How Low Can They Go:

Expert Perspectives on the Future Costs of Fixed-Bottom & Floating Offshore Wind Energy

Ryan Wiser, Joe Rand, Joachim Seel, Philipp Beiter, Erin Baker, Eric Lantz, Patrick Gilman

(with appreciation for all IEA Wind Task 26 participants)

EERA DeepWind 2021
January 2021

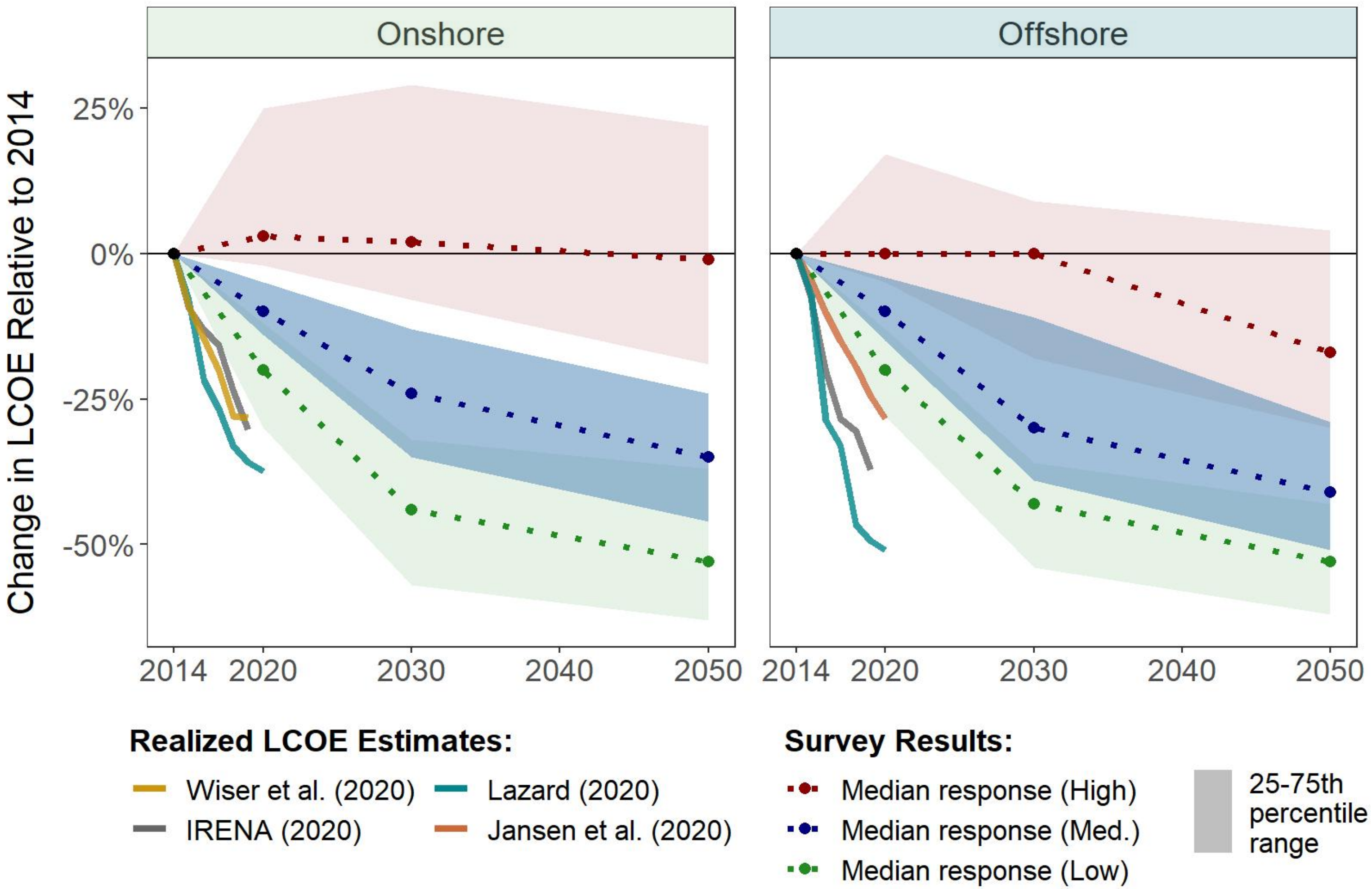
EARLY RESULTS: NOT FOR CITATION

This work was funded by the U.S. Department of Energy's Wind Energy Technologies Office, under Contract No. DE-AC02-05CH11231 (LBNL) and DE-AC36-09GO28308 (NREL)

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

Summary of survey focus and respondents

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 (10th percentile) and high (90th) cost scenarios
- Elicits site conditions and technology expectations, drivers and constraints
- Additional questions explore options to enhance grid-system value

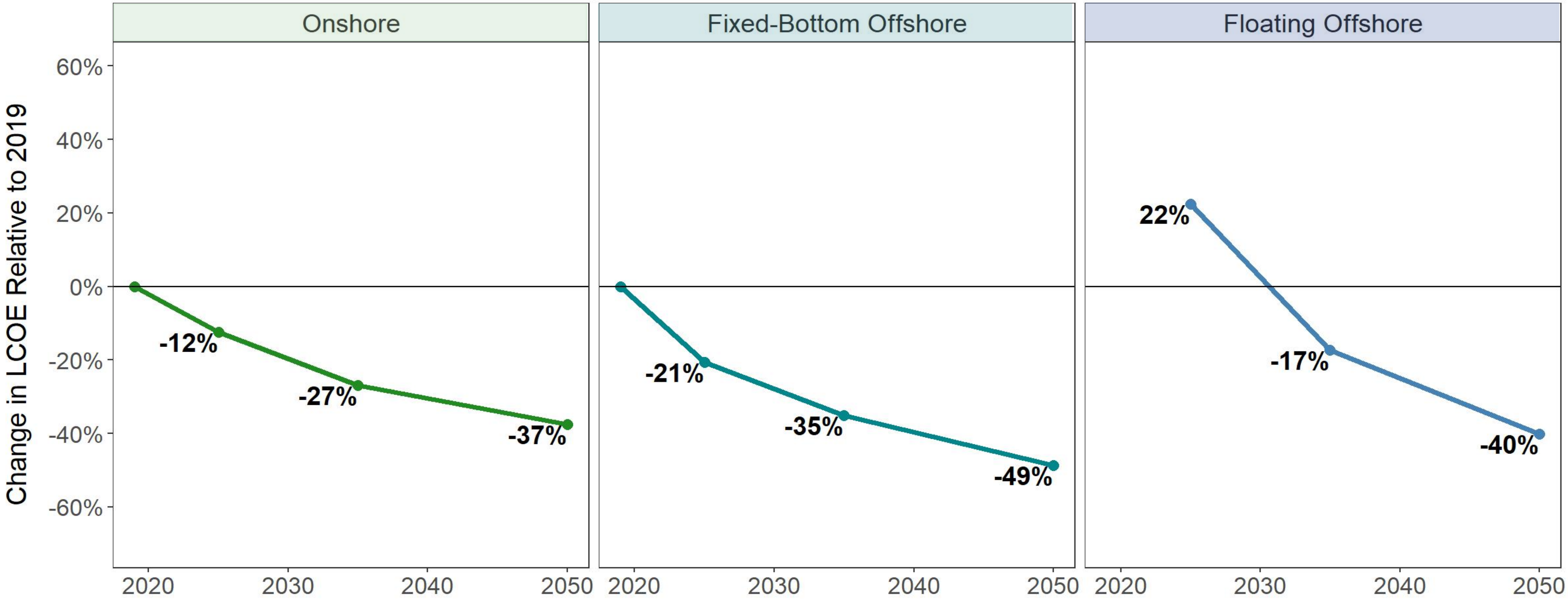
140 survey participants, dominated by Europe and North America but also Asia

Response Rate			
Survey sample: total			645
Survey respondents: total			140
Response rate: total			*22%*
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
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

* 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.

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

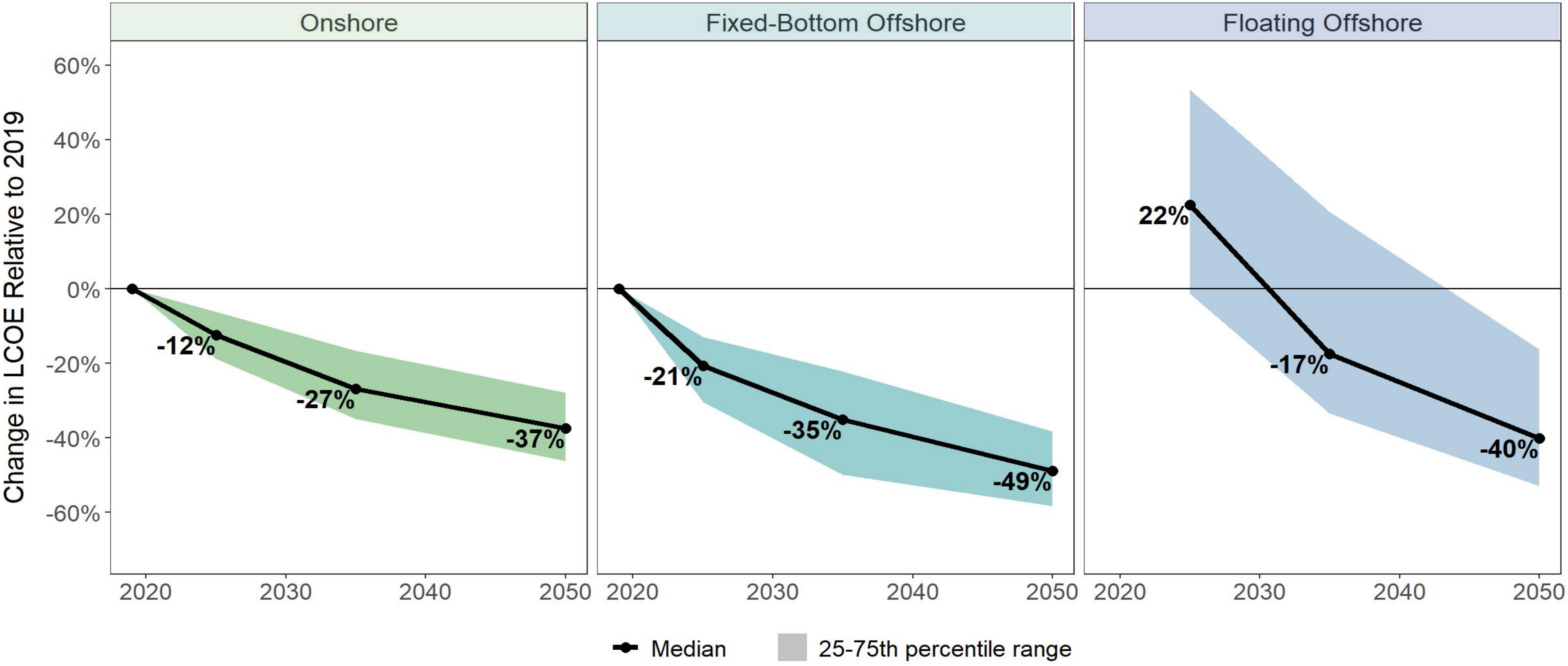
PRELIMINARY RESULTS: NOT FOR CITATION



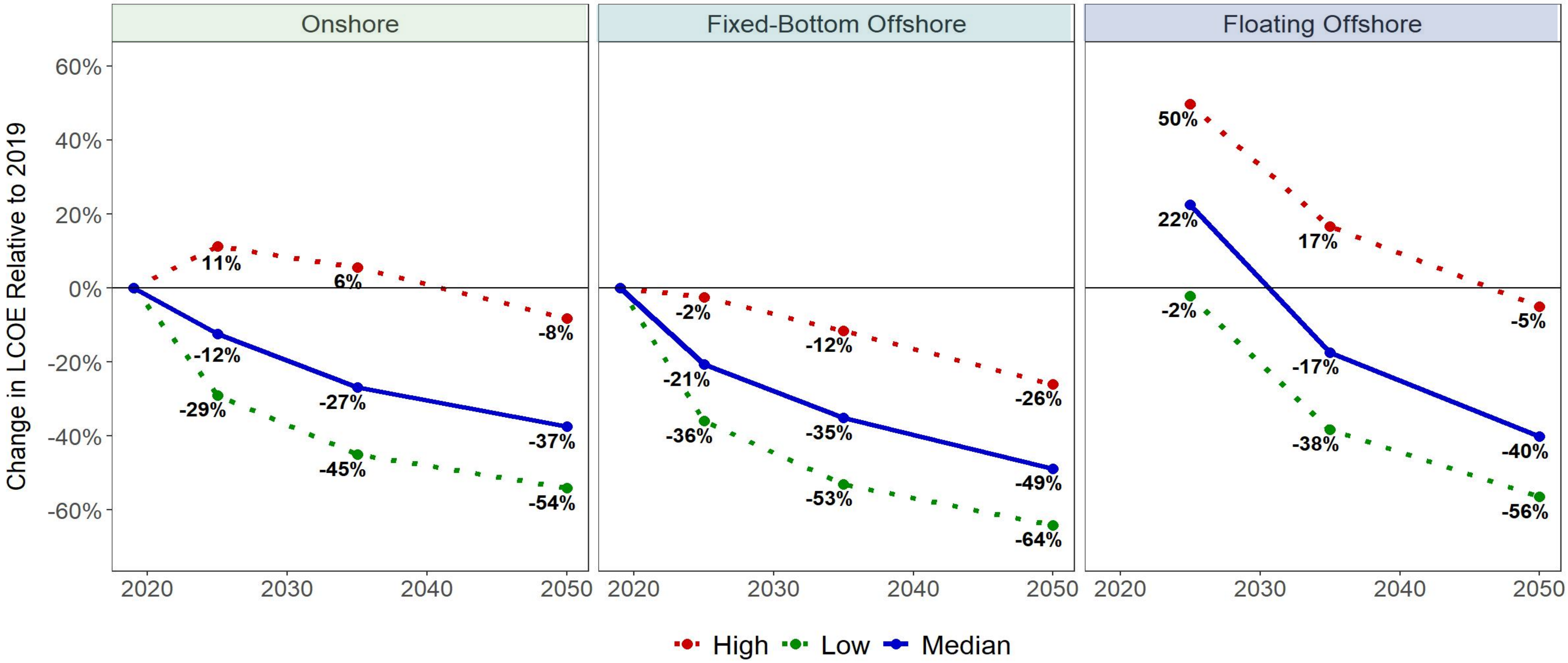
Lines/markers indicate the **median** expert response
For **floating,** change is shown relative to 2019 baseline for fixed-bottom
All dates are based on the year in which a new wind project is commissioned

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

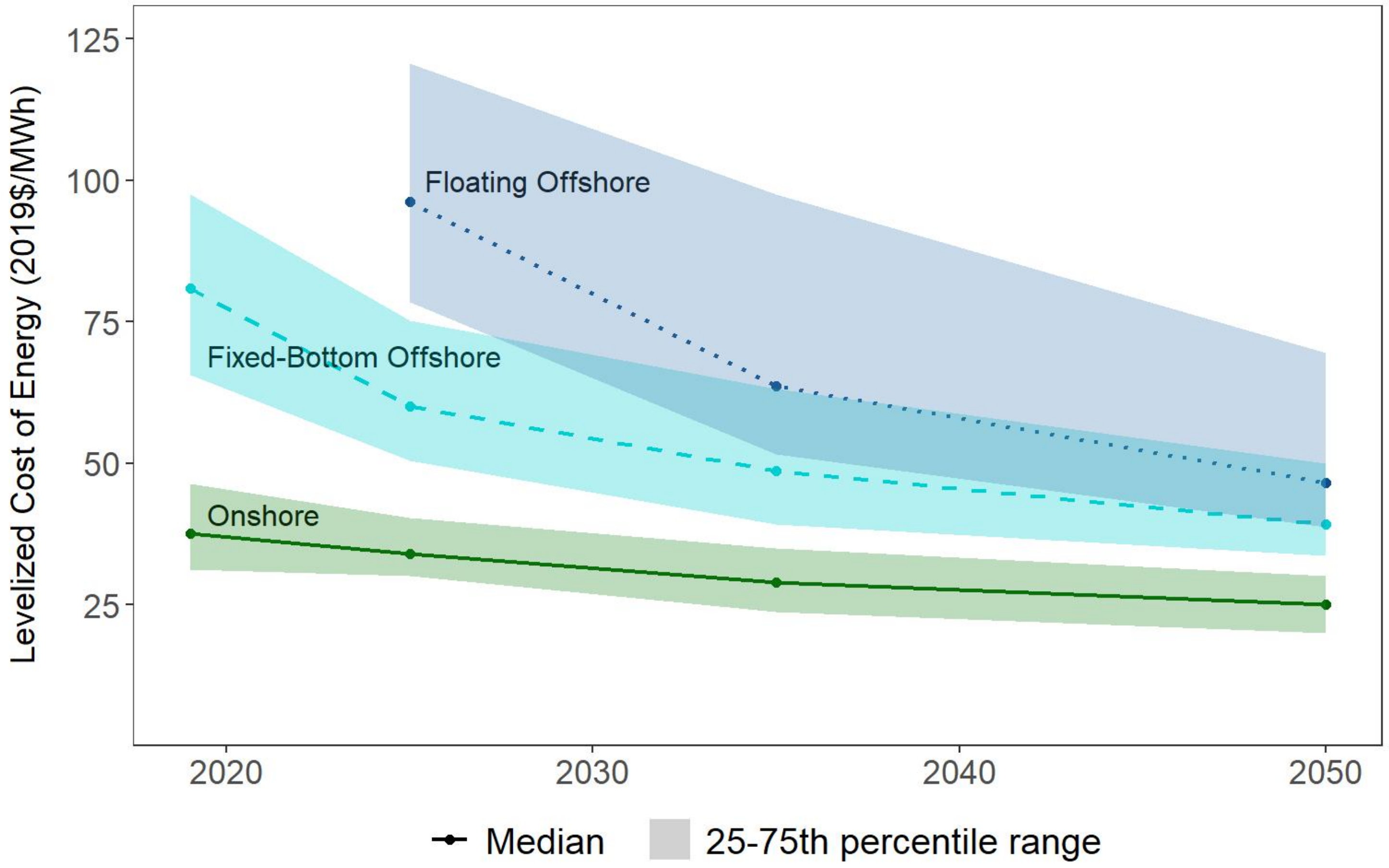
In absolute terms, narrowing gap between onshore & offshore, and fixed-bottom & floating: median scenario

Greater LCOE reductions offshore than onshore

LCOE reductions for floating offshore expected to be especially sizable

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

Not shown: Europe expected to host the lowest-cost fixed-bottom and floating projects



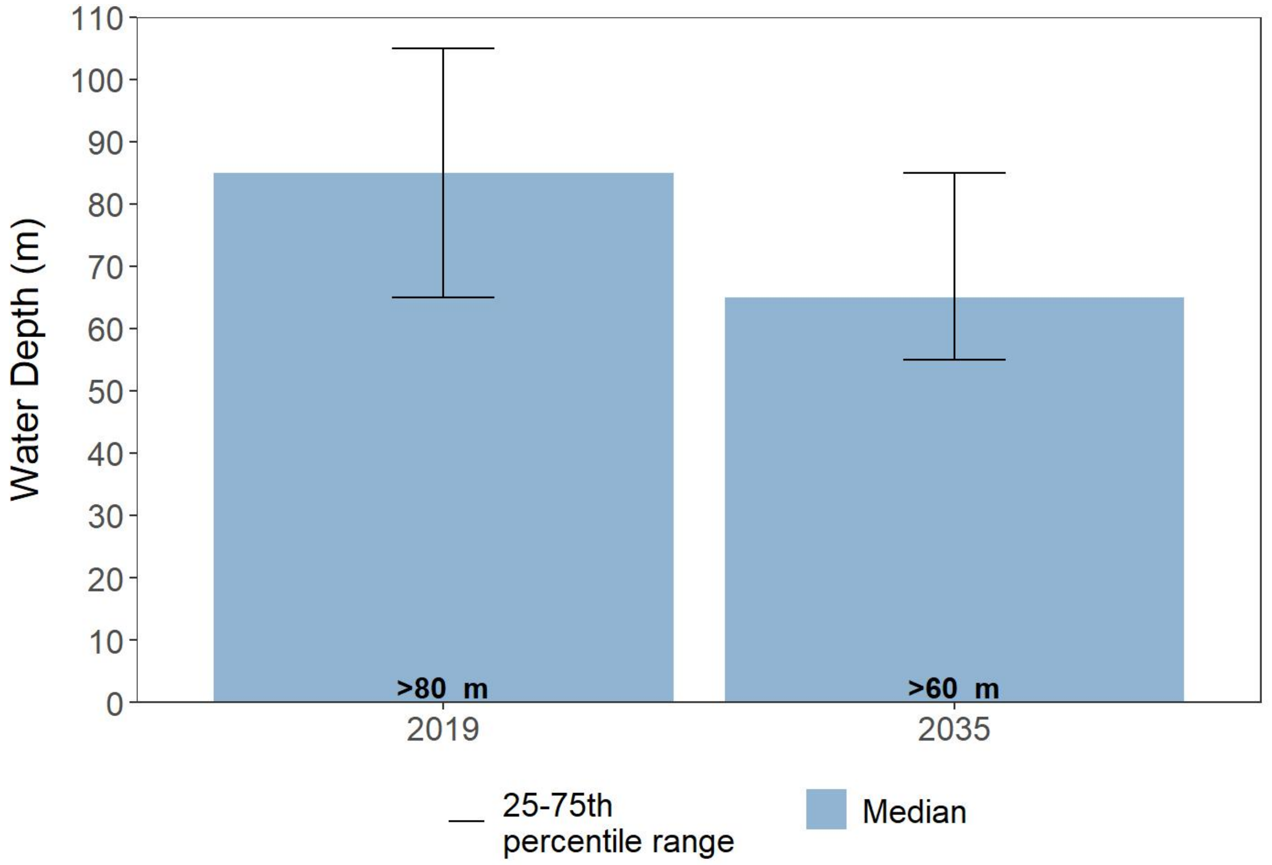
Results assume standardized tax rate (25%), depreciation (20-year straight-line), inflation (2%); exclude interconnection costs outside plant boundary (these interconnection costs tend to be higher for offshore than onshore wind, and should be considered when making overall cost comparisons across wind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

Floating foundations are expected to take a growing share of the offshore market

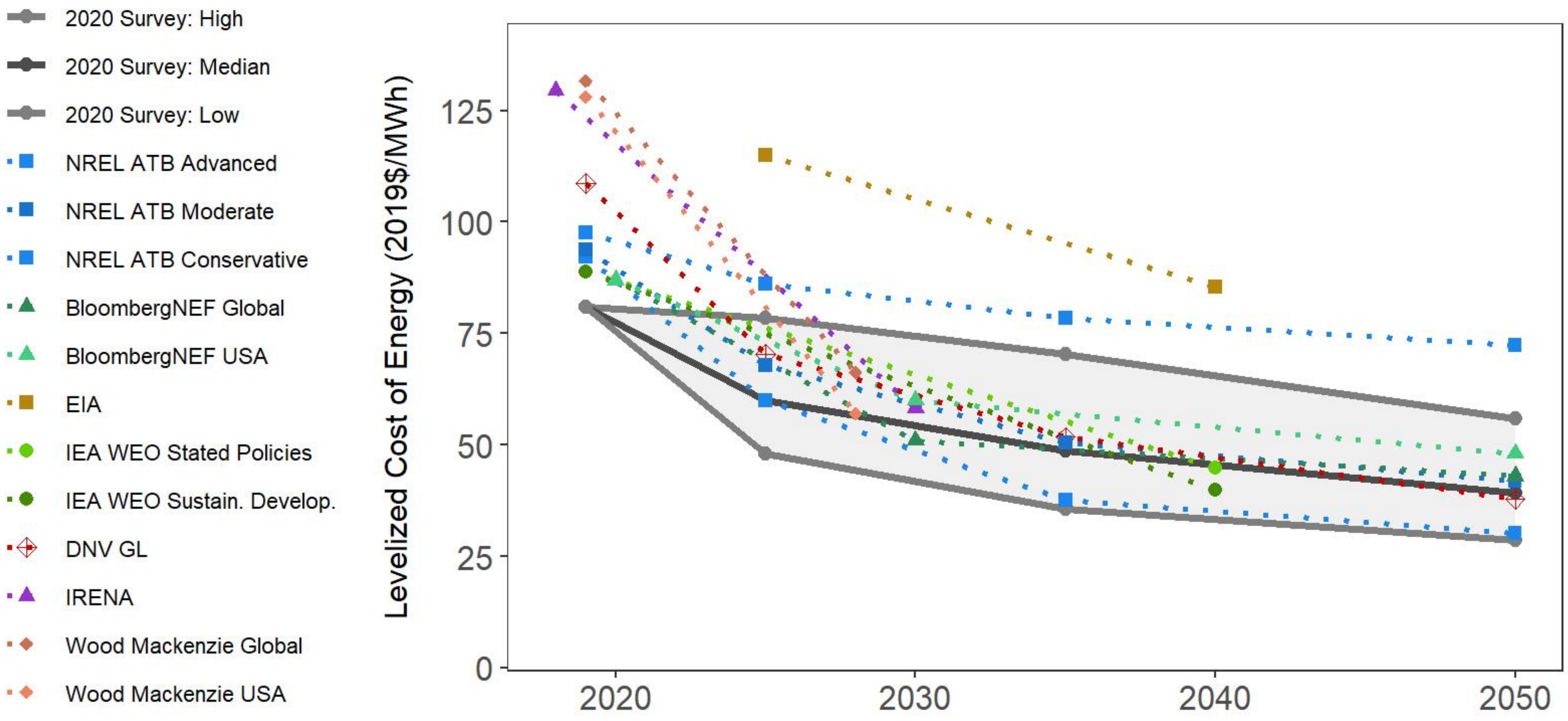
By 2035, the median expert predicts that ***11–25%*** of all new offshore projects globally will feature floating foundations

Wind project developers predict a higher share: median = 26-50%

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



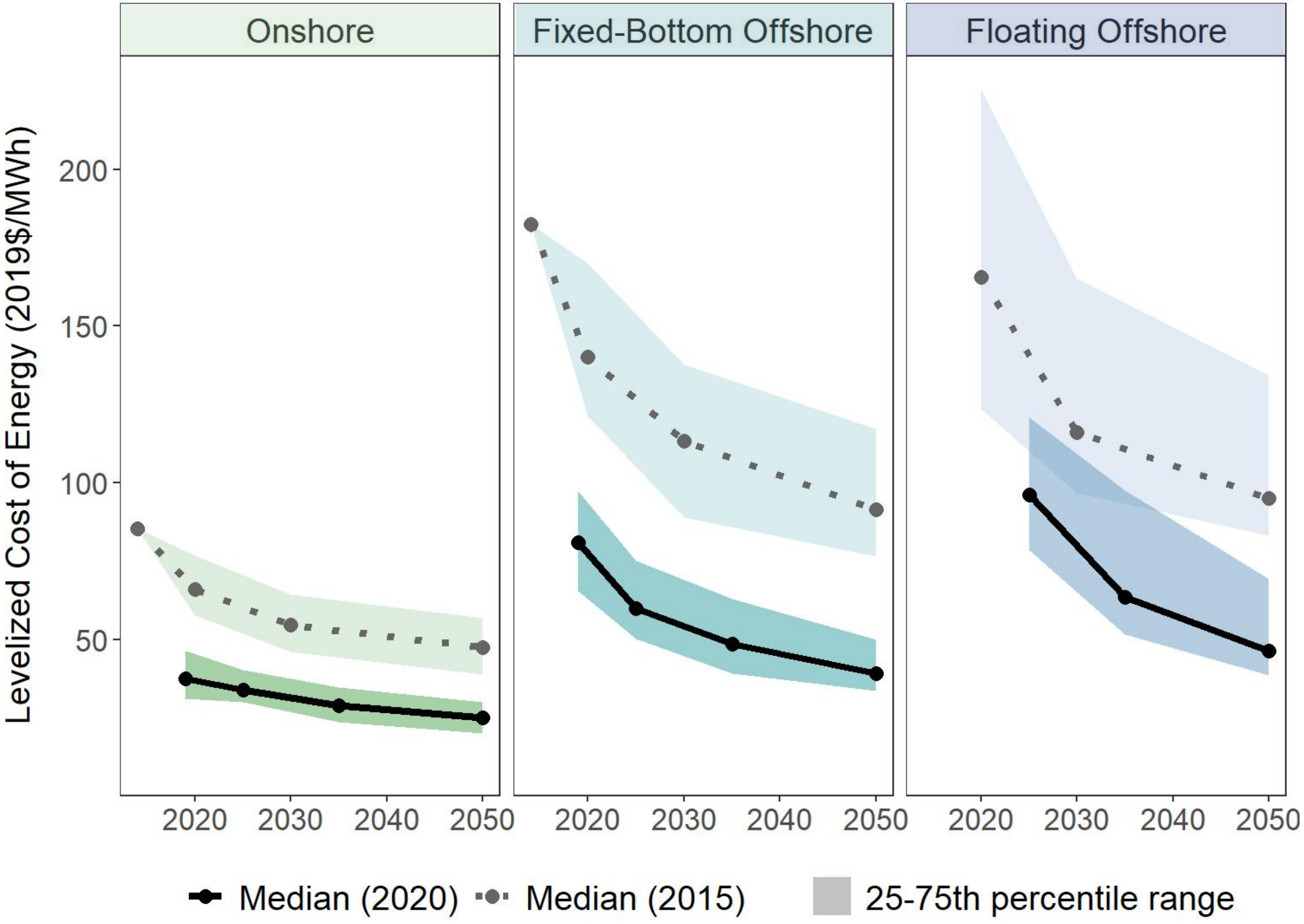
Experts believe costs will be lower than many other recent forecasts in near term, consistent in longer term



Implicit survey-based LCOE learning rate of ~14% for fixed-bottom offshore wind in median-cost scenario

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

PRELIMINARY RESULTS: NOT FOR CITATION



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

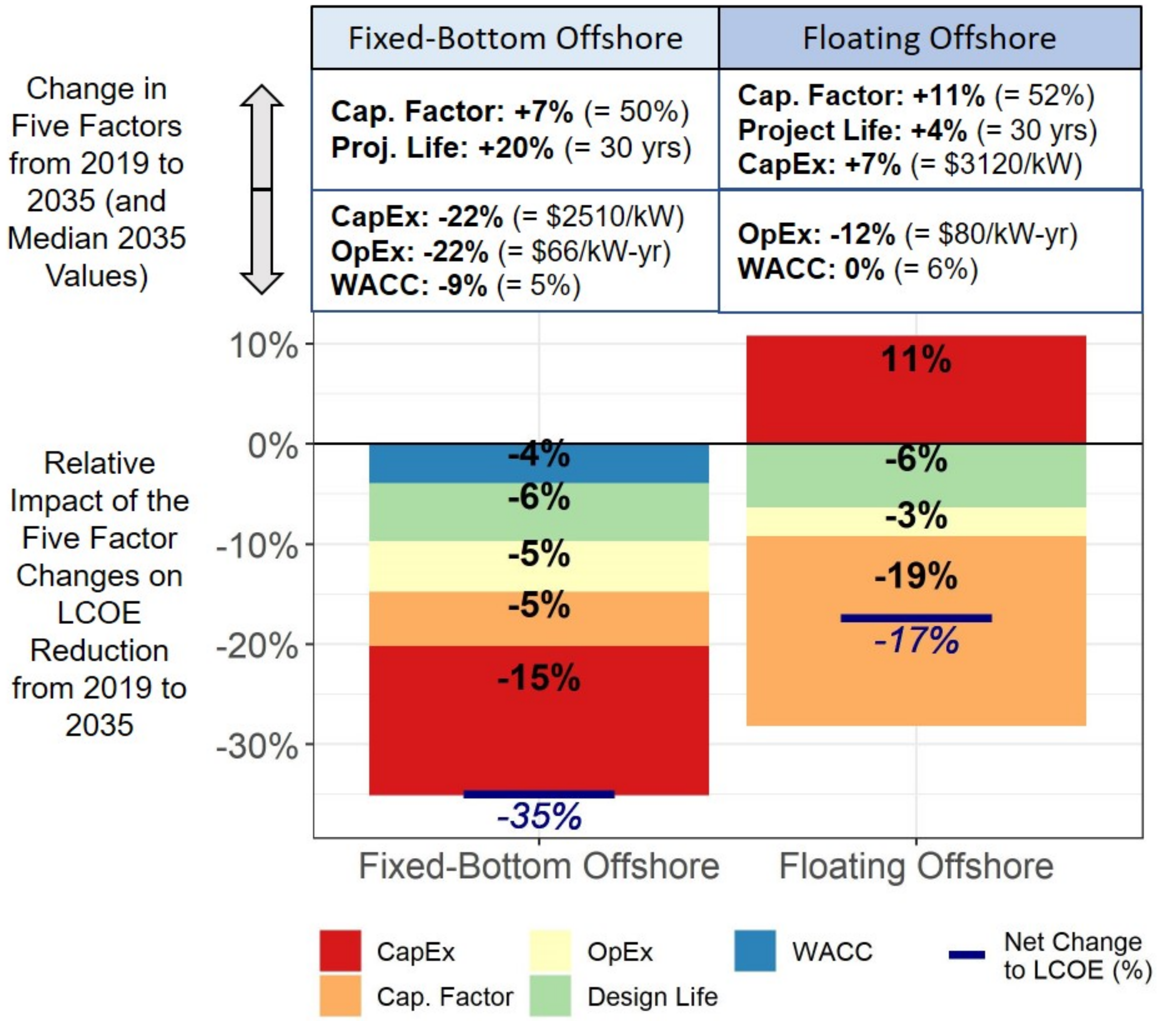
Virtually no overlap between the 25th to 75th percentiles of expert estimates across two surveys

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

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

Typical Offshore Site (newly built in 2035)	**Fixed Bottom** (median)	**Floating** (median)
Distance to Shore	70 km	100 km
Water Depth	42 m	100-199 m
Project Size	900-1299 MW	500-699 MW
Wind Speed (at 100m)	9.5 m/s	10 m/s

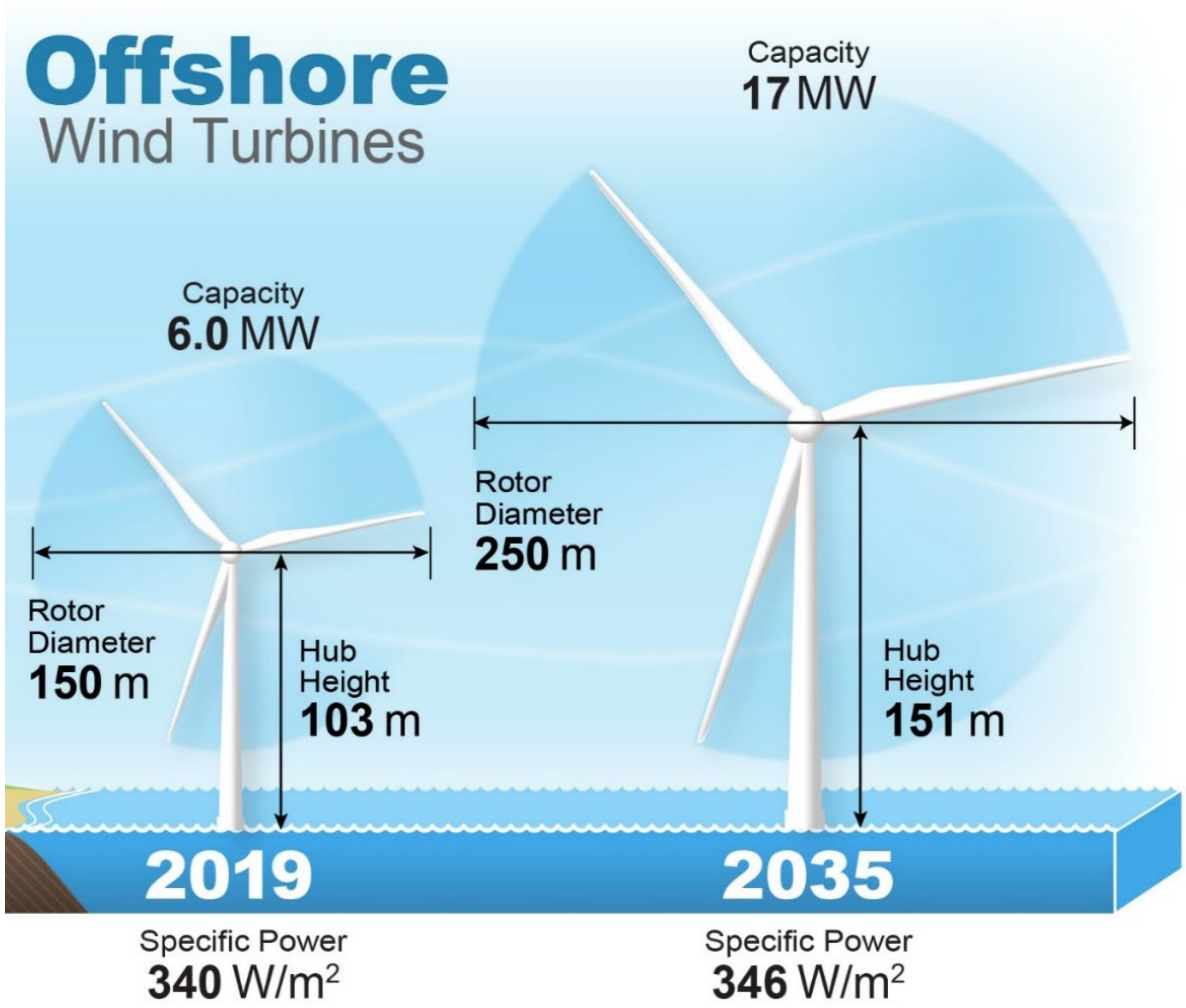
How will we get there? Factor contribution to median scenario LCOE reductions, 2019 to 2035



For **fixed-bottom offshore**, CapEx reductions are viewed as a primary means of LCOE reduction, but important contributions come from all five factors

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

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



Not shown: Somewhat higher capacity ratings expected in Europe

Leading experts predict larger turbines and lower specific power

Manufacturers and developers predict larger turbines than other respondents

Constraints to continued increases in offshore turbine size are diverse, but focus principally on logistics

The primary constraints to further growth in offshore turbine size as cited by the respondents are related to logistics: vessels, cranes, and ports

(*Not shown*: logistics challenges are rated as even more constraining in North America)

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

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

As costs decline, additional focus will turn to the value of wind to the energy system.

Experts anticipate that a large number of value-enhancement options will see significant use (i.e., at more than 10% of new offshore projects installed in 2035), though the majority of experts do not expect to see widespread use of these options (i.e., use in over 50% of projects)

Not shown: greater use of multiple options in **Europe**, including balancing, curtailment, life extension, hydrogen, overplanting; **manufacturers** generally expect greater use of hydrogen and storage hybrids; **public research / universities** more optimistic about life extension and curtailment than private sector

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%

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

Acknowledgements

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.

External Advisors: We also appreciate the large number of external advisors to this effort. For assistance in identifying possible survey respondents and/or the curation of the 'leading expert' group, we thank: Ignacio Martí (DTU), Karin Ohlenforst (Ramboll), Henrik Stiesdal (Stiesdal AS), Mattox Hall (Vestas), Feng Zhao (GWEC), David Weir (Equinor), Pierre-Jean Rigole (Swedish Energy Agency), Franciska Klein (Forschungszentrum Jülich GmbH), Stephan Barth (Forwind), Carlo Bottasso (TU München), Gavin Smart (ORE Catapult), Paul Veers (NREL), Kiersten Ralston (GE), Ashwin Gambhir (Prayas Energy Group), John Hensley (AWEA), Walt Musial (NREL), Guangping Du (CWEA), Aaron Smith (Principle Power), Ivan Komusanac (WindEurope), Alex Lemke (NREL), Joyce Lee (GWEC), and Alyssa Pek (GWEC). For input on survey objectives and design, we also thank Rich Tusing (NREL), Michael Taylor (IRENA), Mark Bolinger (LBNL), John McCann (Sustainable Energy Authority Of Ireland), Karin Ohlenforst (Ramboll), Katherine Dykes (DTU), and Aaron Barr (Wood Mackenzie). We thank Jarett Zuboy for editorial assistance.

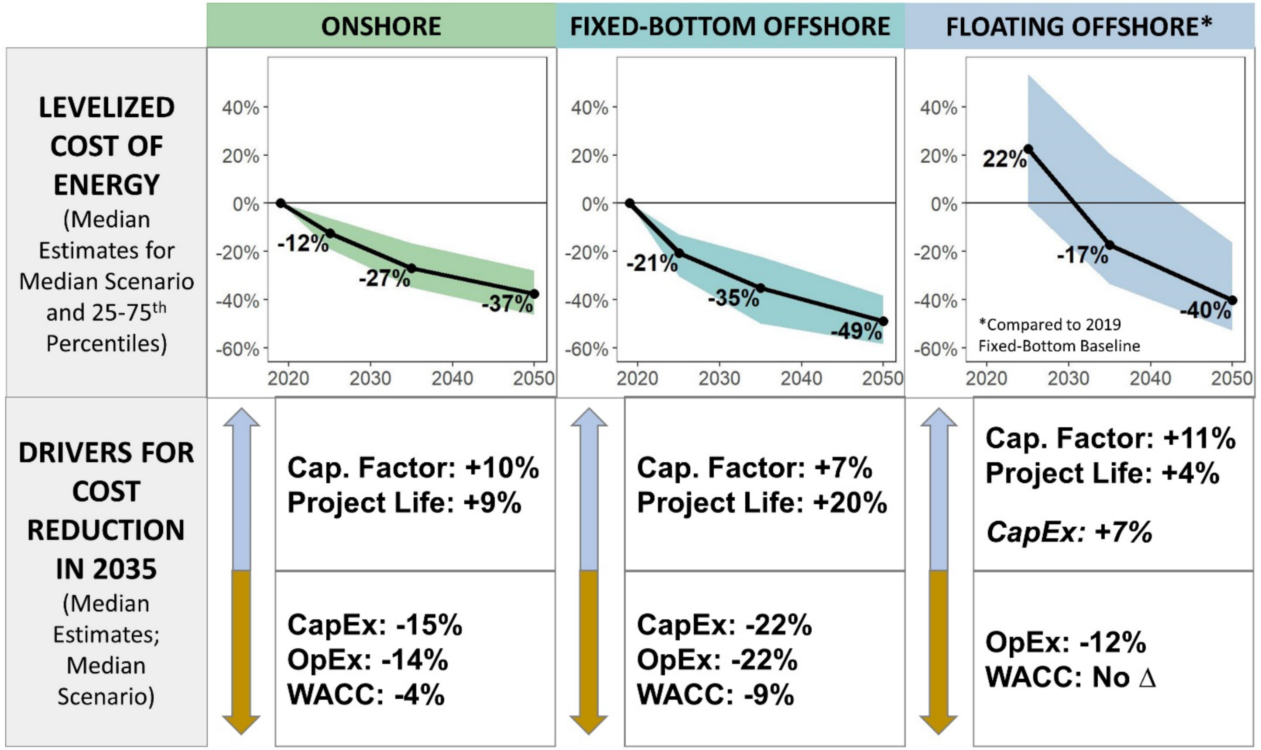
Survey Execution: Ultimately, the survey was implemented online via the Qualtrics survey software but required considerable customization. We greatly appreciate Walker for assistance in survey implementation and execution, with special thanks to Ryne Fanning, John Connolly, and Jeff Wiggington.

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!

Funders: This work was funded by the respective entities in the participating countries of IEA Wind Task 26 on The Cost of Wind Energy. We thank the IEA Wind Executive Committee for supporting this research, particularly those members who sponsor the corresponding research in each of the participating countries. Most significantly, this research would not have been possible without the funding of the U.S. Department of Energy (DOE)'s Wind Energy Technologies Office under Contract No. DE-AC02-05CH11231 (LBNL) and DE-AC36-09GO28308 (NREL).

Contacts for this study

Ryan Wiser, 510-486-5474, rhwiser@lbl.gov
Joe Rand, jrand@lbl.gov
Joachim Seel, jseel@lbl.gov
Philipp Beiter, philipp.beiter@nrel.gov
Eric Lantz, eric.lantz@nrel.gov
Erin Baker, edbaker@ecs.umass.edu
Patrick Gilman, patrick.gilman@ee.doe.gov



For more general information on Berkeley Lab's research

Download publications from the Electricity Markets & Policy Department: https://emp.lbl.gov/publications

Sign up for our email list: https://emp.lbl.gov/mailing-list

Follow the Electricity Markets & Policy Department on Twitter: @BerkeleyLabEMP