applications, come from broad mix of organizations
- Most have systems-level technology, cost, and/or market expertise
- Dominated by North American and European experts, some Asia coverage

Global wind expert elicitation: 2020 version (vs. 2015)

Survey Sample	• Significant effort to expand sample, enhance diversity, curate leading expert group • 645 full sample, 184 leading expert group (2015: 482 total, 42 leading)
Survey Responses	• 140 full sample (22% rate), 55 leading (30%) (2015: 163 [34%], 22 [52%])
LCOE Questions	• Require respondent-specific 2019 baselines (2015: voluntary 2014 baseline) • Focus on 2035 LCOE, 2025/2050 as supplemental (2015: 2030 and 2020/2050) • Additional clarity on region, site conditions, and project details for 2019 and 2035 • Further guidance and tools on cost of finance (WACC) compared to 2015
Supplemental Questions	• Turbine size in 2035: capacity, hub height, rotor diameter (similar to 2015) • Turbine size constraints, turbine selection for onshore sites, fixed-bottom vs. floating tradeoffs, approaches to enhancing grid-system value (replacing 2015 questions on broad cost drivers and specific LCOE-reduction opportunities)

For 2015 survey results, see: https://emp.lbl.gov/publications/forecasting-wind-energy-costs-and

Survey Findings

Summary of key findings

1. Wind energy has experienced accelerated cost reduction over the last five years, making previous cost forecasts obsolete
2. Experts in 2020 anticipate future onshore and offshore wind costs that are approximately 50% lower than predicted in 2015
3. These reductions will be shaped by not only CapEx, but also capacity factor, OpEx, project life, and cost of finance
4. If realized, this will allow wind to play a more substantial role in global energy supply and energy-sector decarbonization than previously anticipated
5. Uncertainties in the magnitude of cost reduction are significant, illustrating the importance of uncertainty in modeling and in policy, planning, investment, & research decisions
6. As costs decline, additional focus may turn to the value of wind in energy markets, and to the many barriers that hinder deployment

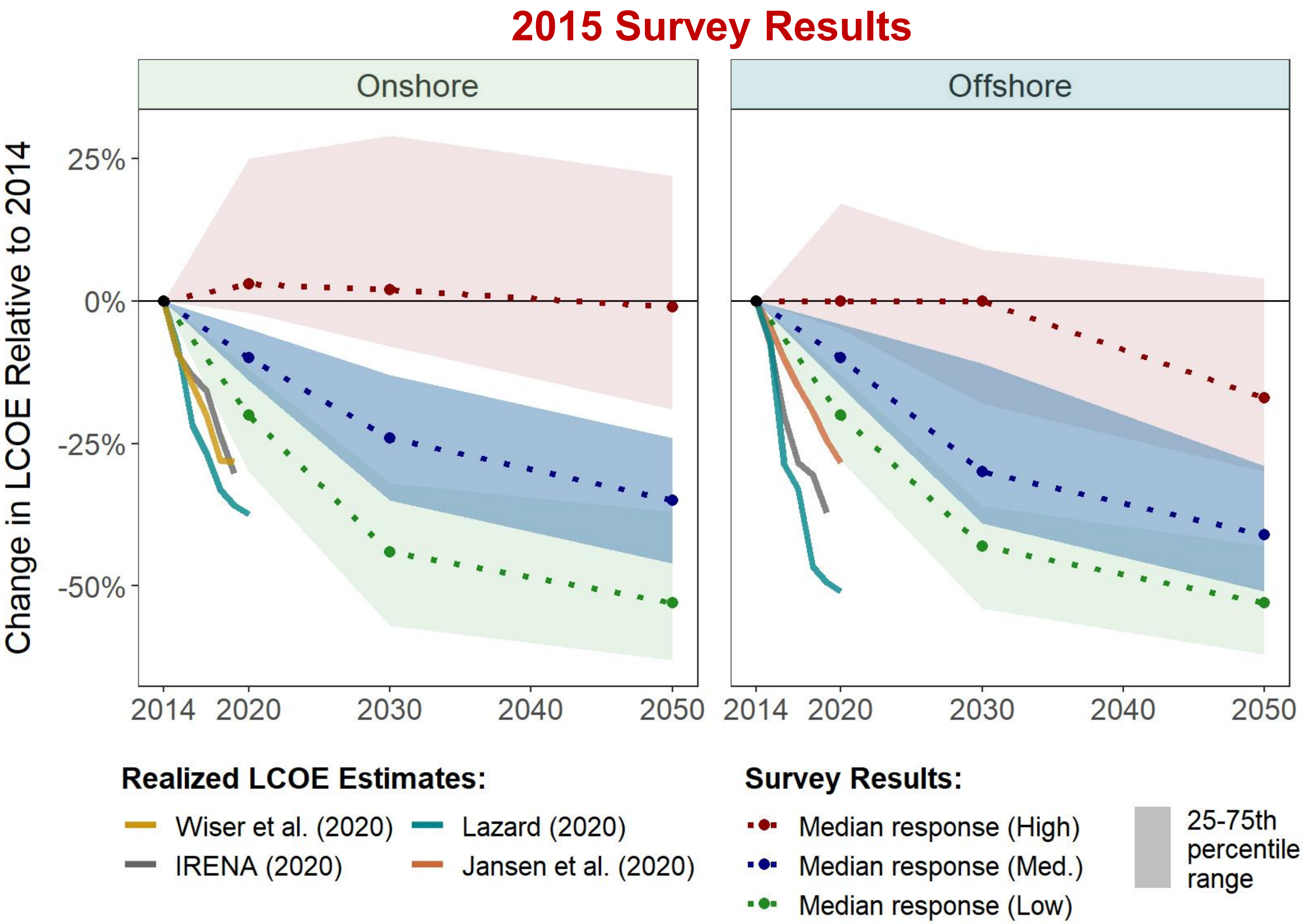
Accelerated wind energy cost reduction over the last five years makes previous cost forecasts obsolete

Actual LCOE reduction has outpaced predictions from 2015 survey, even in low-cost scenario

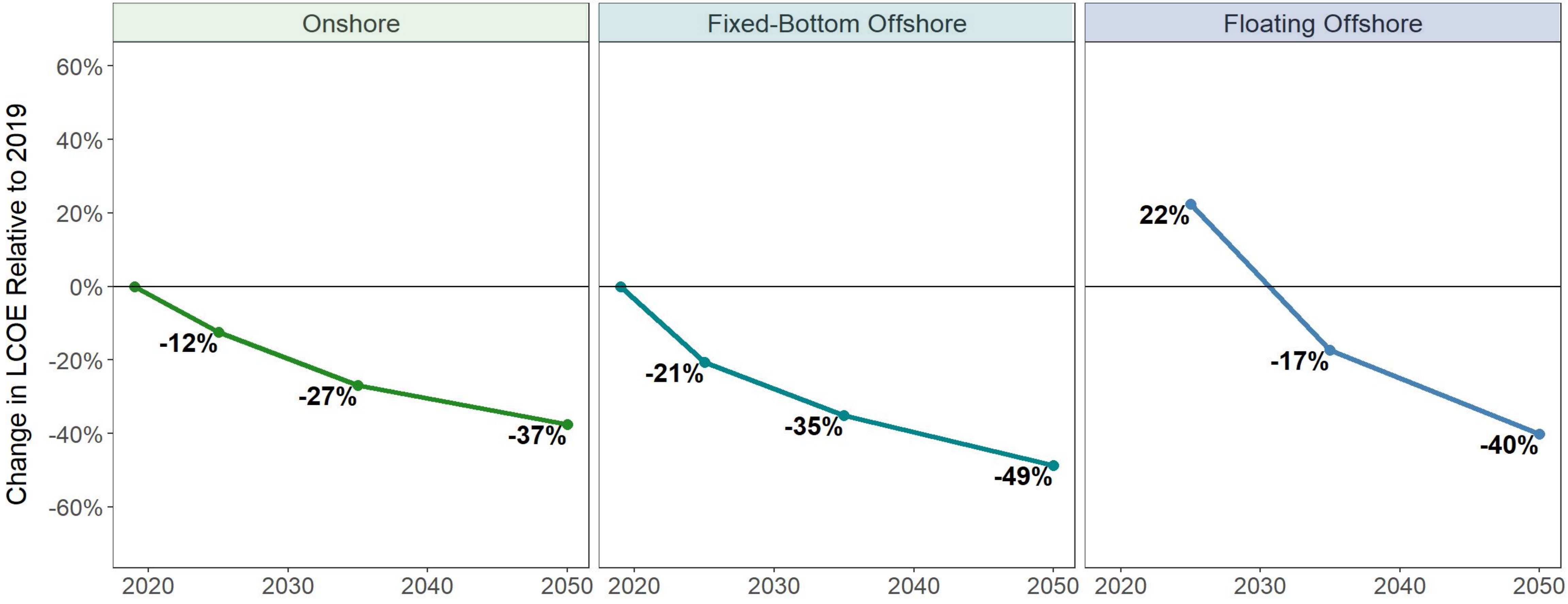
Possible reasons: cost pressure from auctions, turbine scaling, industrialization of non-turbine components, low finance and materials costs

Experts not alone in missing rapid decline: other forecasts at the time similarly inaccurate; actual costs have declined far-faster than historical trends (onshore: 35-46% learning rate from 2014-2019 vs. 10-20% over long-term history)

NEED UPDATED ASSESSMENT



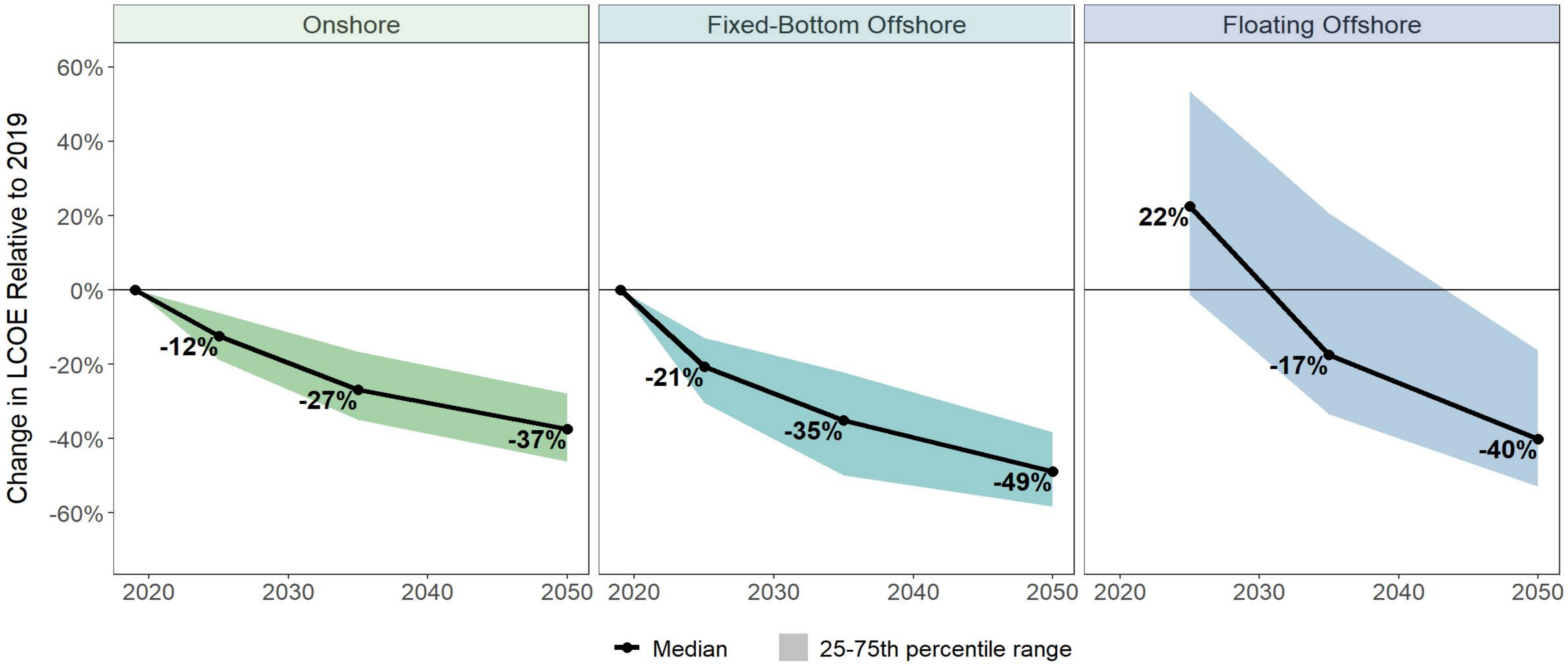
2020 respondents expect significant LCOE reduction: median "best guess" scenario, median respondent



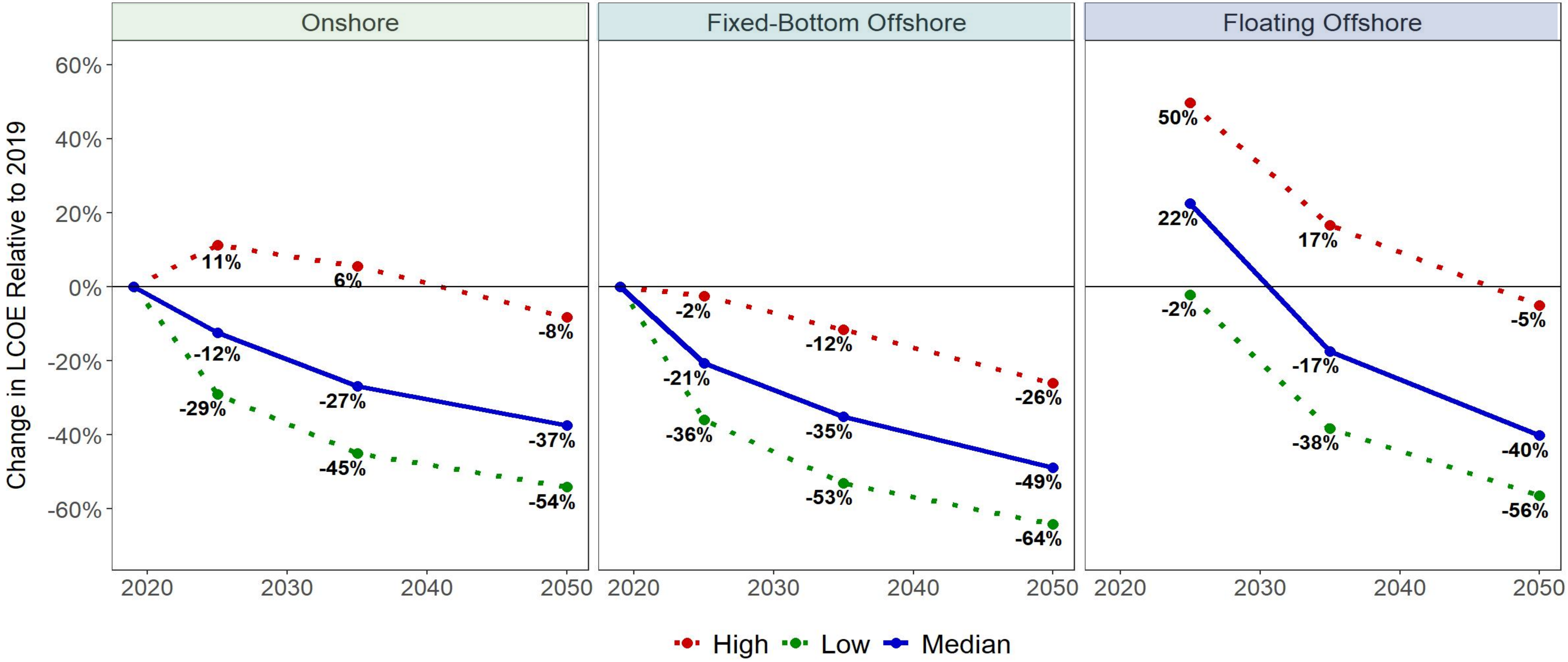
Lines/markers indicate the **median** expert response
For **floating,** change is shown relative to 2019 baseline for fixed-bottom
All dates are based on the year in which a new wind project is commissioned

Pace of cost reduction greatest for floating offshore, then fixed-bottom offshore, then onshore wind

Uncertainty revealed when reviewing range of expert responses: median scenario, 25-75th respondent range

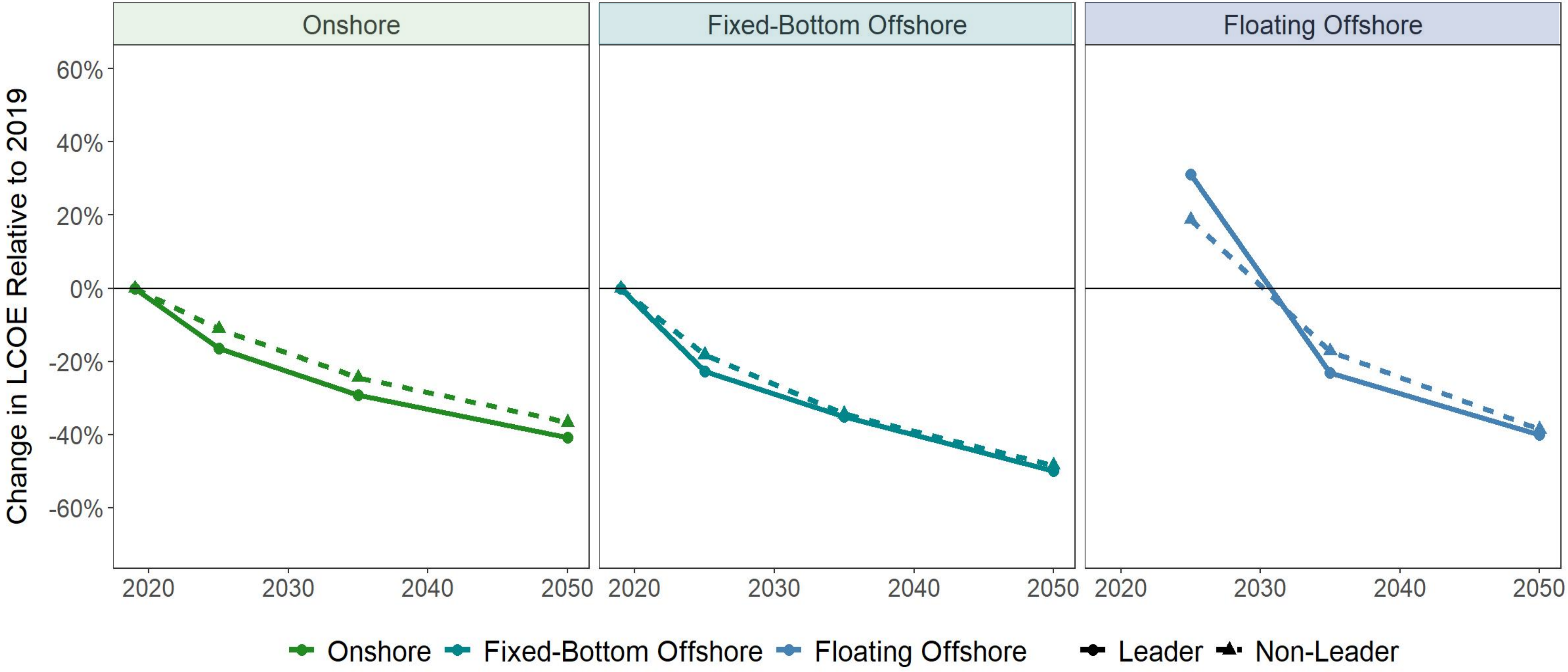


Uncertainty in and sizable opportunity space for LCOE reduction also illustrated by low / high scenario results



Low: Median project cost in 10th percentile of low-cost possible futures
High: Median project cost in 90th percentile of high-cost possible futures

Leading experts tend to anticipate slightly lower costs in 2035 and beyond: median scenario



Differences are relatively modest; modest differences also exist across organizational and expertise type

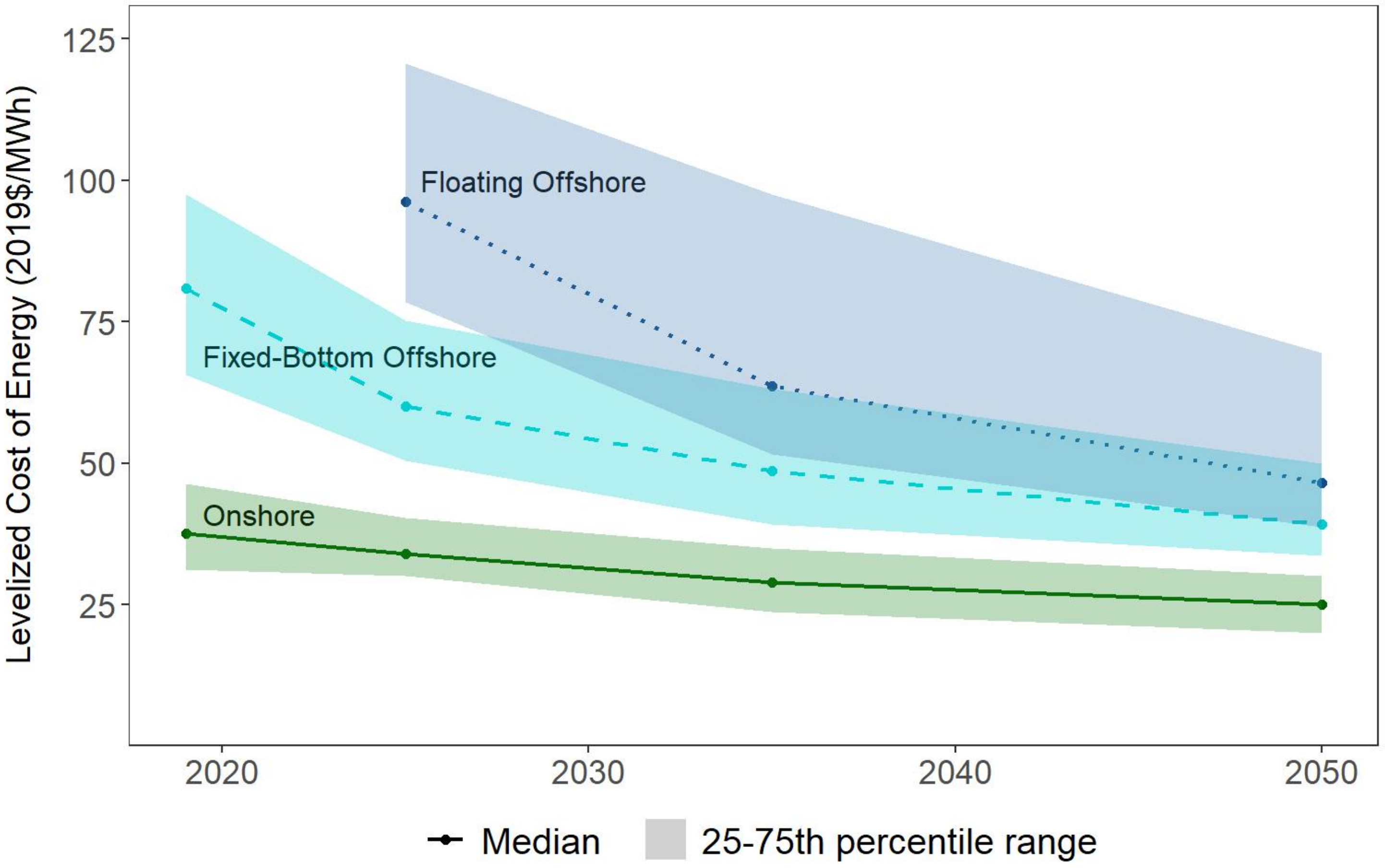
In absolute terms, narrowing gap between onshore & offshore, and fixed-bottom & floating: median scenario

Onshore generally expected to remain lower cost than offshore

LCOE reductions for floating offshore expected to be especially sizable

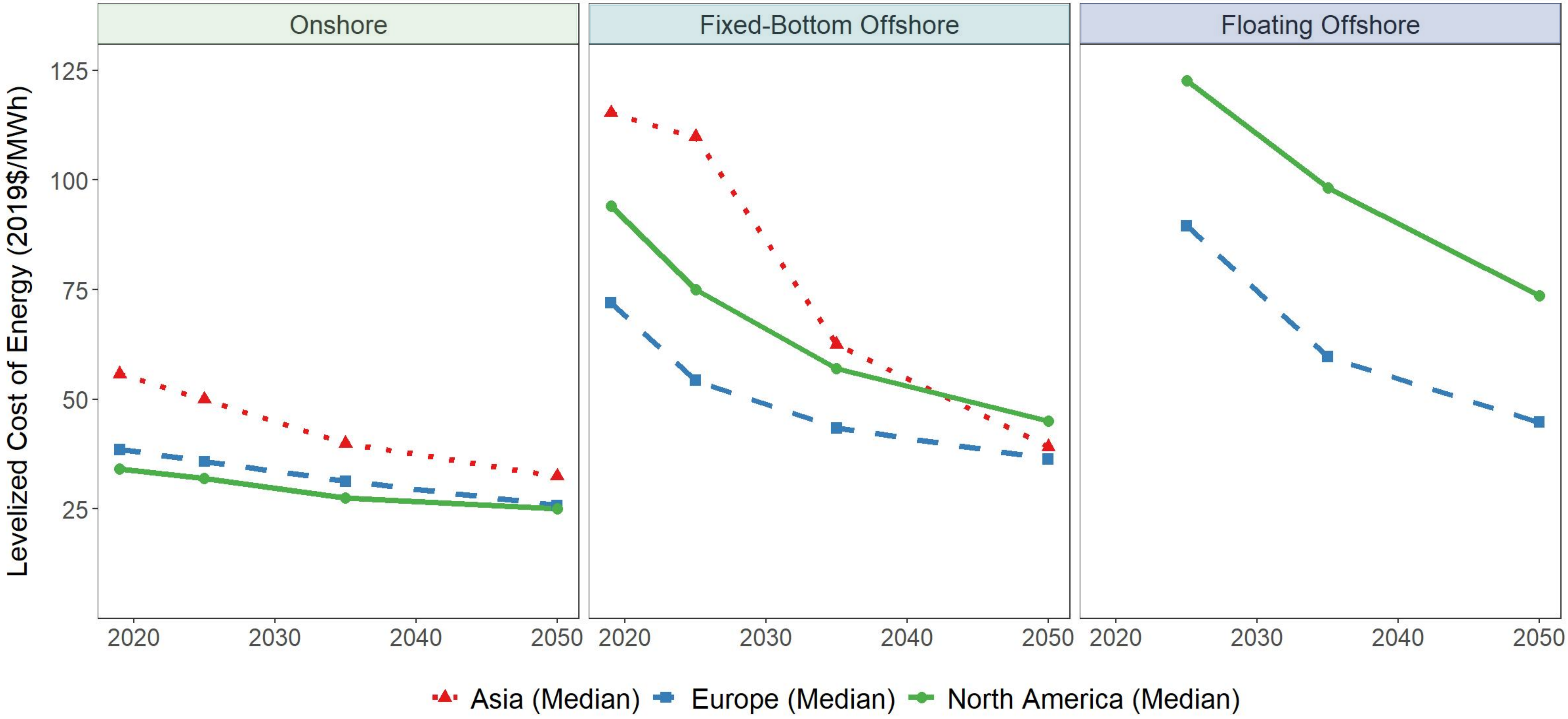
Expected water depth at which floating becomes less costly than fixed-bottom declines from >80 m in 2019 to >60 m in 2035

Greater uncertainty in offshore (especially floating) wind LCOE than in onshore LCOE

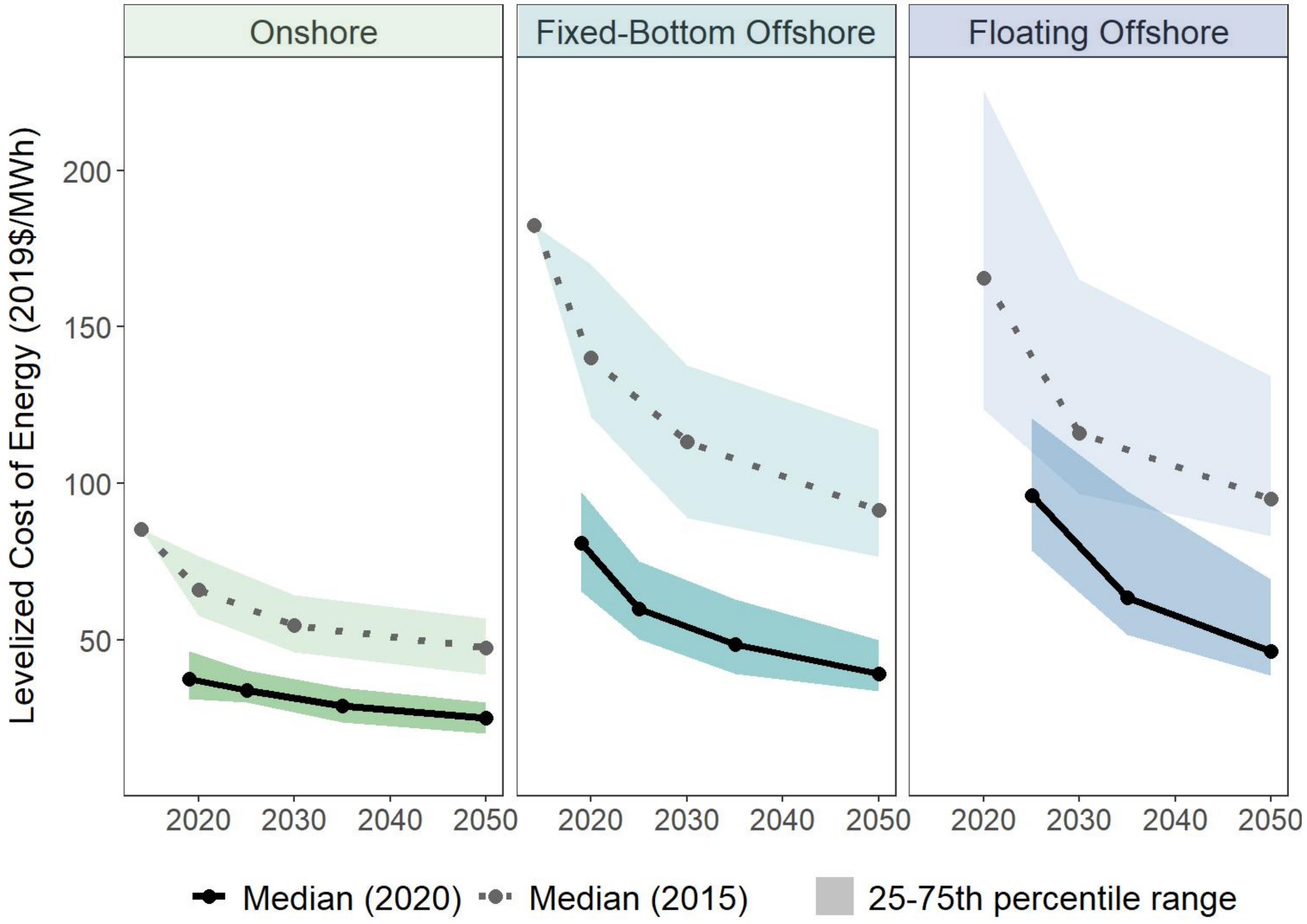


Results assume standardized tax rate (25%), depreciation (20-year straight-line), inflation (2%); exclude interconnection costs outside plant boundary (these interconnection costs tend to be higher for offshore than onshore wind, and should be considered when making overall cost comparisons across wind applications)

North America expected to host the lowest-cost onshore projects; Europe the lowest-cost offshore



Expert perspectives about future cost trajectories have fundamentally changed: median scenario, 2020 vs. 2015



Experts in both surveys anticipated LCOE reductions: *similar amount in percentage terms*

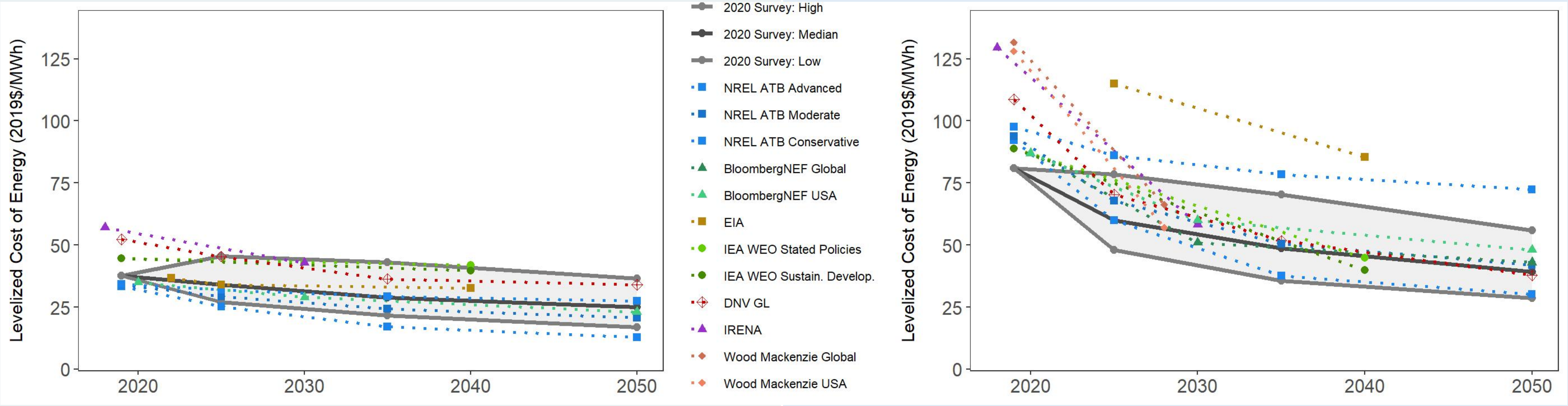
Starting baseline values differ dramatically after steep decline in LCOE over last 5 years

Virtually no overlap between the 25th to 75th percentiles of expert estimates across two surveys

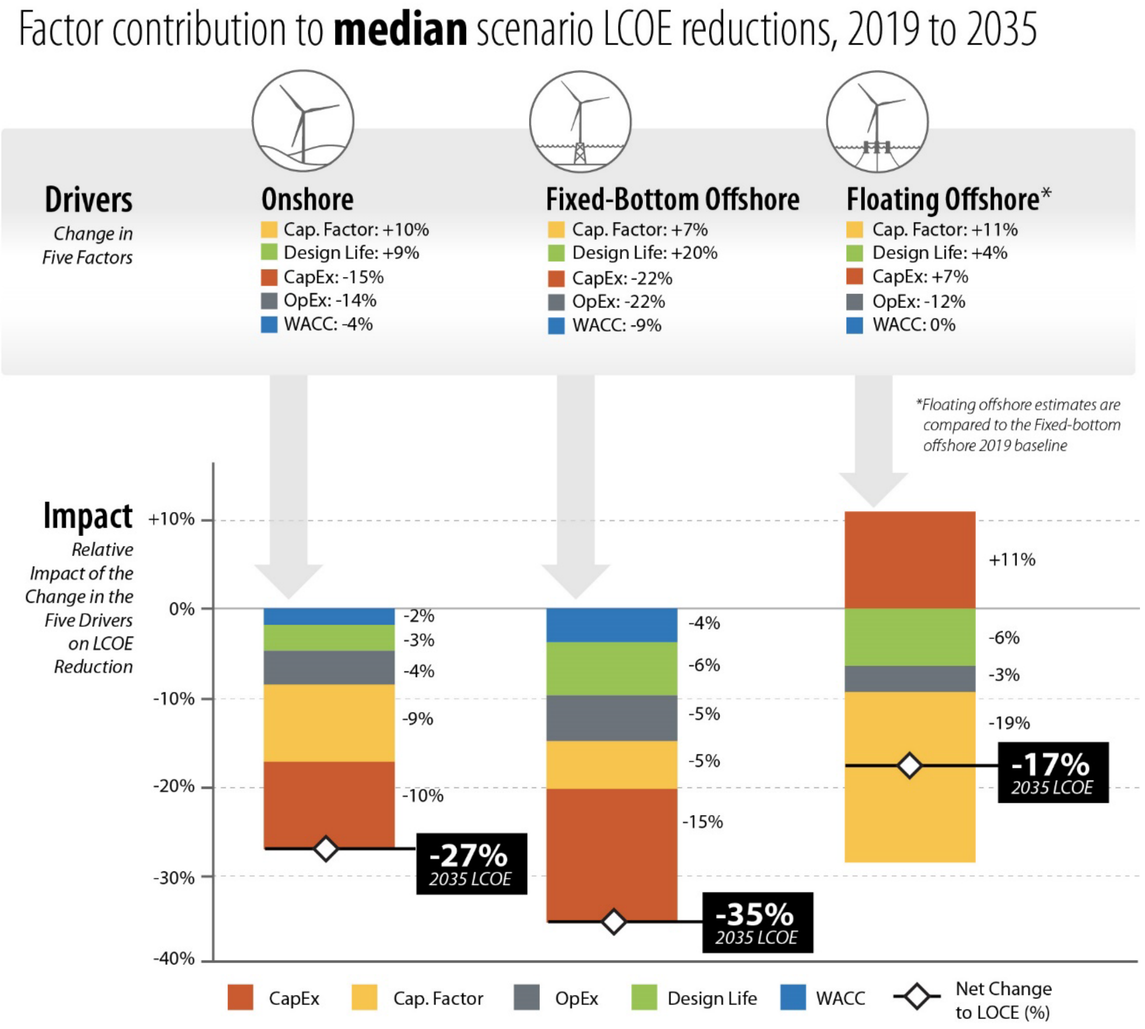
Expected LCOE in 2050 is half what was anticipated in 2015 survey across all applications

2020 survey results are reasonably consistent with historical learning and many other recent forecasts

Onshore Wind	Offshore Wind
Implicit survey-based LCOE learning rate of ~13%, consistent with long-term trend (10-20%); lower than accelerated learning rate (35-46%) over last 5 years	Implicit survey-based LCOE learning rate of ~14%, towards bottom of range of accelerated learning rate (14-33%) over last 5 years, higher than longer term
Experts more optimistic than IEA , EIA, IRENA, DNV GL and assumptions in integrated assessment models; reasonably consistent with NREL and BloombergNEF	Experts have lower starting point values than many other forecasts, but absolute LCOE estimates are highly consistent by 2030 and beyond; EIA projects higher costs



How will we get there? Factor contribution to median scenario LCOE reductions, 2019 to 2035

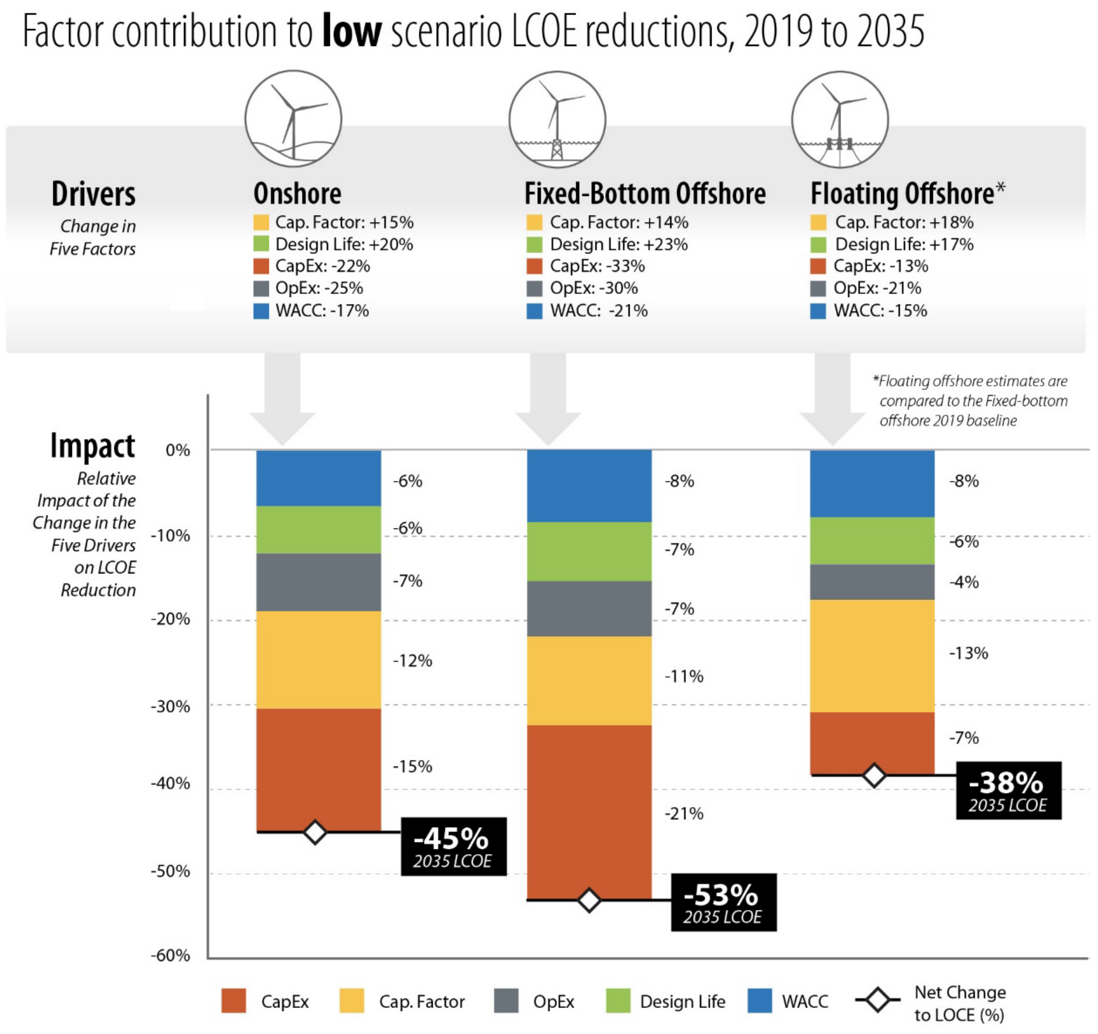


For **onshore wind**, CapEx and capacity factor improvements are most important

For **fixed-bottom offshore**, relative to onshore, capacity factor improvement is less significant, but CapEx and other factors more crucial

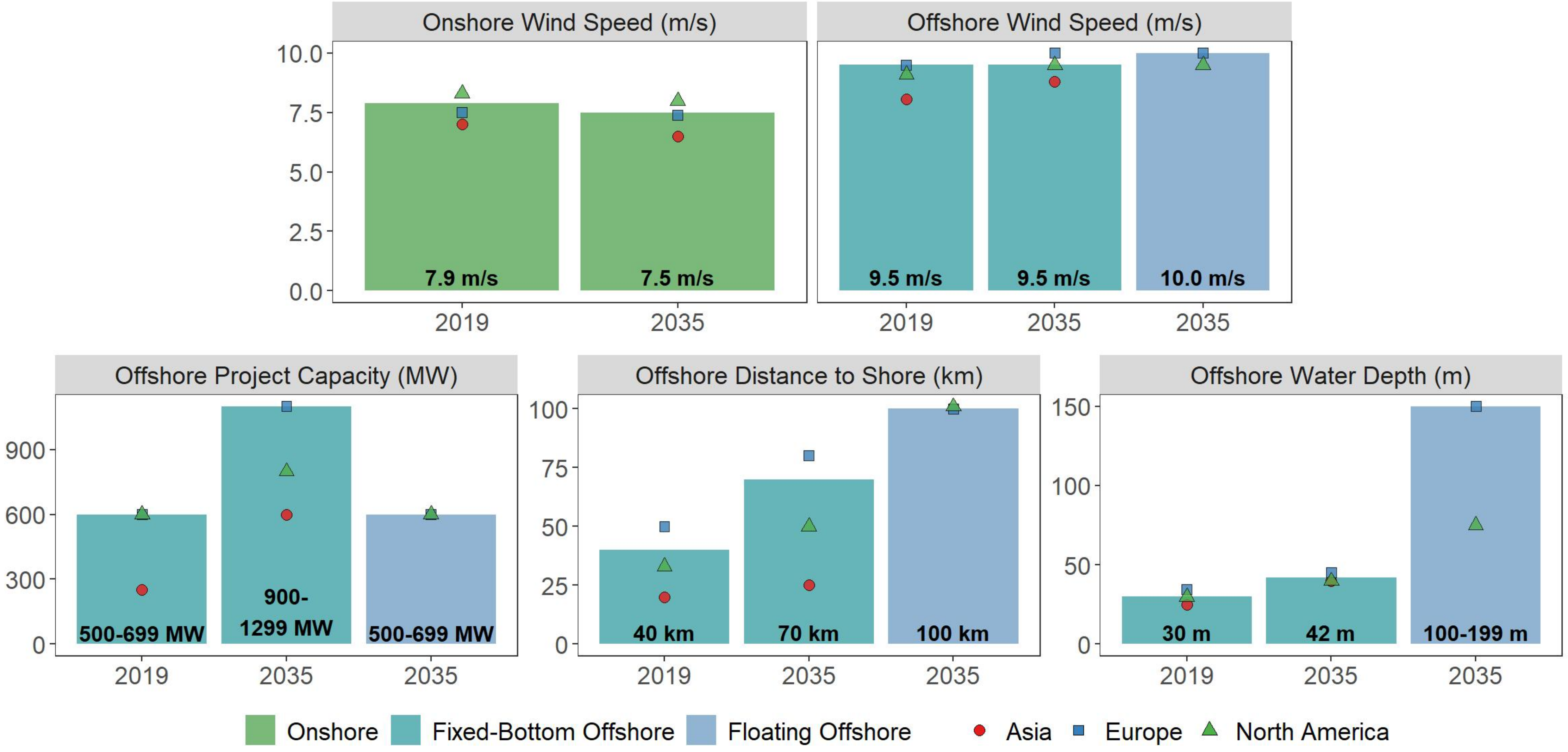
Relative to 2019 fixed-bottom baselines, LCOE reductions for **floating offshore** are dominated by enhanced capacity factors; CapEx in 2035 remains higher than 2019 CapEx for fixed-bottom

How will we get there? Factor contribution to low scenario LCOE reductions, 2019 to 2035

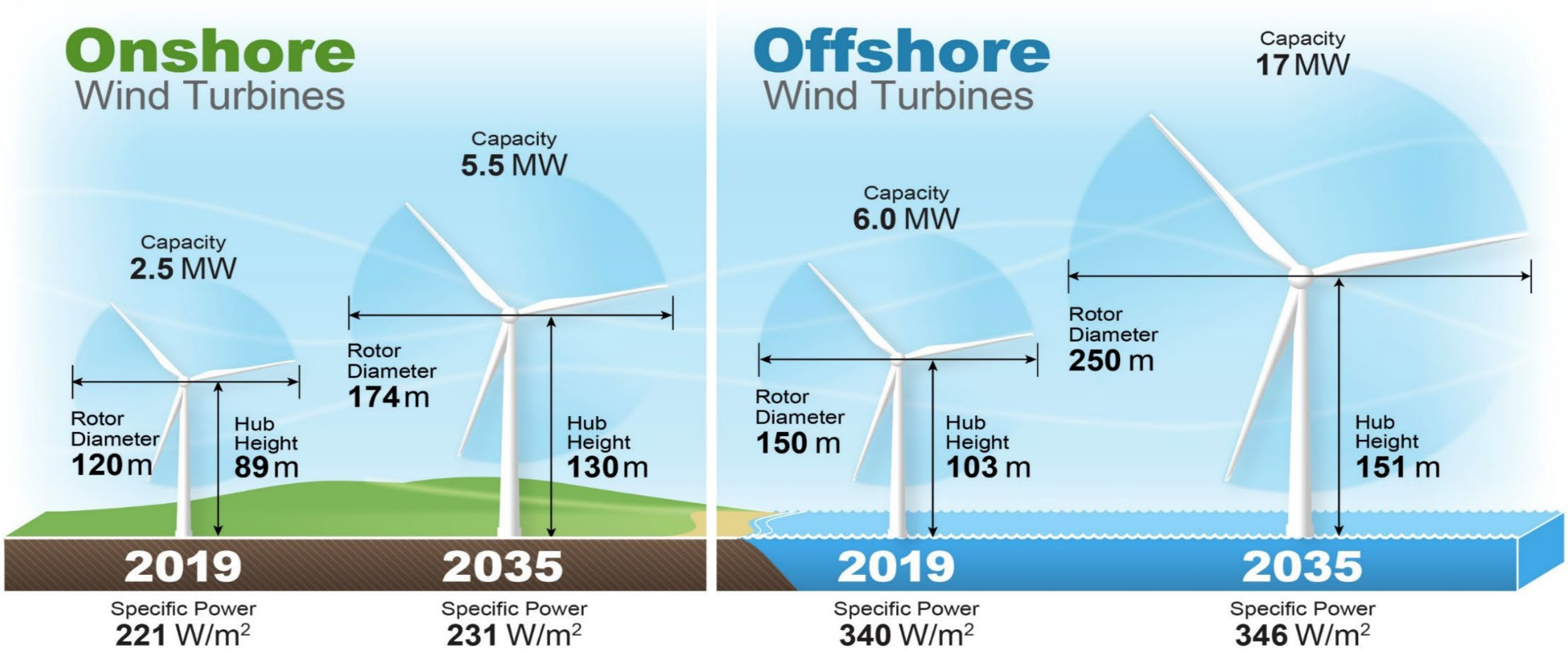


For **floating offshore wind,** change and impact are shown relative to 2019 baseline for fixed-bottom

LCOE reductions are expected despite a tendency in some respects towards less-attractive wind power sites



LCOE improvements driven in part by growth in turbine size: median expected turbine size in 2035 (vs. 2019)



For offshore, 2035 estimates are compared to a global 2019 median; for onshore, a 2019 U.S. median is shown

Relatively modest differences by region: Onshore: lower specific power (and larger rotors) and lower hub height in North America than in Europe. Offshore: somewhat higher capacity ratings in Europe. **Leading experts** predict larger turbines and lower specific power. For onshore, **manufacturers** predict lower specific power and higher hub heights than **developers**. For offshore, **manufacturers** and **developers** predict larger turbines than other respondents.

Constraints to continued increases in turbine size are diverse, and differ between onshore and offshore wind

Onshore wind: factors that may limit future growth in turbine size	No impact (0) ↔ Large impact (3)
Permitting: Siting and permitting regulations and requirements	2.4
Transportation: Transportation limitations and costs	2.4
Community: Local community concerns	2.2
Design/materials: Design and materials constraints, leading to high costs	1.8
Cranes: Lifting / crane capabilities and costs	1.8
Risk: Increased risk given larger impact associated with failure of single turbine	1.1

Offshore wind: factors that may limit future growth in turbine size	No impact (0) ↔ Large impact (3)
Vessels: Vessel capabilities and costs	2.3
Cranes: Lifting / crane capabilities and costs	2.2
Ports: Port capabilities and costs	2.2
Design/materials: Design and materials constraints, leading to high costs	1.9
Permitting: Siting and permitting regulations and requirements	1.8
Transportation: Transportation (e.g., bridge clearances) limitations and costs	1.5
Community: Local community concerns	1.3
Risk: Increased risk given larger impact associated with failure of single turbine	1.2

Constraints to continued increases in turbine size vary regionally

Transportation, vessels, cranes and ports all more challenging in North America than in Europe. Community acceptance a greater constraint in Europe for onshore, less so in Asia.

	North America	Europe	Asia
Onshore: turbine size	No impact (0) ↔ Large impact (3)	No impact (0) ↔ Large impact (3)	No impact (0) ↔ Large impact (3)
Permitting	2.3	2.6	2.2
Transportation	2.5	2.2	2.5
Community	2.1	2.4	1.3
Design/materials	1.8	1.8	2.3
Cranes	2.0	1.6	1.7
Risk	1.1	1.1	1.3
Offshore: turbine size	No impact (0) ↔ Large impact (3)	No impact (0) ↔ Large impact (3)	No impact (0) ↔ Large impact (3)
Vessels	2.7	2.2	2.5
Cranes	2.4	2.1	2.0
Ports	2.4	2.1	2.0
Design/materials	1.8	1.8	2.4
Permitting	1.8	1.7	2.0
Transportation	1.8	1.3	1.6
Community	1.6	1.2	0.8
Risk	1.4	1.0	1.8

Note: sample size for 'Asia' is very limited

Onshore: factors that will be most important in selecting specific turbines for specific sites in 2035

Factors influencing onshore turbine selection for specific sites in 2035	No impact (0) ↔ Large impact (3)
Revenue: Maximize revenue in wholesale power markets per MWh of output of wind energy	2.6
Permitting: Siting and permitting regulations at the local, state/provincial, and/or federal level	2.5
LCOE: Minimize plant-level levelized cost of energy	2.4
Logistics: Transportation and/or erection limitations and costs	2.3
Energy per MW: Maximize energy (MWh) for each MW of capacity in part due to grid limits	2.3
Community: Addressing local community concerns	2.2
Energy per turbine: Maximize energy production (MWh) from each individual turbine	2.1
Policy: Design of policy incentives that influence technology choice	1.5

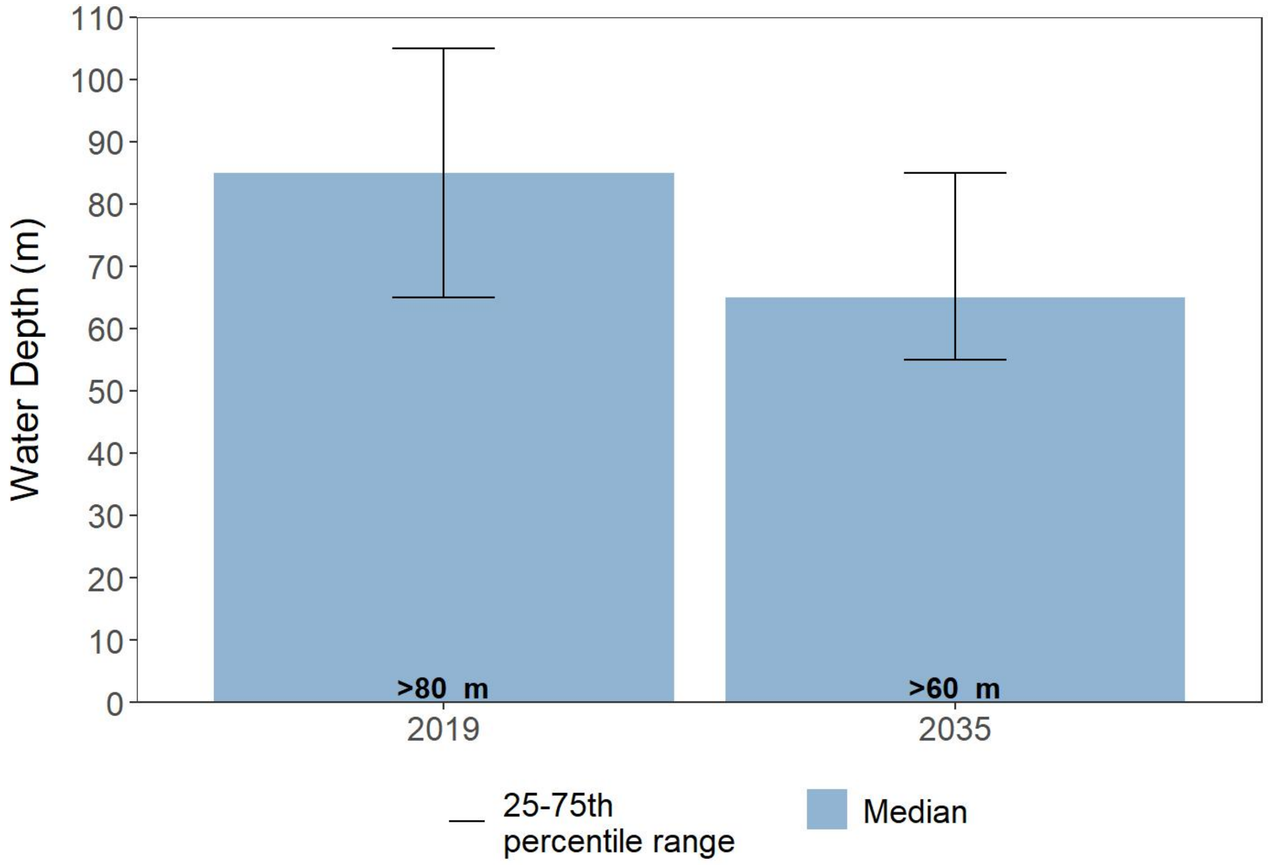
Logistics expected to be a larger driver in **North America**; permitting and energy per turbine somewhat larger drivers in **Europe**. Community concerns less of a factor in **Asia**. **Developers** rate revenue, LCOE and energy per turbine higher than other organizations. **Leading experts** rate LCOE, permitting, and community concerns higher than full sample.

Offshore: floating foundations are expected to take a growing share (but still minority) of the offshore market

By 2035, the median expert predicts that ***11–25%*** of all new offshore projects globally will feature floating foundations

Developers predict a higher share: median = 26-50%

Water depth at which floating becomes less costly than fixed-bottom expected to decline over time



Beyond LCOE: wind plant design and operation will be impacted by options to enhance grid-system value

Onshore wind: frequency of use of grid-value enhancement options in 2035	Widespread use: *over 50% of projects*	Significant use: *over 10% of projects*
Large rotors: Employing larger rotors and/or taller towers to increase production when wholesale prices are higher	77%	95%
Storage hybrids: Co-locating wind projects with storage at the plant site or point of interconnection	46%	83%
Curtailment: Self-curtailment when wholesale prices are low or negative to avoid financial losses during those times	45%	79%
Life extension: Operating to reduce mechanical stress when wholesale prices are low, in part to extend project life	38%	71%
Interconnection: Interconnecting projects to locations with higher wholesale prices and/or lower levels of curtailment	30%	70%
Balancing services: Using wind plants to provide balancing reserves and/or other essential reliability services	29%	81%
Generator hybrids: Co-locating wind projects with other generating sources at the plant site or point of interconnection	26%	80%
Hydrogen: Using wind energy to produce fuels, such as hydrogen, at the plant site or point of interconnection	22%	56%
Overplanting: Building more wind power capacity than transmission interconnection capacity	17%	65%

Offshore wind: frequency of use of grid-value enhancement options in 2035	Widespread use: *over 50% of projects*	Significant use: *over 10% of projects*
Large rotors: Employing larger rotors and/or taller towers to increase production when wholesale prices are higher	43%	78%
Balancing services: Using wind plants to provide balancing reserves and/or other essential reliability services	35%	87%
Interconnection: Interconnecting projects to locations with higher wholesale prices and/or lower levels of curtailment	30%	75%
Curtailment: Self-curtailment when wholesale prices are low or negative to avoid financial losses during those times	28%	56%
Storage hybrids: Co-locating wind projects with storage at the plant site or point of interconnection	26%	70%
Life extension: Operating to reduce mechanical stress when wholesale prices are low, in part to extend project life	26%	58%
Hydrogen: Using wind energy to produce fuels, such as hydrogen, at the plant site or point of interconnection	23%	73%
Overplanting: Building more wind power capacity than transmission interconnection capacity	21%	44%
Generator hybrids: Co-locating wind projects with other generating sources at the plant site or point of interconnection	11%	30%

Expected frequency of use of grid-value enhancement options varies regionally

Large rotors and storage hybrids expected to be popular in all regions for onshore wind

Greater use of multiple options for offshore in Europe, including balancing, curtailment, life extension, hydrogen, overplanting

Lower use of many options in Asia *(but small sample size)*

	North America	Europe	Asia
Onshore: grid value	**Widespread use:** *over 50% of projects*	**Widespread use:** *over 50% of projects*	**Widespread use:** *over 50% of projects*
Large rotors	81%	73%	80%
Storage hybrids	45%	45%	50%
Curtailment	48%	47%	0%
Life extension	45%	34%	0%
Interconnection	33%	21%	50%
Balancing services	26%	30%	0%
Generator hybrids	23%	24%	33%
Hydrogen	19%	24%	0%
Overplanting	11%	24%	17%
Offshore wind: grid value	**Widespread use:** *over 50% of projects*	**Widespread use:** *over 50% of projects*	**Widespread use:** *over 50% of projects*
Large rotors	41%	46%	20%
Balancing services	22%	40%	25%
Interconnection	39%	26%	0%
Curtailment	17%	33%	20%
Storage hybrids	22%	24%	20%
Life extension	11%	33%	0%
Hydrogen	12%	28%	0%
Overplanting	12%	26%	0%
Generator hybrids	11%	10%	0%

Onshore: **developers** predict higher use of curtailment, hybrids, interconnection, overplanting; **public research / universities** expect higher use of life extension, curtailment, and balancing services than private sector; **leading experts** generally more optimistic about all options except hybrids. Offshore: **manufacturers** expect greater use of hydrogen and storage hybrids; **public research / universities** more optimistic about life extension and curtailment than private sector.

Conclusions

Key findings

1. Wind energy has experienced accelerated cost reduction over the last five years, making previous cost forecasts obsolete
2. Experts in 2020 anticipate future onshore and offshore wind costs that are approximately 50% lower than predicted in 2015
3. These reductions will be shaped by not only CapEx, but also capacity factor, OpEx, project life, and cost of finance
4. If realized, this will allow wind to play a more substantial role in global energy supply and energy-sector decarbonization than previously anticipated
5. Uncertainties in the magnitude of cost reduction are significant, illustrating the importance of uncertainty in modeling and in policy, planning, investment, & research decisions
6. As costs decline, additional focus may turn to the value of wind in energy markets, and to the many barriers that hinder deployment

Implications for expert elicitation are tentative, given limited ex-post validation sample

Expert Selection

- Analysis of accuracy of predictions by organization type, level and type of expertise, other characteristics reinforces the general importance of expert selection

Overconfidence

- Results add to other evidence suggesting overconfidence, leading experts to understate uncertainty in outcomes; protocols to try to reduce this bias should be emphasized

Advocacy Bias

- Despite concerns that experts may be optimistic by intention or not (advocacy bias), the opposite has been true, at least over the last five years for wind

Validation Efforts

- Long-duration validation efforts are needed to investigate the persistence of the various biases, enabling more universally applicable findings

Berkeley Lab

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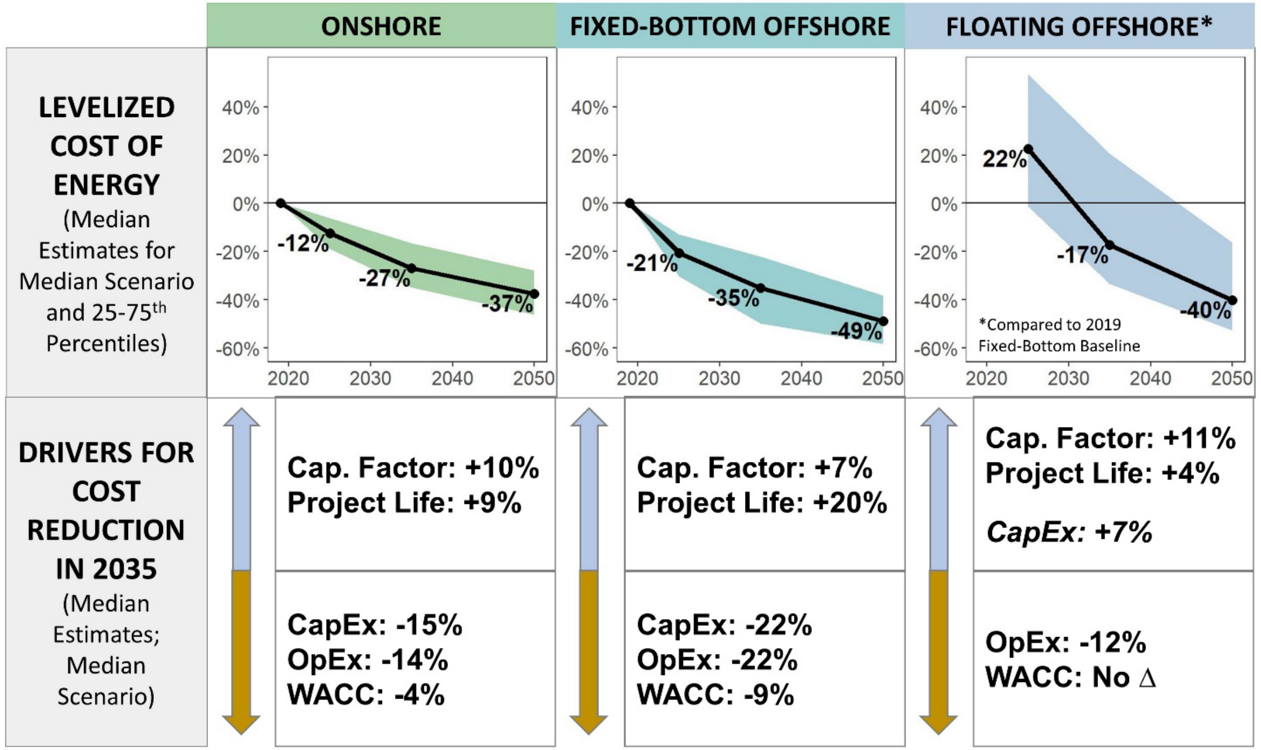

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Additional Details and Results

Notes: For all subsequent slides, summary statistics are withheld for any analysis grouping (i.e., cohort) with fewer than five respondents. For floating offshore wind, changes are shown relative to 2019 baselines for fixed-bottom offshore wind.

Background on the calculation of LCOE (1 of 2)

- The LCOE estimate used in this study equates to the minimum power price a project must obtain in order to cover all project costs, service debt, and pay expected returns to equity shareholders.
- LCOE is calculated at the plant boundary and **excludes** the valuation of public benefits as well as ratepayer, taxpayer, or other forms of project-level government support.
- The LCOE calculation relies on five primary inputs (provided by survey respondents):
  - Total capital expenditures (**CapEx**) ($/kW), in real 2019 currency
  - Levelized total operating expenditures (**OpEx**) ($/kW-yr), in real 2019 currency
  - Average annual wind plant net capacity factor (**NCF**) (%)
  - Wind project design life (**PDL**) (years)
  - Nominal after-tax weighted average cost of capital (**WACC**) (%)
- We assume a standardized tax rate (TR=25%), depreciation schedule (20-year straight-line), and long-term inflation rate (inf=2%). 100% of capital costs are assumed depreciable.
- The nominal WACC is converted to a real WACC in order to compute the real LCOE in 2019 currency.

$$Real\_WACC = \frac{1 + \mathrm{nom\_WACC}}{1 + \mathrm{inf}} - 1$$

Background on the calculation of LCOE (2 of 2)

The equation used to estimate LCOE is as follows:

$$LCOE\ (in\ \$/MWh) = \frac{\text{CapEx} * \text{CRF} * \text{TaxAdj} + \text{OpEx}}{8760 * \text{NCF}}$$

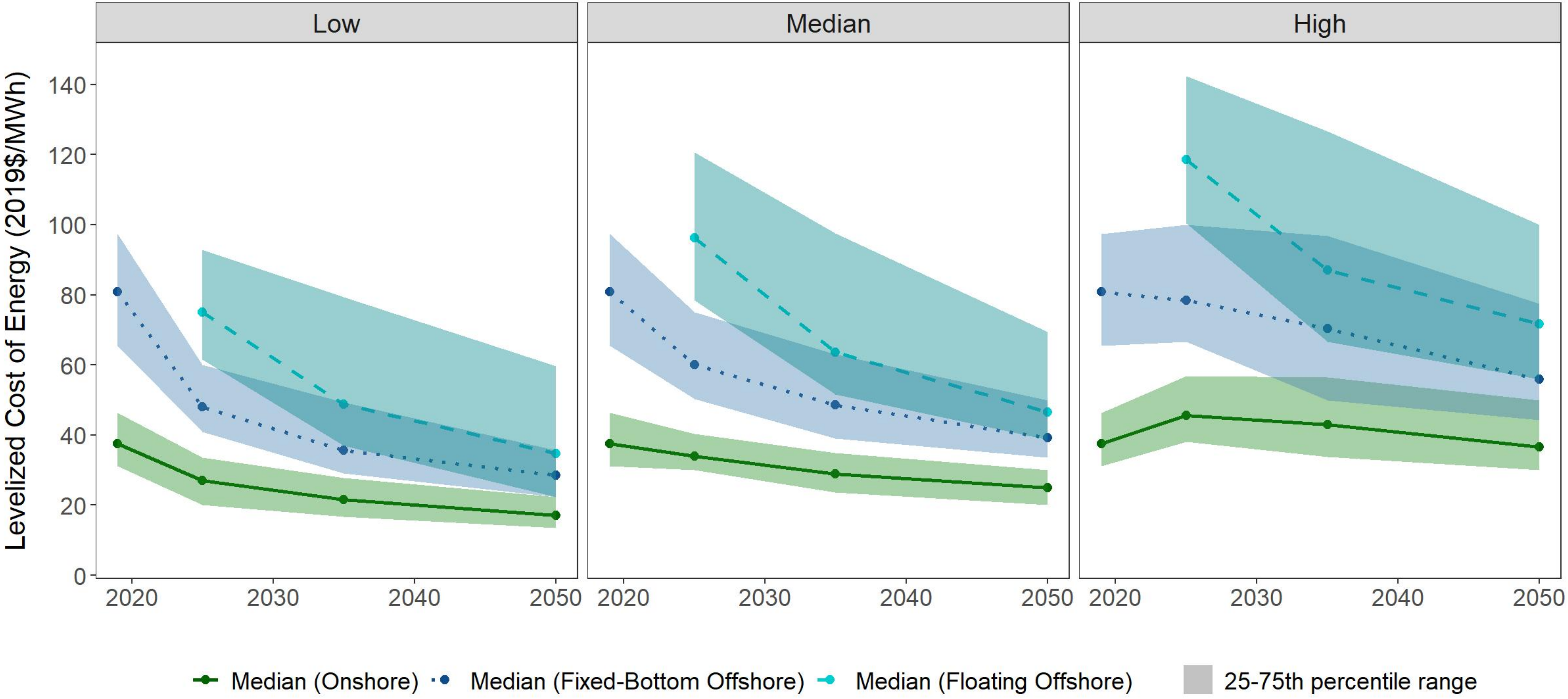
With:

$$Capital\ Recovery\ Factor\ (CRF) = \frac{\text{Real\_WACC} * (1+\text{Real\_WACC})^{\text{PDL}}}{(1+\text{Real\_WACC})^{\text{PDL}} - 1}$$

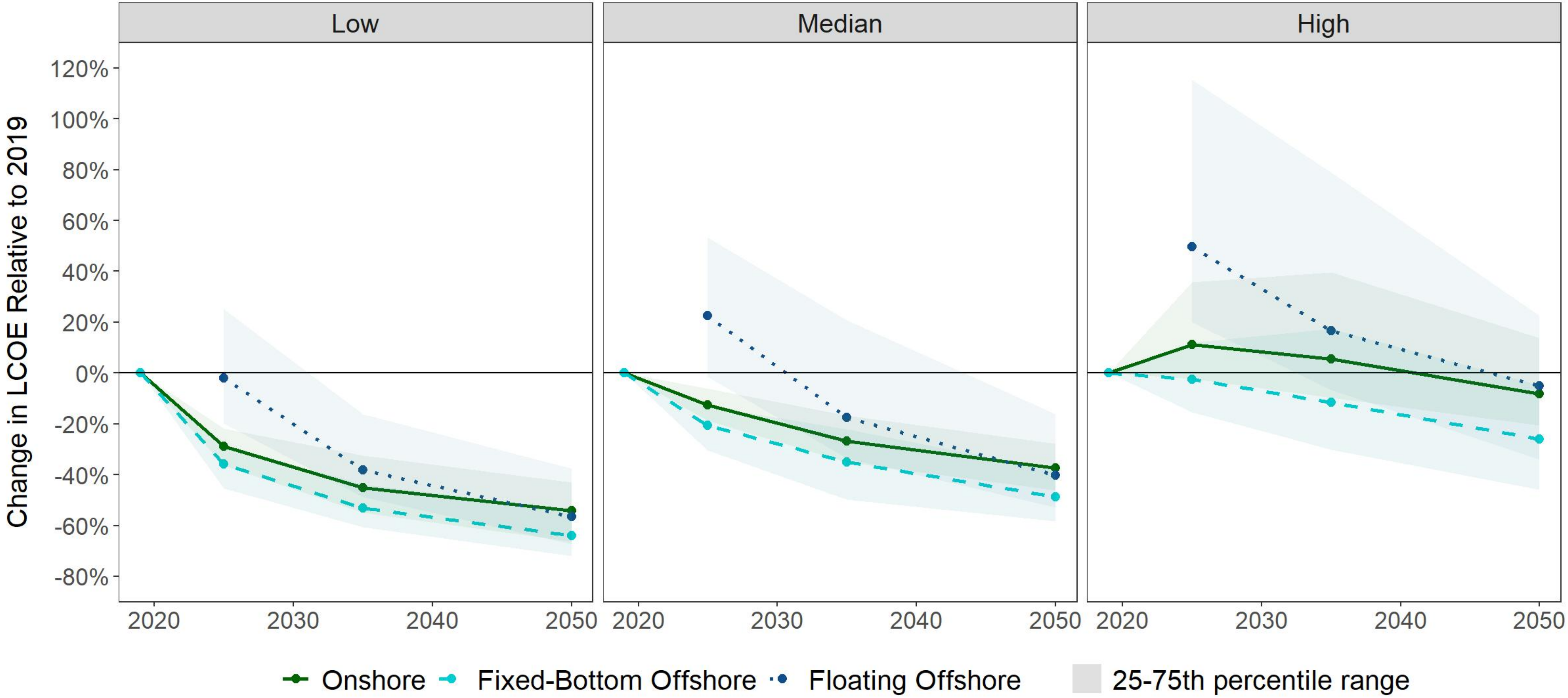
$$Tax\ Adjustment\ (TaxAdj) = \frac{1 - \text{TR} * \text{PVd}}{1 - \text{TR}}$$

$$Present\ value\ of\ depreciation\ (PVd) = \sum_{t=1}^{20} \frac{0.05}{(1+\text{nom\_WACC})^{t}}$$

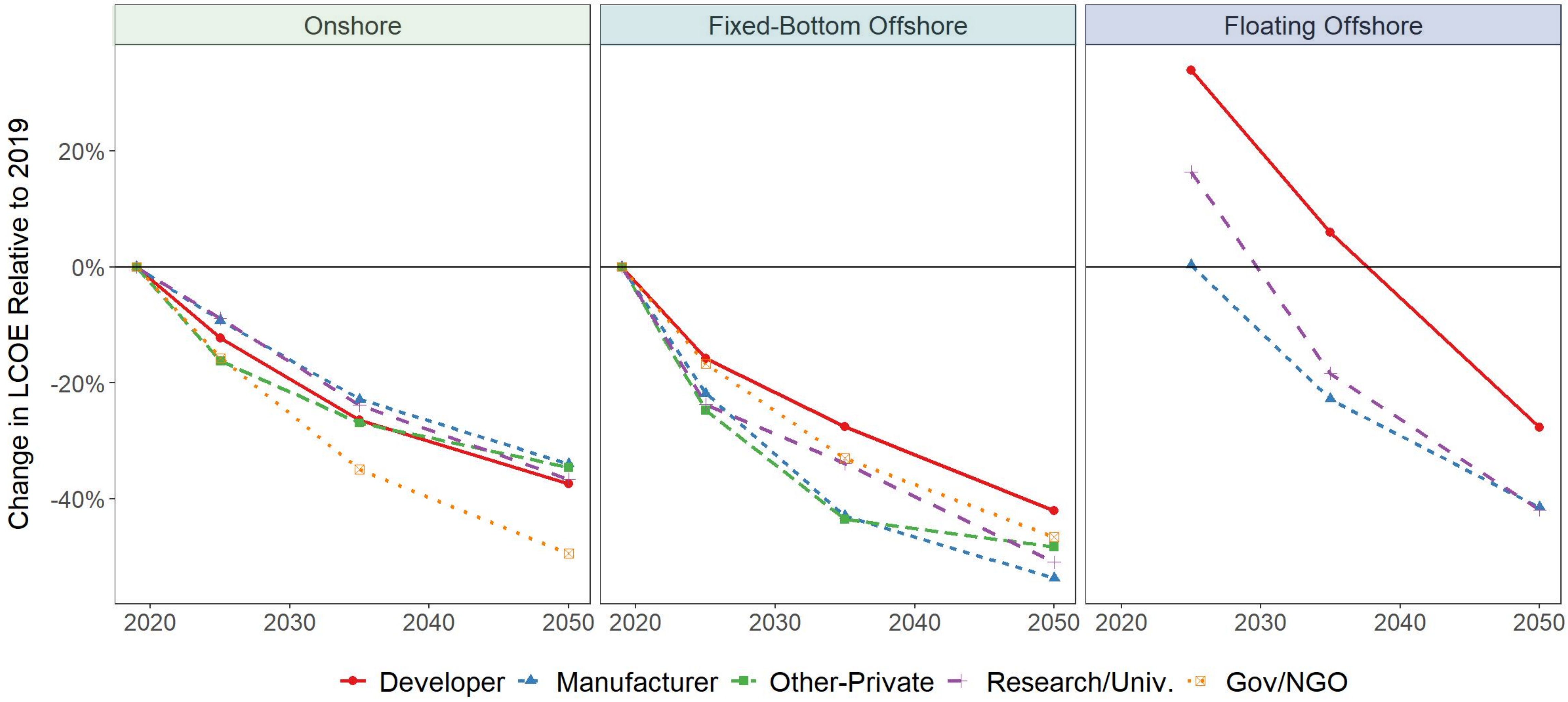
Absolute LCOE estimates across all three scenarios



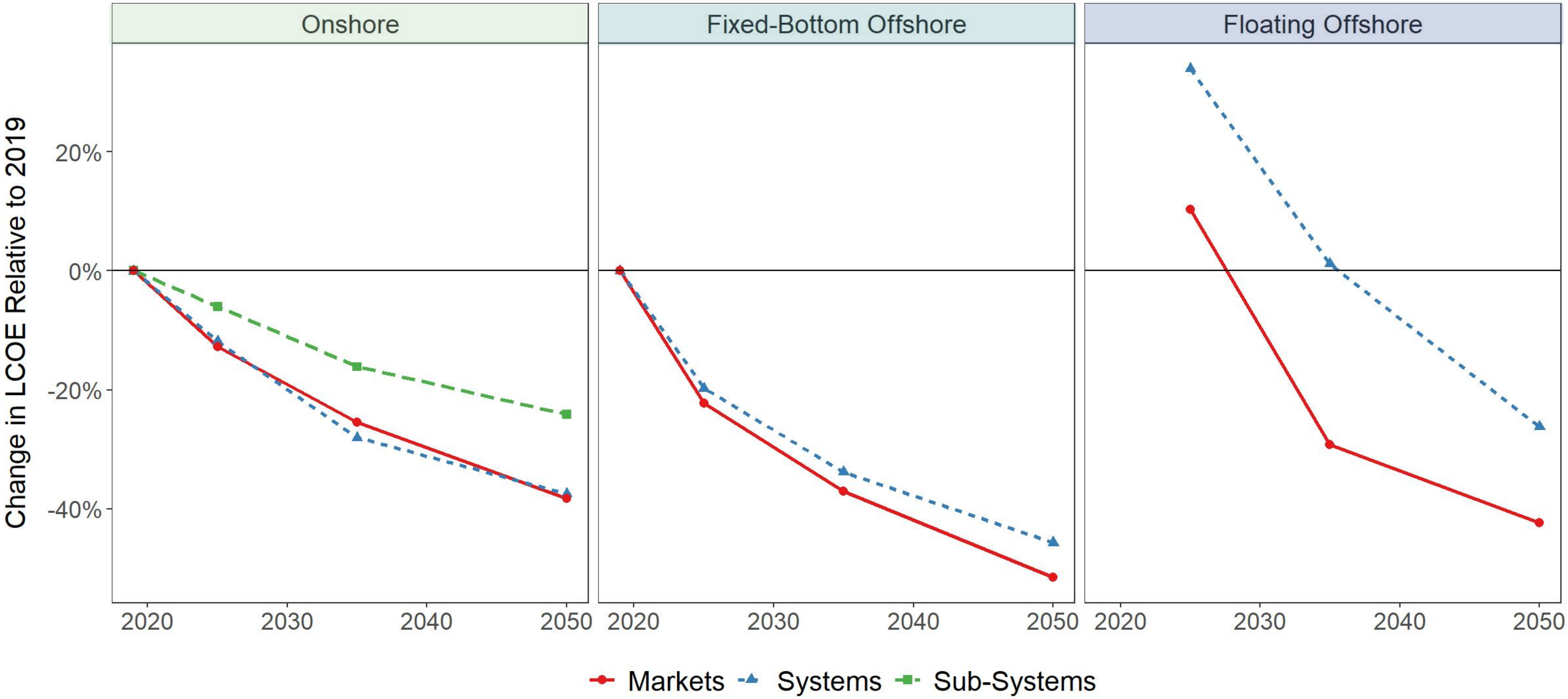
Expected changes in LCOE relative to 2019 baseline values, across all three scenarios



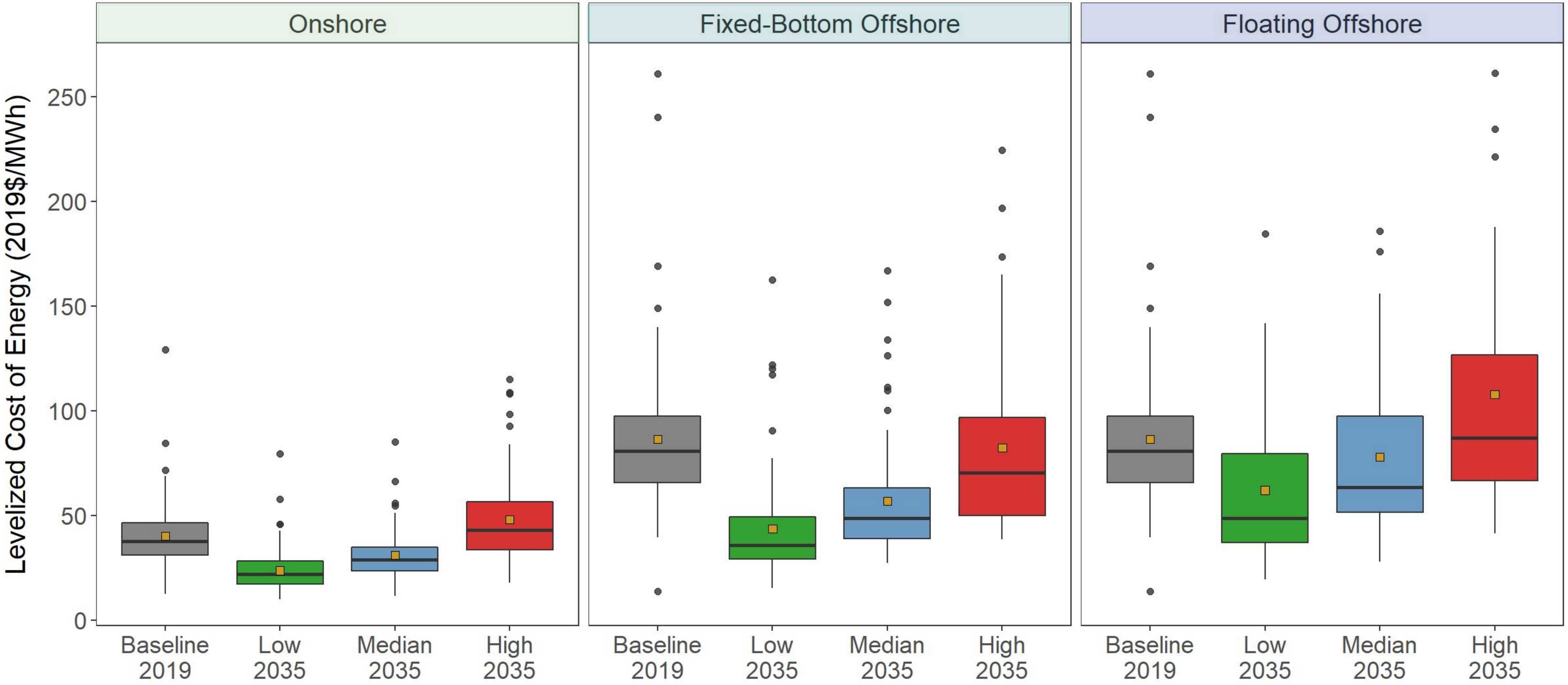
LCOE reduction expectations vary somewhat based on *organization type*: median "best guess" scenario



LCOE reduction expectations vary somewhat based on *expertise type*: median “best guess” scenario

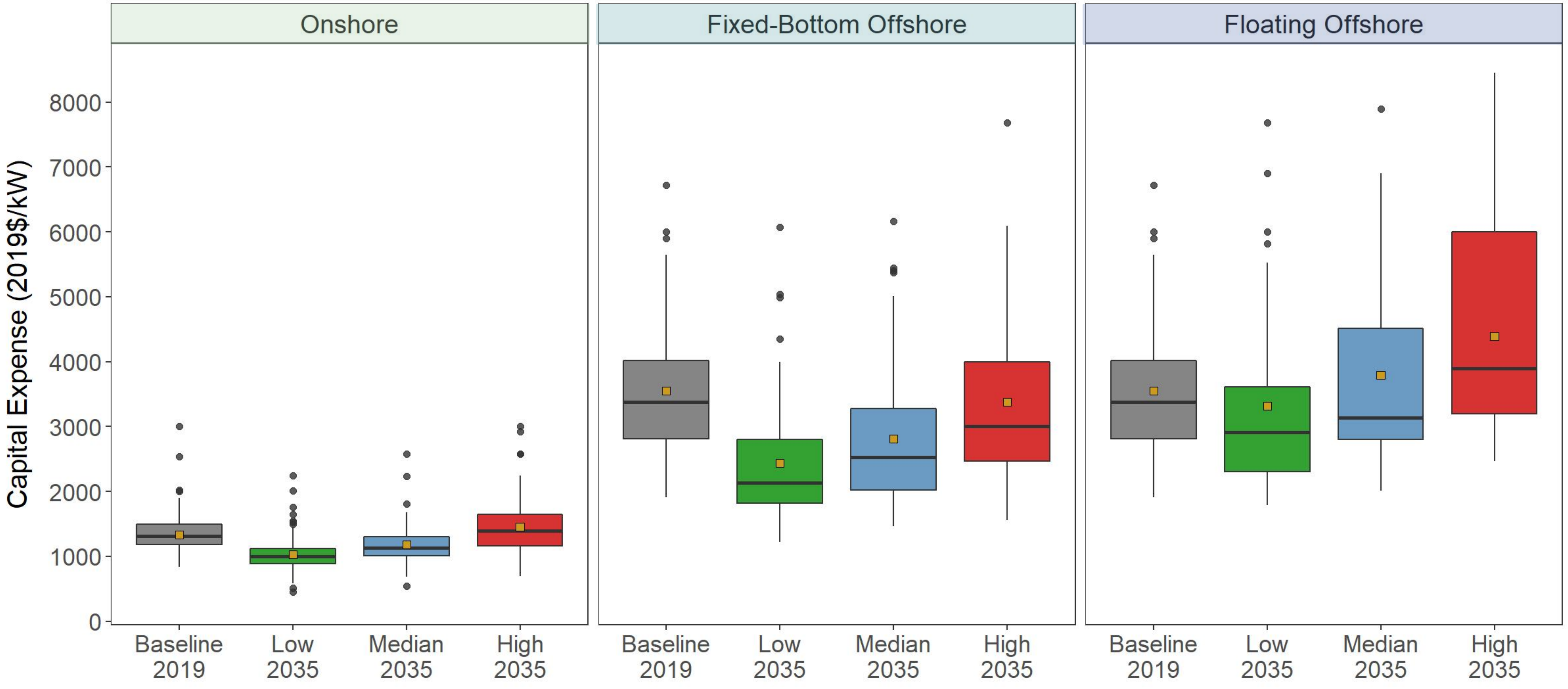


Respondent-level estimates for LCOE in 2019 & 2035



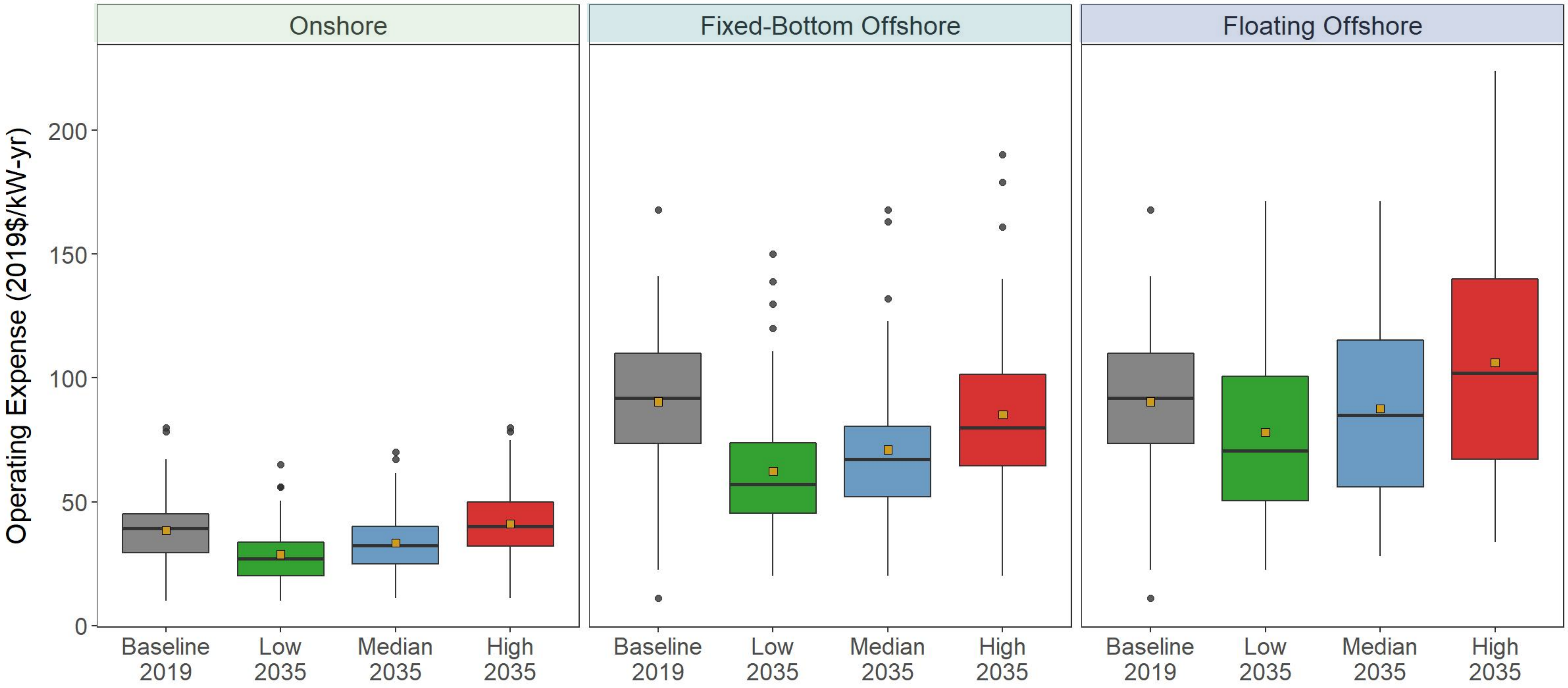
Horizontal black bars are medians. Yellow squares are means. Boxes show interquartile range (IQR). Vertical lines extend to the minimum or maximum value if there are no outliers, or up to a length of 1.5 x IQR if outliers exist. Black dots are outliers. **For floating offshore wind, 2019 baselines are for fixed-bottom offshore wind.**

Respondent-level estimates for CapEx in 2019 & 2035



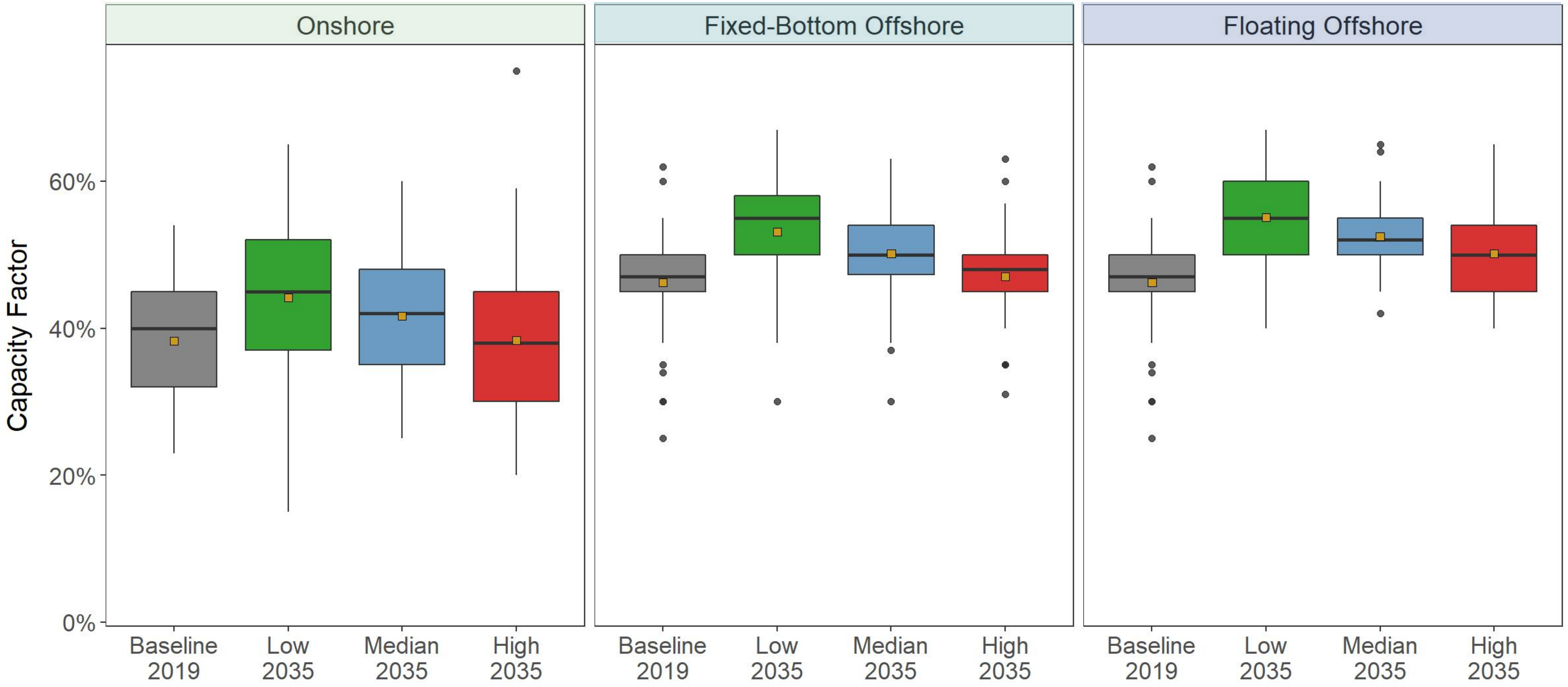
For **floating offshore wind**, 2019 baselines are for fixed-bottom offshore wind.

Respondent-level estimates for OpEx in 2019 & 2035



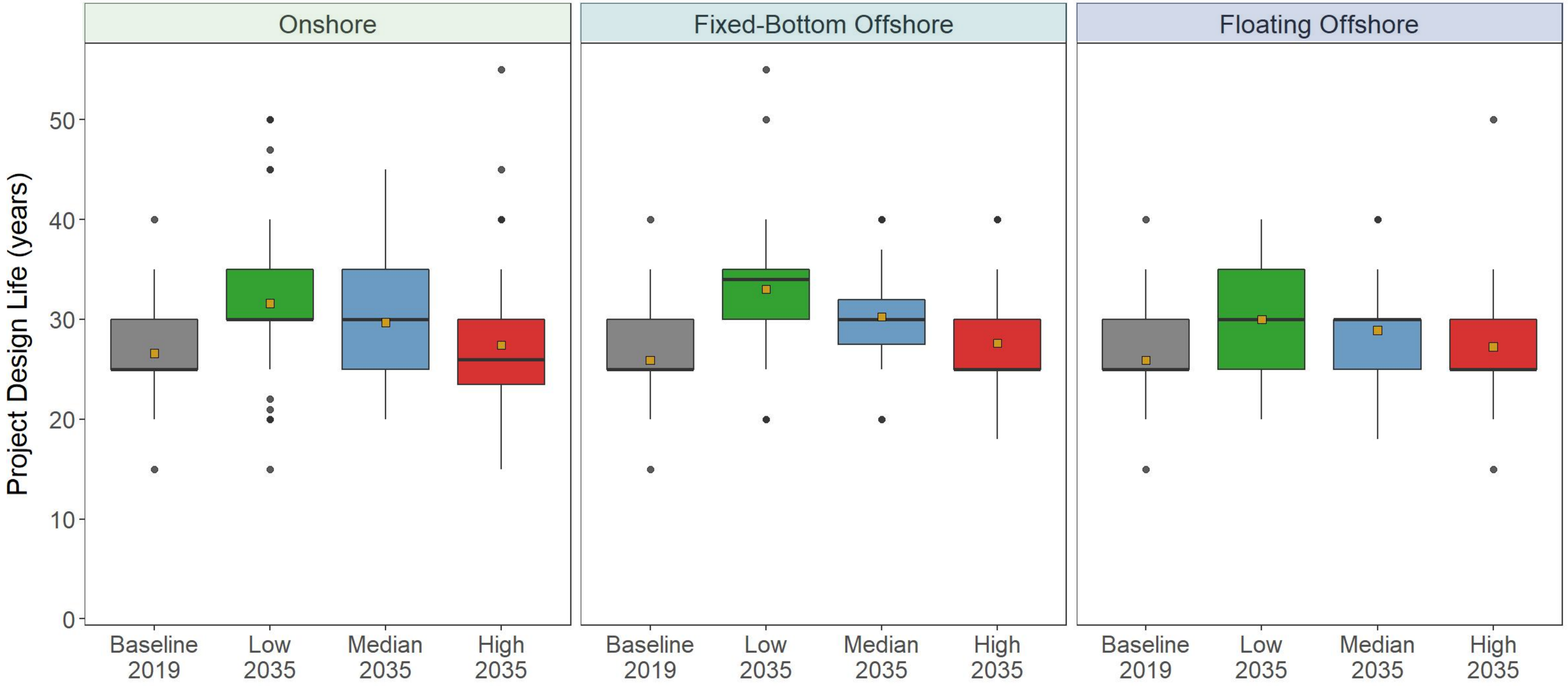
For **floating offshore wind**, 2019 baselines are for fixed-bottom offshore wind.

Respondent-level estimates for capacity factor in 2019 & 2035



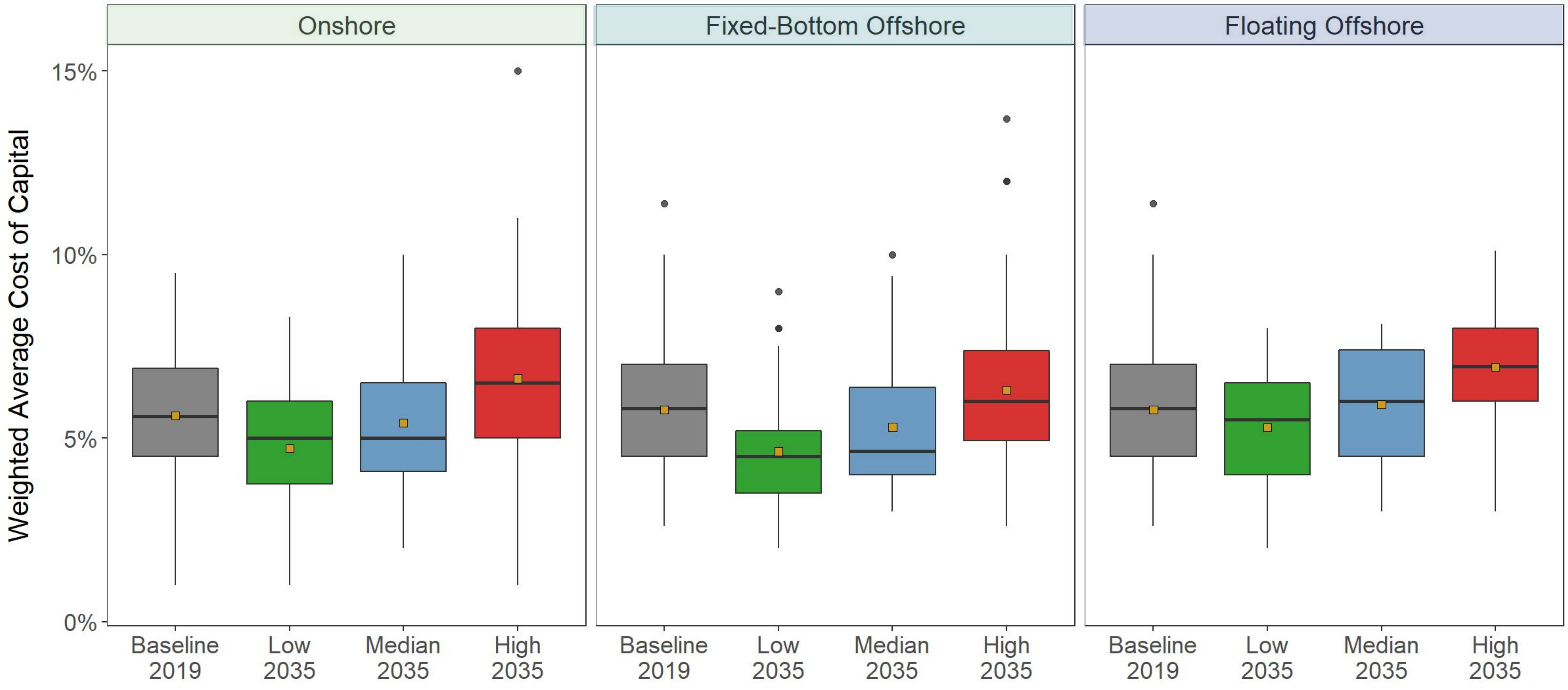
For **floating offshore wind**, 2019 baselines are for fixed-bottom offshore wind.

Respondent-level estimates for project design life in 2019 & 2035



For **floating offshore wind**, 2019 baselines are for fixed-bottom offshore wind.

Respondent-level estimates for WACC in 2019 & 2035



For **floating offshore wind**, 2019 baselines are for fixed-bottom offshore wind.

Changes in LCOE factors by region, leading vs. others, organization type, expertise: onshore wind, 2019 to 2035

	Median Change from 2019 Baseline to 2035 Median-Scenario (Onshore)						
	n	**LCOE**	**CapEx**	**OpEx**	**Cap. Factor**	**Project Life**	**WACC**
All respondents	***97***	***-27%***	***-15%***	***-14%***	***10%***	***9%***	***-4%***
Europe	39	-22%	-14%	-17%	9%	12%	0%
North America	46	-26%	-16%	-13%	10%	6%	-7%
Asia	6	-36%	-24%	-31%	11%	0%	-13%
Leading expert	32	-29%	-17%	-20%	7%	0%	-7%
Non-leading expert	65	-24%	-14%	-13%	10%	11%	0%
Developer	20	-26%	-16%	-14%	11%	4%	-6%
Manufacturer	16	-23%	-12%	-14%	7%	9%	-12%
Other Private	25	-27%	-13%	-17%	10%	12%	0%
Research/University	20	-24%	-13%	-13%	6%	0%	-5%
Government/NGO	16	-35%	-23%	-12%	11%	4%	0%
Markets	50	-25%	-15%	-14%	11%	6%	0%
Systems	39	-28%	-16%	-17%	7%	12%	-10%
Subsystems	8	-16%	-12%	-12%	3%	3%	0%

Changes in LCOE factors by region, leading vs. others, organization type, expertise: fixed-bottom offshore wind

	Median Change from 2019 Baseline to 2035 Median-Scenario (Fixed-Bottom Offshore)						
	n	**LCOE**	**CapEx**	**OpEx**	**Cap. Factor**	**Project Life**	**WACC**
All respondents	***71***	***-35%***	***-22%***	***-22%***	***7%***	***20%***	***-9%***
Europe	44	-35%	-22%	-22%	8%	20%	-8%
North America	18	-34%	-23%	-20%	3%	16%	-9%
Asia	5	-38%	-30%	-10%	9%	0%	-5%
Leading expert	33	-35%	-25%	-20%	6%	20%	-12%
Non-leading expert	38	-34%	-21%	-24%	8%	18%	-7%
Developer	15	-28%	-18%	-20%	2%	13%	-16%
Manufacturer	9	-43%	-21%	-13%	10%	22%	-8%
Other Private	14	-44%	-26%	-30%	10%	31%	-13%
Research/University	21	-34%	-17%	-24%	7%	20%	-5%
Government/NGO	12	-33%	-30%	-17%	6%	8%	-3%
Markets	34	-37%	-27%	-24%	8%	20%	-11%
Systems	34	-34%	-21%	-20%	6%	20%	-8%

Changes in LCOE factors by region, leading vs. others, organization type, expertise: floating offshore wind

	Median Change from 2019 Baseline to 2035 Median-Scenario (Floating Offshore)						
	n	LCOE	CapEx	OpEx	Cap. Factor	Project Life	WACC
All respondents	***37***	***-17%***	***8%***	***-10%***	***11%***	***4%***	***0%***
Europe	29	-18%	7%	-12%	11%	10%	0%
North America	5	-23%	0%	-15%	2%	10%	-14%
Leading expert	19	-23%	0%	-20%	10%	20%	-6%
Non-leading expert	18	-17%	9%	0%	15%	0%	0%
Developer	10	6%	21%	10%	9%	0%	-1%
Manufacturer	8	-23%	6%	-23%	10%	20%	3%
Research/University	13	-18%	8%	-3%	22%	12%	-6%
Markets	15	-29%	-13%	-22%	11%	20%	0%
Systems	18	1%	28%	9%	10%	0%	-1%

For floating offshore wind, changes are shown relative 2019 baselines for fixed-bottom offshore wind.

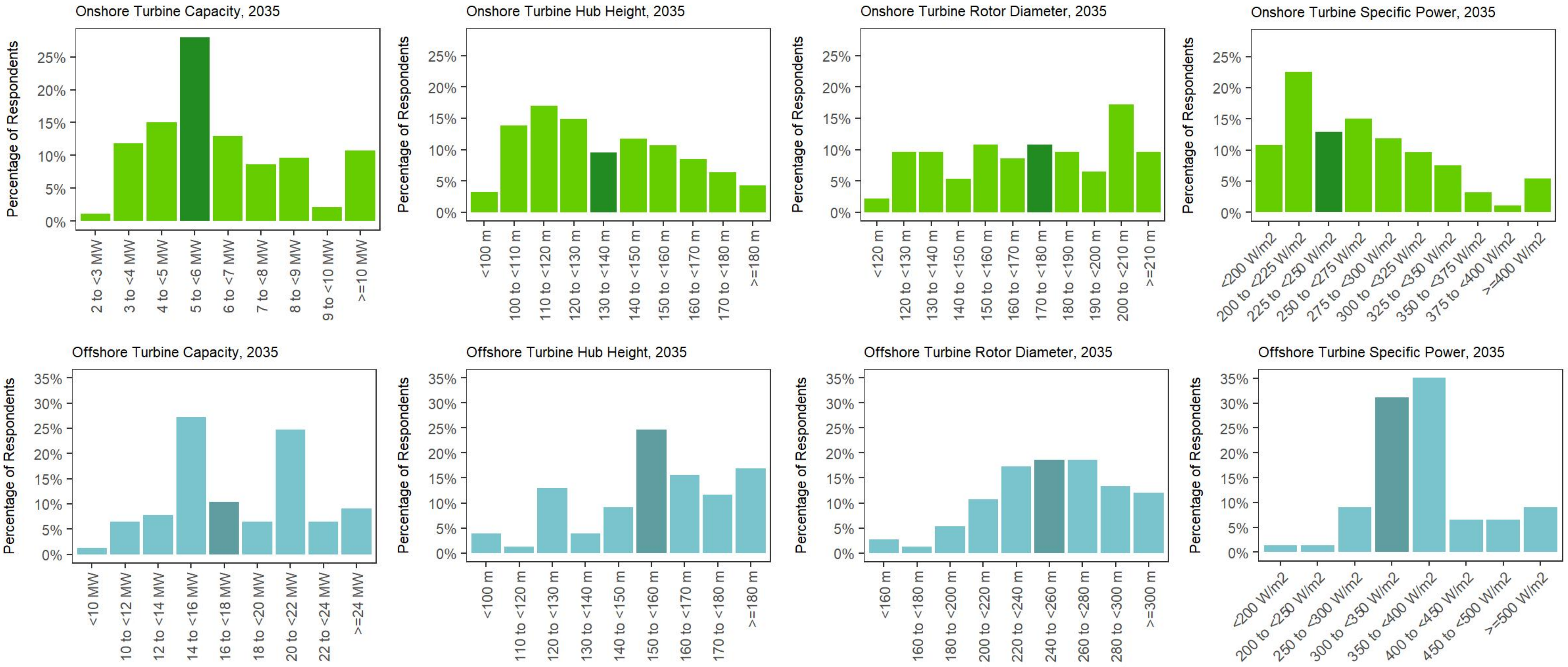
Expected site characteristics in 2035 (vs. 2019) by region, leading vs. others, organization type, expertise

2019 values in parentheses	Onshore Wind Speed (m/s)	Fixed-Bottom Offshore Wind Speed (m/s)	Floating Offshore Wind Speed (m/s)	Fixed-Bottom Offshore Capacity (MW)	Floating Offshore Capacity (MW)
All respondents	***7.5 (7.9*)***	***9.5 (9.5*)***	***10.0***	***1100 (500*)***	***600***
Europe	7.4 (7.5*)	10.0 (9.5*)	10.0	1100 (600*)	600
North America	8.0 (8.3*)	9.5 (9.1*)	9.5	800 (600*)	600
Asia	6.5 (7.0*)	8.8 (8.1*)	-	600 (250*)	-
Leading expert	7.8 (8.0*)	9.9 (9.5*)	10.0	1100 (600*)	800
Non-leading expert	7.5 (7.8)	9.5 (9.5*)	10.0	800 (400*)	600
Developer	7.6 (8.0*)	9.6 (9.6*)	10.0	1100 (600*)	700
Manufacturer	7.5 (8.0*)	10.0 (9.5*)	10.0	1100 (600*)	1100
Other Private	7.4 (7.5*)	9.5 (9.4*)	-	1100 (500*)	-
Research/Univ.	7.5 (8.0*)	9.5 (9.5*)	10.0	800 (400*)	600
Government/NGO	7.5 (7.8*)	9.5 (9.5*)	-	700 (400*)	-
Markets	7.5 (7.6*)	9.5 (9.5*)	10.0	1100 (600*)	600
Systems	7.5 (8.0*)	9.6 (9.5*)	10.0	950 (600*)	600
Subsystems	8.0 (8.3*)	-	-	-	-

Expected site characteristics in 2035 (vs. 2019) by region, leading vs. others, organization type, expertise

**2019 values in parentheses*	Fixed-Bottom Offshore Dist. to Shore (km)	Floating Offshore Dist. to Shore (km)	Fixed-Bottom Offshore Water Depth (m)	Floating Offshore Water Depth (m)
All respondents	***70 (40*)***	***100***	***42 (30*)***	***150***
Europe	80 (50*)	100	45 (35*)	150
North America	50 (33*)	101	40 (30*)	75
Asia	25 (20*)	-	40 (25*)	-
Leading expert	80 (50*)	100	45 (35*)	150
Non-leading expert	50 (32*)	102	41 (30*)	150
Developer	106 (50*)	100	48 (38*)	150
Manufacturer	79 (60*)	100	40 (30*)	75
Other Private	68 (30*)	-	43 (30*)	-
Research/Univ.	55 (35*)	100	40 (30*)	150
Government/NGO	41 (25*)	-	43 (30*)	-
Markets	60 (33*)	78	40 (30*)	150
Systems	80 (40*)	101	45 (35*)	150
Subsystems	-	-	-	-

Expected turbine size in 2035 across all respondents



***Darker bars** indicate median values*

Expected turbine size in 2035 by region, leading vs. others, and organization type

	Onshore				Offshore			
	Capacity (MW)	Hub (m)	Rotor (m)	S.P. (W/m^2)	Capacity (MW)	Hub (m)	Rotor (m)	S.P. (W/m^2)
All respondents	***5.5***	***130***	***174***	***231***	***17.0***	***151***	***250***	***346***
Europe	5.0	130	160	249	17.1	158	250	348
North America	5.6	123	178	224	15.6	150	248	324
Asia	5.7	133	170	249	15.0	170	220	395
Leading expert	5.8	133	183	220	18.0	160	266	325
Non-leading expert	5.1	123	162	247	15.1	150	230	363
Developer	6.0	125	150	340	20.0	160	260	377
Manufacturer	5.6	145	183	212	20.2	162	275	339
Other Private	5.6	138	177	229	16.5	151	243	357
Research/University	5.0	125	178	201	15.1	150	250	308
Government/NGO	5.3	120	150	300	13.8	140	220	362

Note: sample size for 'Asia' is very limited

Expected onshore turbine size constraints by leading vs. others, organization type, expertise

	Turbine Size Constraints (Onshore)					
0 = no impact *3 = large impact*	**Community Concerns**	**Materials / Design Constraints**	**Cranes / Lifting Limitations**	**Increased Risk**	**Siting / Permitting Regulations**	**Transportation Limitations**
All respondents	***2.2***	***1.8***	***1.8***	***1.1***	***2.4***	***2.4***
Leading expert	2.4	1.9	1.8	1.0	2.5	2.4
Non-leading expert	2.1	1.1	1.8	1.2	2.4	2.4
Developer	2.0	2.2	1.9	1.1	2.5	2.5
Manufacturer	2.1	2.0	1.9	1.1	2.4	2.6
Other Private	2.3	1.8	1.8	1.1	2.5	2.4
Research/University	2.2	1.6	1.8	1.2	2.2	2.3
Government/NGO	2.2	1.7	1.5	1.1	2.5	2.1
Markets	2.2	1.9	1.7	1.1	2.4	2.3
Systems	2.2	1.7	1.9	1.1	2.4	2.4
Subsystems	2.0	1.9	2.3	1.4	2.0	2.6

Expected offshore turbine size constraints by leading vs. others, organization type, expertise

	Turbine Size Constraints (Offshore)							
0 = no impact *3 = large impact*	**Community Concerns**	**Materials / Design Constraints**	**Cranes / Lifting Limitations**	**Port Capabilities & Cost**	**Increased Risk**	**Siting / Permitting Regulations**	**Transportatio n Limitations**	**Vessel Capabilities & Cost**
All respondents	***1.3***	***1.9***	***2.2***	***2.2***	***1.2***	***1.8***	***1.5***	***2.3***
Leading expert	1.1	2.0	2.0	2.0	1.1	1.8	1.4	2.2
Non-leading expert	1.4	1.8	2.4	2.3	1.3	1.8	1.5	2.4
Developer	1.2	1.4	2.2	2.3	1.3	2.1	1.7	2.4
Manufacturer	1.4	1.8	1.9	2.0	0.9	1.4	1.7	1.9
Other Private	1.2	2.1	2.1	2.0	1.3	2.0	1.1	2.2
Research/Univ.	1.3	2.0	2.4	2.4	1.4	1.7	1.5	2.4
Government/NGO	1.3	1.8	2.3	1.8	1.0	1.7	1.5	2.5
Markets	1.1	1.9	2.1	2.1	1.1	1.7	1.4	2.3
Systems	1.4	1.9	2.3	2.2	1.3	1.9	1.6	2.3

Onshore turbine selection in 2035 by region

Factors influencing onshore turbine selection in 2035	North America	Europe	Asia
	No impact (0) ↔ Large impact (3)	No impact (0) ↔ Large impact (3)	No impact (0) ↔ Large impact (3)
Revenue	2.5	2.6	2.7
Permitting	2.3	2.6	2.5
LCOE	2.4	2.4	2.5
Logistics	2.5	2.1	2.3
Energy per MW	2.2	2.3	2.7
Community	2.2	2.3	1.5
Energy per turbine	1.9	2.2	2.0
Policy	1.4	1.6	1.8

Note: sample size for 'Asia' is very limited

Onshore turbine selection in 2035 by leading vs. others, organization type, expertise

	Onshore Turbine Selection in 2035							
0 = no impact *3 = large impact*	**Revenue**	**Permitting**	**LCOE**	**Logistics / Transportation**	**Energy per MW**	**Community Concerns**	**Energy per Turbine**	**Policy Incentives**
All respondents	***2.6***	***2.5***	***2.4***	***2.3***	***2.3***	***2.2***	***2.1***	***1.5***
Leading expert	2.5	2.7	2.7	2.4	2.2	2.5	2.1	1.3
Non-leading expert	2.6	2.4	2.3	2.3	2.3	2.1	2.0	1.7
Developer	2.8	2.4	2.6	2.4	2.2	2.0	2.4	1.5
Manufacturer	2.6	2.4	2.4	2.5	2.5	2.0	2.0	1.3
Other Private	2.5	2.6	2.4	2.6	2.0	2.5	2.1	1.4
Research/University	2.5	2.5	2.4	2.3	2.4	2.2	1.6	1.8
Government/NGO	2.4	2.5	2.4	1.9	2.4	2.3	2.3	1.6
Markets	2.6	2.5	2.5	2.2	2.1	2.2	2.3	1.4
Systems	2.6	2.5	2.4	2.5	2.4	2.2	1.8	1.6
Subsystems	2.0	2.1	2.6	2.4	2.1	2.1	2.0	1.8

Offshore foundation tradeoffs by leading vs. others, organization type, expertise

	Offshore Foundation Tradeoffs		
	Water Depth Crossover (2019)	**Water Depth Crossover (2035)**	**Percentage of Projects Using Floating Foundations**
All respondents	***>80 m***	***>60 m***	***11-25%***
Leading expert	>80 m	>60 m	11-25%
Non-leading expert	>80 m	>60 m	11-25%
Developer	>70 m	>60 m	26-50%
Manufacturer	>90 m	>60 m	11-25%
Other Private	>80 m	>60 m	11-25%
Research/Univ.	>80 m	>60 m	11-25%
Government/NGO	>80 m	>70 m	11-25%
Markets	>80 m	>60 m	11-25%
Systems	>80 m	>60 m	11-25%

Onshore grid-value enhancement options in 2035 by leading vs. others, organization type, expertise

	Onshore Grid-Value Enhancement Options in 2035								
0 = no use *3 = widespread use*	**Life Extension**	**Curtailment (Losses)**	**Balancing Services**	**Generator Hybrids**	**Hydrogen**	**Point of Interconnect**	**Large Rotors / Tall Towers**	**Over-planting**	**Storage Hybrids**
All respondents	***1.9***	***2.0***	***2.0***	***2.0***	***1.6***	***1.8***	***2.6***	***1.7***	***2.2***
Leading expert	2.1	2.2	2.2	2.0	1.8	1.9	2.7	1.9	2.1
Non-leading expert	1.8	2.0	1.9	2.0	1.6	1.8	2.5	1.6	2.3
Developer	1.8	2.3	1.8	2.4	1.8	2.1	2.7	2.1	2.4
Manufacturer	1.9	1.6	2.1	1.9	1.6	1.8	2.8	1.8	2.1
Other Private	1.9	1.9	1.8	1.8	1.6	1.5	2.5	1.5	2.1
Research/Univ.	2.3	2.4	2.4	2.1	1.8	1.8	2.5	1.7	2.3
Government/NGO	1.7	1.9	1.9	2.1	1.4	2.1	2.4	1.5	2.3
Markets	1.8	2.1	1.7	2.0	1.4	1.8	2.6	1.7	2.2
Systems	2.2	2.0	2.3	1.9	1.9	1.8	2.6	1.7	2.3
Subsystems	1.8	2.1	2.1	2.4	2.0	2.1	2.6	2.0	2.4

Offshore grid-value enhancement options in 2035 by leading vs. others, organization type, expertise

	Offshore Grid-Value Enhancement Options in 2035								
0 = no use *3 = widespread use*	**Life Extension**	**Curtailment (Losses)**	**Balancing Services**	**Generator Hybrids**	**Hydrogen**	**Point of Interconnect**	**Large Rotors / Tall Towers**	**Over-planting**	**Storage Hybrids**
All respondents	***1.7***	***1.7***	***2.0***	***1.3***	***1.8***	***1.8***	***2.1***	***1.4***	***1.9***
Leading expert	1.4	1.8	1.9	1.2	1.8	1.9	2.1	1.6	1.8
Non-leading expert	1.9	1.6	2.1	1.3	1.8	1.8	2.1	1.3	1.9
Developer	1.4	1.9	1.8	1.5	1.6	1.8	2.1	1.6	1.8
Manufacturer	1.6	1.0	2.0	1.3	2.2	1.7	2.1	1.3	2.3
Other Private	1.7	1.9	2.1	0.9	1.8	2.0	1.7	1.5	1.4
Research/Univ.	1.9	2.0	2.0	1.5	2.0	1.6	2.2	1.5	2.1
Government/NGO	1.7	1.4	2.2	1.0	1.4	2.1	2.3	1.0	1.7
Markets	1.7	1.6	2.0	0.9	1.7	1.9	2.1	1.2	1.7
Systems	1.7	1.8	2.0	1.5	1.9	1.8	2.1	1.6	2.0