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Offshore wind power in the Asia-Pacific: Expert elicitation on costs and policies

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ABSTRACT

Offshore wind power is an important technology option for decarbonising the electricity sector. An emerging region for the deployment of offshore wind is the Asia-Pacific. We conduct an expert elicitation of future cost expectations for offshore wind in the Asia-Pacific region, covering fixed-bottom and floating offshore wind technologies. We also examine views on policies that support the more rapid cost reductions for fixed bottom and floating offshore wind. We find expectations of decreases in the average levelized cost of electricity (LCOE) to USD72/MWh in 2040 (fixed-bottom) and USD81/MWh in 2050 (floating). The largest factors contributing to falling technology costs are identified as installation costs and capital costs for turbines and foundations, along with increased capacity factors. The creation of policy targets along with improved regulatory streamlining are identified as important policy measures that governments could implement to support technology cost reductions. We also find that preferred policy mixes depend on the level of technological maturity. Competitive tendering processes are identified as important for both technologies, but floating offshore wind auctions should be introduced after technology costs have fallen. In the near term, other policies are identified as more important for floating offshore technologies.

1. Introduction

Offshore wind is emerging as a key technology supporting the decarbonization of electricity systems globally (International Energy Agency, 2021). While Europe has led in the development and deployment of offshore wind, markets in North America and the Asia-Pacific region are now emerging as important regions of activity (IRENA, 2021).

The increasing contribution of offshore wind to decarbonization is supported by cost declines (IRENA, 2021; Lee and Zhao, 2021). Increases in the size of wind turbines have reduced balance of system and operation and maintenance costs (Henderson et al., 2003; Shields et al., 2021). Competitive procurement mechanisms are used in multiple countries in order to drive down the Levelized Cost of Electricity (LCOE) for offshore wind, and the share of global capacity subject to auction is expected to rise to 97% by 2030 (Jansen et al., 2020). Governments in numerous markets have also introduced framework legislation, targets for offshore wind deployment, renumeration schemes, and other measures to provide certainty to offshore wind project proponents (IRENA, 2021).

The Asia-Pacific is expected to play an important role in the future development of offshore wind. In 2022 the Asia-Pacific region had 147,082 Megawatts (MW) in its offshore wind project pipeline, against 157, 618 MW in Europe and 40,083 MW in the United States (Musial et al., 2022). The Global Wind Energy Council (GWEC) projects the Asia-Pacific region will account for more than 60% of total global installations by 2050, followed by Europe and North America (Lee and Zhao, 2021). Floating offshore wind technologies are an important technology in the Asia-Pacific, enabling the deployment of offshore wind at greater water depths and unlocking larger maritime areas for development (Musial et al., 2021).

Despite this progress there remains uncertainty about future offshore wind technology costs. Supply chains are immature across the Asia-Pacific region, and future innovation in floating offshore wind technologies will be important for Asia-Pacific markets where near-shore opportunities are lower. Further, policy frameworks that provide the context within which offshore wind projects are developed differ markedly across markets, and poorly designed public policies can limit opportunities to lower technology costs (Santhakumar et al., 2021).

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Uncertainty about policy support schemes can affect the costs of capital, which is an important factor determining overall technology costs (International Renewable Energy Agency, 2023, 18).

In this paper we answer two questions. What are the expected changes in the future technology costs of fixed-bottom and floating offshore wind in the Asia-Pacific? And what policies are expected to support reductions in offshore wind technology costs in the region? To answer these questions we implement an expert elicitation of expectations of future offshore wind technology costs, with a geographic focus on the Asia-Pacific. We also ask experts about their views on policies that would support future reductions in costs. We separate the analysis into the commercially mature fixed-bottom offshore wind industry segment, and the less mature floating offshore wind technologies.

We find the mean expectation for the LCOE of newly installed fixed-bottom offshore wind is USD72.50 per Megawatt hour (MWh) by 2040, and the LCOE of newly installed floating offshore wind by 2050 is USD81.40/MWh. This suggests there is an expectation that floating offshore wind will approach competitiveness with fixed-bottom offshore wind in the long-run. We find relative agreement that the largest factors contributing to falling technology costs are reductions in installation costs and capital costs for turbines and foundations, along with increased capacity factors.

We also find relative agreement about the policy measures that would reduce offshore wind technology costs, but with differences between fixed-bottom and floating offshore wind. Respondents selected policy targets and regulatory streamlining as important measures to support reductions in technology costs, suggesting an ongoing need for governments to ensure policy credibility and certainty. For fixed-bottom offshore wind experts selected the near-term use of competitive auctions as important, along with the provision of economic incentives such as renumeration schemes. For floating offshore wind technologies experts noted the importance of continued research, development, and deployment support in the near-term, with competitive auctions identified as important over the long term. This implies the importance of distinguishing policy supports between fixed-bottom and floating offshore wind, and the importance of sequencing forms of policy support.

Our research is distinguished by three contributions. First, the future cost trends for offshore wind is understudied, as are the factors contributing to changes in technology costs (Santhakumar et al., 2022). We collect and analyze expert views about expectations for offshore wind power technology costs with a specific focus on the Asia-Pacific region, complementing studies that focus on Europe, or that are global in scope (Henderson et al., 2003; Rentier et al., 2023; Santhakumar et al., 2022; Santhakumar et al., 2021; Schwanitz and Wierling, 2016; Vieira et al., 2019; Voormolen et al., 2016; Wiser et al., 2021). Obtaining estimates from experts with specific knowledge about Asia-Pacific markets is important because of the projected importance of the region for future deployment of offshore wind, and the significance of the region to decarbonization globally.

Second, we show long-run expectations of cost declines in the Asia-Pacific, improving the competitiveness of both fixed-bottom and floating offshore wind technologies. The mean assessment of the size of cost declines for fixed-bottom and floating technologies is −38 to 47 percent by 2040 and 2050 respectively. We compare our results with auction outcomes reported by Jansen et al. (2020) and the expert elicitation by Wiser et al. (2021), which is a global survey of expected offshore wind technology costs with a preponderance of experts from Europe and North America. Cost declines and drivers of reductions in LCOE were similar, suggesting an expectation that trends for offshore wind in other markets will support cost reductions in the Asia-Pacific region. Expert assessments of future costs nevertheless remain high relative to auction outcomes in the mature European markets, and future research can investigate the reasons for these differences.

Legal and policy frameworks in many markets in the Asia-Pacific region vary markedly, and remain under development. The third contribution is our focus on which policy mechanisms experts believe will help support technology cost reductions for offshore wind. Preferred policy mixes depend on the level of technological maturity, which suggests policymakers should focus on general policy approaches such as reducing regulatory complexity, while also developing policy mixes targeting each of the technology platforms.

In the next section we describe trends in prices and policies in the offshore wind sector globally, developments in Asia-Pacific markets, and the state of knowledge in relation to offshore wind technology costs. We then describe in detail the specific method and protocols used to implement the expert elicitation survey, before presenting the results. A discussion section concludes.

2. Offshore wind in the Asia-Pacific

Installed offshore wind capacity reached 56 GW globally in 2021, with Europe representing the largest share at 50.4%, followed by the Asia-Pacific with 49.5% of total capacity. Based on the project pipeline and declared targets, the Global Wind Energy Council expects installed capacity to reach 370 GW by the end of 2031, with China making up 34%, and non-China Asia-Pacific markets representing an additional 11% of total installations. Offshore wind's share of total installed wind capacity is projected to be at least 30% globally by the same year (Global Wind Energy Council, 2022).

Offshore wind deployment has been supported by falling technology costs. IRENA (2021) finds the mean LCOE of offshore wind was USD162/MWh in 2010, falling to USD84/MWh in 2020. The reduction represents a fall of 48% when weighted by the capacity of the offshore wind plant. While the mean LCOE for offshore wind has fallen, there are differences across markets. In 2010, the LCOE ranged from USD111/MWh (Denmark) to USD215/MWh (Japan), although the range had narrowed to between USD84/MWh (China) and USD115/MWh (United Kingdom) by 2020 (IRENA, 2021). Voormolen et al. (2016) suggest differences in national policy frameworks contribute to variation in LCOE values across Europe, and that shortening the time required for project delivery can support lower offshore wind technology costs. For floating offshore wind farms the primary determinants of the LCOE are identified as manufacturing costs, including the cost of wind turbines, substructures and mooring systems (Lerch et al., 2018).

Public policies play an important role in supporting reduced technology costs for offshore wind. IRENA (2021) identifies best practice policies as including policy targets such as establishing goals for offshore wind under construction or operating, offering early stage technology support, and establishing legal frameworks specific to offshore wind. Jansen et al. (2020) show that administrative price support schemes such as a FIT were used by governments to support the deployment of offshore wind in early stages of market development, and that competitive award mechanisms are now emerging as the dominant approach. Đukan and Kitzing (2021) find auctions can improve the costs of capital for offshore wind projects by reducing planning risk. In an assessment of auction outcomes for offshore wind, Jansen et al. (2020) find offshore wind is commercially competitive in mature markets in Europe.

Governments in some Asia-Pacific markets have already implemented policy frameworks specific to offshore wind. A common policy instrument is the establishment of long-term deployment targets (Table 1), combined with additional policy support measures. The largest market in the region and globally is the People's Republic of China (PRC). The government of China established a 1 GW deployment target for 2010 in the 11th Five Year Plan of Renewable Energy Development, rising to 5 GW by 2020 under the 13th Five Year Plan of Wind Power Development. Administrative price support was initially provided through a Feed-In-Tariff (FIT), which was phased out for projects connecting to the transmission grid after 2021 (de Castro et al., 2019a, b; Li, 2022). Taiwan is a second lead market for offshore wind in the

Table 1
Selected offshore wind deployment targets in Asia-Pacific markets.

Market	Long-term Deployment Target	Source
Australia	9 GW by 2040[a]	State Government of Victoria (2022)
China	Over 150 GW included in provincial government targets	Musial et al. (2022)
India	30 GW by 2030	Krishnan et al. (2022)
Japan	30–45 GW by 2040	Li (2022)
South Korea	13 GW offshore wind by 2030	Park and Kim (2019)
Taiwan	15.5 GW by 2035	Gao et al. (2021a)
Vietnam	1 GW by 2030	Do et al. (2022)

[a] State government of Victoria deployment target.

Asia-Pacific, where the government introduced a deployment target of 40 GW by 2050, of which 15 GW is to be developed between 2026 and 2035 and a further 5.5 GW allocated to commence operations by 2025. Developers have been supported by a FIT, with development rights allocated through a mix of direct selection including the application of Local Content Requirements (LCRs), and competitive auctions to support local supply chain development (Gao et al., 2021a, b). In the case of Japan, policy certainty is provided through a capacity target of 10 GW under development by 2030, and 30–45 GW under development by 2040, coupled with a long-term price target for offshore wind of 8 to 9 yen per kilowatt hour by 2030. The government initially supported deployment through an administratively-set FIT, followed by the use of a competitive auction to set a FIT price and to allocate development rights in pre-specified zones, and shifting to the use of a Feed-in-Premium (FIP) for fixed-bottom offshore wind projects from 2023 (Hughes et al., 2022). Governments in South Korea, Vietnam and Australia have also developed legal and regulatory frameworks supporting of offshore wind (Briggs et al., 2021; Do et al., 2022; Ha-Duong et al., 2021; Park and Kim, 2019). Governments in the region are also revising initial policy frameworks, although Voormolen et al. (2016) warn policy instability had a negative impact on offshore wind costs in Europe. Poorly designed policy frameworks can also slow project development and limit opportunities for reducing technology costs (Santhakumar et al., 2021).

Competitive auctions are increasingly used by governments to support renewable energy deployment, including for offshore wind. In some Asia-Pacific markets, competitive auctions have been used to allocate development rights and set support rates. Auction results have realized lower winning bid prices than administratively-determined renumeration schemes, which suggests technology costs have fallen over time. In China, for example, the 2019 winning auction bid prices were 6–11% lower than the 2014 FIT rate in nominal terms, while in Taiwan the average winning bid in the first auction was almost 60% lower than the 2018 FIT rate in nominal terms (Jansen et al., 2020). In Japan, round one auction results announced in December 2021 were 61% lower than the administratively-determined FIT applied prior to the introduction of the auction framework.[1]

Changes in future technology costs nevertheless remain uncertain. In Europe, for example, Santhakumar et al. (2021) find offshore wind technology costs increased between 2000 and around 2013 before observing a rapid decline. Vieira et al. (2019) find a similar pattern for capital costs, which rose between 2000 and 2015 before beginning to decline. Santhakumar et al. (2022) find capital expenditures increased between 2000 and 2010 in the early stages of offshore wind development in Europe and the United Kingdom, leading to an increase in LCOE, with declines attributable to improved financing, increased capacity factors, and falling operational costs.

Navigating this uncertainty and planning for future investments requires information on expected future technology costs. Accordingly, we use expert elicitation to assess expectations for future technology costs for offshore wind in the Asia-Pacific. In the next section we outline the method used to collect expert opinions on these questions. We then describe the results. The full survey used in eliciting expert views is included in the annex to the manuscript.

3. Methodology

We developed an online survey to elicit estimates of the LCOE for fixed-bottom and floating wind projects across the Asia-Pacific region. The survey also focused on the contributors to technology cost declines, and policies that could support a reduction in the offshore wind technology costs.

Expert elicitation is used as a method for understanding technology cost trajectories under conditions of uncertainty, and is applied to emerging technologies where estimates may not obtainable through other empirical approaches (Verdolini et al., 2015a). Expert elicitation can also be used to obtain judgements about factors that may affect future cost trajectories, and can complement other methodologies that inform decision-making (Whiston et al., 2022). Expert elicitation methods have been used to examine the future costs of many low carbon energy technologies, including solar photovoltaics (Verdolini et al., 2015b), concentrated solar power technology (Bosetti et al., 2012; Lam et al., 2018), coal power and carbon capture and sequestration (Chan et al., 2011), and fuel cell electric vehicles and advanced biofuels (Fiorese et al., 2013). Expert elicitation approaches have also been widely used to estimate capital costs for renewable energy technologies, as summarized in Steffen (2020).

In the case of wind power technologies, a 2021 study used expert elicitation to assess future wind energy costs for onshore and offshore wind globally, finding expectations of large declines in the costs of wind energy by 2050 for onshore wind, and for fixed-bottom and floating offshore wind (Wiser et al., 2021). Expert elicitation has also been used to inform assessments of the role of renewable energy technologies, including offshore wind power, in future energy mixes. Kanyako and Baker (2021), for example, use expert elicitation results as an input into the Integrated Assessment Model the Global Climate Assessment Model (GCAM) to estimate how changes in the future costs of wind power, including offshore wind, affect global electricity generation. Another example used an expert elicitation to set the learning rate for batteries used in electric drive vehicles to model transport sector decarbonization within the World Induced Technical Change Hybrid (WITCH) model (Bosetti and Longden, 2013).

Expert elicitation differs from survey methodologies in which a sample is taken in order to study an underlying population of interest, with the sample size determining statistical confidence. Instead, respondent views incorporate expert information about the relevant technology space or policy area, and there is no established number of experts required for a study to be valid. Rather, selecting a qualified and diverse group of experts increases confidence judgments provided are credible and representative (Verdolini et al., 2015b).

We implement an expert elicitation survey focused on identified

[1] The FIT rate was fixed at 36 yen/kWh, while the winning bids were 13.26 yen/kWh (Noshiro), 11.00 yen/kWh (Yurihonjo), and 16.49 yen/kWh (Choshi). The auction for Goto City, Nagasaki Prefecture is excluded from the calculated as the FIT rate was fixed, with competition occurring under qualitative elements of the auction scheme only.

experts to examine expectations of LCOE for fixed-bottom and floating offshore wind technologies in the Asia-Pacific region, and to identify views on appropriate policy frameworks needed to support reductions in technology costs. Given our focus on technology costs and policy options, we elicited views from experts working in industry, government, and academia, policy, and think tanks. Respondents were asked to select their area of expertise, and were only asked questions relevant to that area. Thus, if the respondent selected their expertise was in floating offshore wind technologies, they were asked questions relevant to floating offshore wind only. Experts who selected 'policy only' were only asked about policy options for lowering offshore wind technology costs.

3.1. Survey design

The survey was self-completed. After agreeing to participate, respondents were asked a series of questions about their expectations for future costs of offshore wind technologies, and their views on appropriate policy frameworks to support cost reductions for offshore wind.

We used a separate consent form that asked for personal details about the expert (i.e. email address, organization they worked for, and position), which were optional, and the expert was able to inform us how we could use this information. An overview of the survey design is provided in Fig. 1. The full list of questions are provided in the annex, showing how questions were presented to the experts based on their areas of expertise.

As the survey was self-completed, we created an innovative design for the second and third survey blocks. In these survey blocks, which only appeared if the expert had selected these as areas of expertise, we first asked for a base year estimate (2025 [fixed-bottom]/2030 [floating]) for the LCOE of fixed-bottom/floating wind projects using a sliding scale. Then, we included two follow-up questions with a drop-down menu of percentage decreases between 5% and 95% for a future year (2030 [fixed-bottom]/2040 [floating]) and another drop-down menu of possible percentage decreases for the next year of interest (2040 [fixed-bottom]/2050 [floating]). This second set of menu options were based on the initial percentage decrease selected, so if the expert had chosen a 10% decrease by 2030/2040, the range of possible percentage decreases presented for the next year of interest was 15%–95%. The options started with a 1% decrease and then a 5% decrease and all subsequent 5% decrease options until the maximum of 95%. For example, if an expert selected 1% in 2030, they were then presented with 20 options for 2040, which started from 1%, then 5% and the 18 increments of 5 percentage points until the maximum reduction (95%). Our approach was designed to show the expert a constrained but wide range of possible options, and to minimize confusion across the questions. All options were shown to all experts and, due to the expectation of a small sample size, there was no experimentation with the options provided to survey respondents.

The second group of questions asked respondents to consider which policies they expect to reduce fixed-bottom and floating offshore wind technology costs. We focused on the role of public policy because of the early stage of market development in many Asia-Pacific markets, and the importance of policy settings in supporting falling technology costs identified in the literature (Santhakumar et al., 2021). Choices available to respondents were chosen from a subset of IRENA recommendations for best-practice policies for supporting offshore wind deployment centered on the use of policy targets, competitive auctions, financial incentives such as FITs, support for innovation, and regulatory streamlining (IRENA, 2021).

3.2. Survey respondents

We sent out 133 invitations to complete the survey using the online survey platform Qualtrics. Details of the survey respondents are shown in Tables 2 and 3 below. A total of 22 responses were received, which is a response rate of 17%. This is similar to the response rate of other studies (Wiser et al., 2021). Seven respondents were experts with knowledge of Australia and 15 were experts focusing on countries in Northeast Asia, South Asia, and Southeast Asia (Table 2). Eight experts worked in industry, six worked in consultancies, and six worked in academia (Table 3). Nine experts self-identified as policy experts and did not provide an estimate of the LCOE of wind projects. We asked whether we could identify the organizations that these experts worked for and 13 agreed. Table 3 shows that we surveyed experts from a range of well-known and reputable organizations. Respondents were not required to answer all questions, meaning the number of responses changes by question. The number of respondents (n) is shown when relevant in the graphics below.

In the first group of questions we asked respondents to consider factors that contributed to the LCOE for offshore wind technologies, including capital costs, operating and maintenance costs, project capacity factor, project lifetime, and the cost of financing. Respondents were provided with recent data on the LCOE for offshore wind in selected countries to support their assessment of cost pathways, and were then asked for their assessment of future technology costs for different years. Respondents were then asked which factors they expected to make the largest contribution to future cost declines in fixed-bottom and floating offshore wind technologies.

In the next section we discuss the results of the expert elicitation. We begin with a discussion of the results for assessments of LCOE for fixed and floating offshore wind technologies. We then discuss expert opinions on appropriate policy measures for supporting the deployment of offshore wind in the Asia-Pacific region.

4. Results

4.1. Fixed-bottom offshore wind technologies

For fixed-bottom offshore wind projects, experts provided an average estimate of USD116/MWh for 2025, USD92/MWh for 2030 and USD72/MWh for 2040 (Fig. 2). There are important differences between LCOE estimates and auction results that make them not directly comparable (Đukan and Kitzing, 2021). The average estimate for 2025 is nevertheless within the range of auction bid outcomes shown in Fig. 2a for the Asia-Pacific region as reported in Jansen et al. (2020), where the unweighted mean reported auction outcome was USD128, and where the range of bids in China (2019–2020) was USD105-127/MWh, for Taiwan (2018) between USD74-184,[2] and for Japan between USD112-154/MWh.[3] There was a convergence in the average estimate for 2040 to between USD68 and 76/MWh. This is consistent with a view that falling technology costs, improving financing conditions, and other factors are judged to be more significant than the investment environment in different markets in determining the long-run costs of offshore wind technology.

In Fig. 2b we also compare the estimates of our experts to those in Wiser et al. (2021). Our estimates are within the range of Wiser's for fixed-bottom offshore projects in the Asia-Pacific in 2025, but then follow the 75th percentile estimates. In this study the 75th percentile for fixed-bottom offshore projects in the Asia-Pacific in 2025 was USD163/MWh and the median was USD110/MWh. The 75th percentile for fixed-bottom offshore projects in the region for 2050 was USD69/MWh, and the median was USD39/MWh. The differences in our results could be associated with countries the estimates apply to, experts' areas of expertise, and/or their organizations. For example, our experts for Taiwan, South Korea, and Japan provided an estimated

[2] Auction results drawn from Jansen et al. (2020), and converted into US dollars from Euros using the mean exchange rate for EUR/USD for 2020.

[3] The auction for the floating offshore wind project off Goto City is excluded as the bid price was fixed, with competition occurring over non-price elements in the auction only.

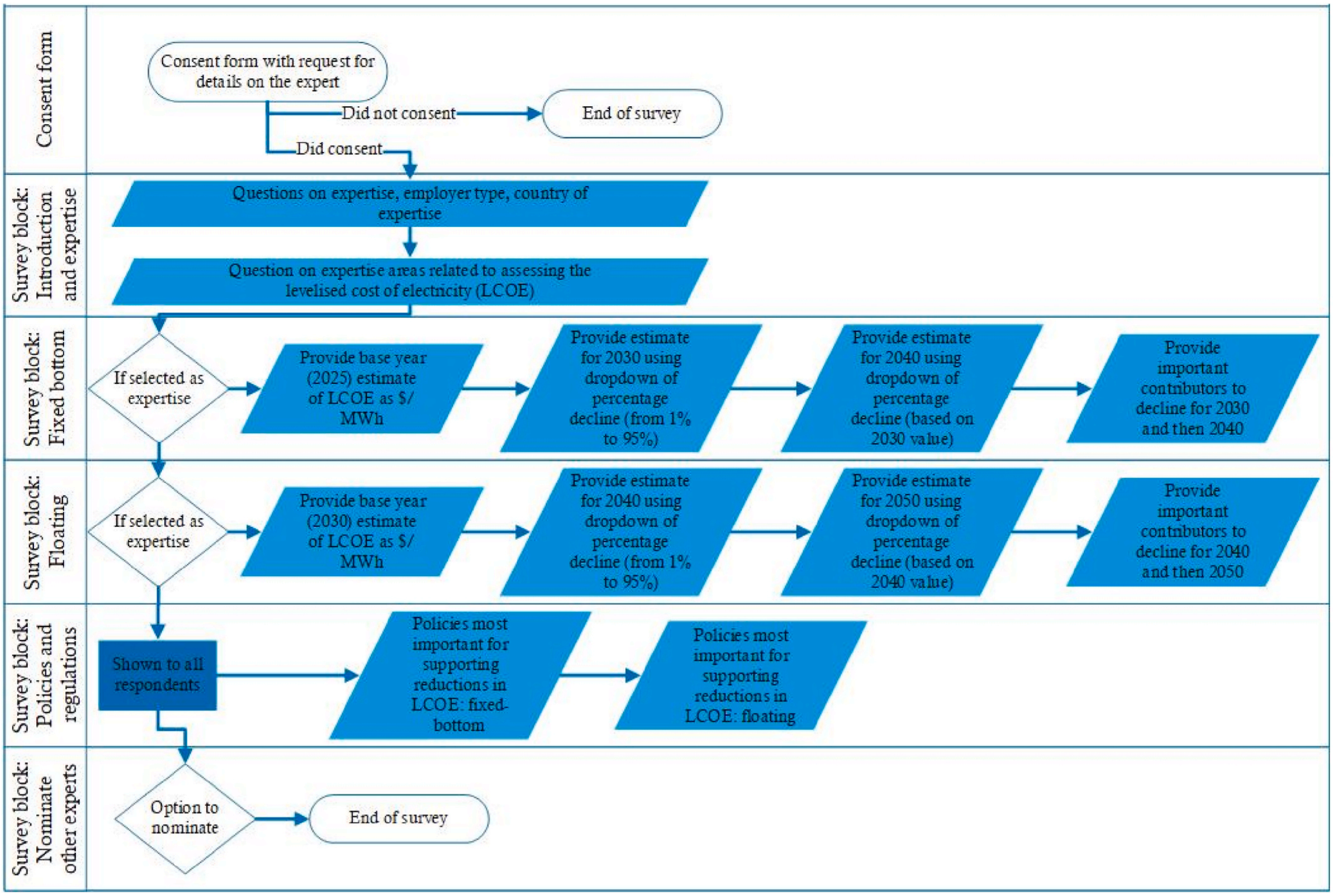

Fig. 1. Survey design and the structure of the questions presented to experts.

Table 2
Breakdown of respondents.

Region/Country	Number
Australia	7
Northeast Asia	7
South Asia	3
Southeast Asia	5
Total	22
Expertise area	**Number**
Fixed-bottom only	5
Floating only	1
Both	7
Policy only	9
Total	22

−31% in LCOE between 2025 and 2050. This is less than the −52% to −58% decrease in the 25th and 75th percentiles of LCOE estimates from experts in the Asia-Pacific reported in Wiser et al. (2021), as shown in pink shading in Fig. 2. However, it is similar to the decrease drawn from the broader expert sample, which was primarily focused on the European and North American markets, i.e. −23% to −28% between 2025 and 2050 (Wiser et al., 2021).

Respondents were also asked which factors would contribute to cost declines for fixed-bottom technologies to 2030 (Fig. 3). Respondents could select up to three factors from a list. For fixed-bottom technologies, falling installation costs were identified as important by the largest number of respondents. This is consistent with the expectation that costs will fall as a function of deployment as project developers, governments and other stakeholders, learning through the development of projects. Capacity factors, which are affected by site location, was also identified as important.

The next most frequently identified factors contributing to near-term

Table 3
Breakdown of employer types and organizations.

Type of employer	Number	Organizations
Industry	8	Equinor New Energy; National Energy Resources Australia (NERA); Ørsted; RWE Renewables
Academia	6	Harvard Kennedy School; Macquarie University; University of Melbourne
Consultancy	6	Pondera Consult; The Renewables Consulting Group; WSP
Government	5	No experts allowed disclosure
Think-tank	2	Beyond Zero Emissions; Council on Energy, Environment and Water (CEEW)
Total	26*	

Note: * Some experts had multiple employers so the total for employer type is higher than 22. Organizations shown for the 13 experts who allowed this information to be made public via the consent form.

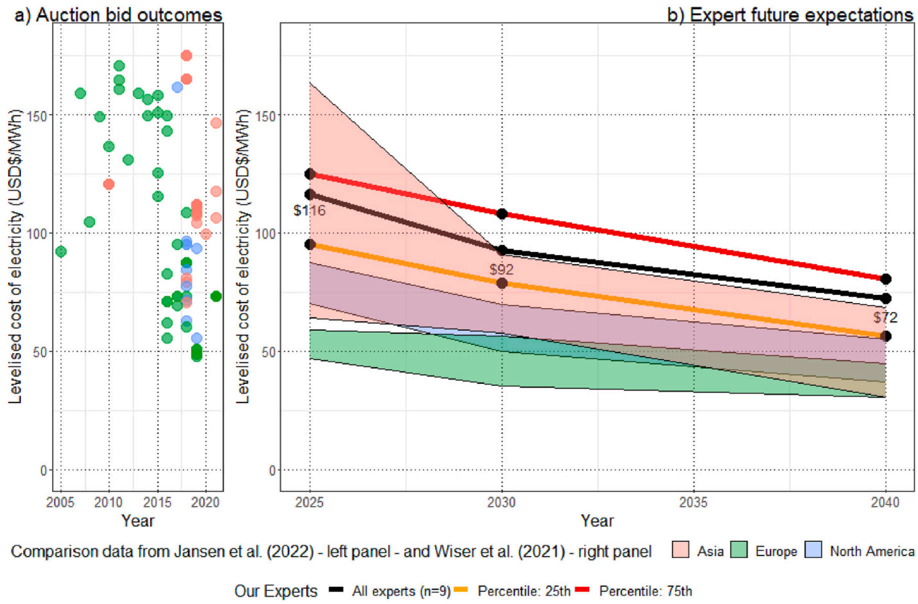

Fig. 2. LCOE for newly installed fixed-bottom projects – average by region.

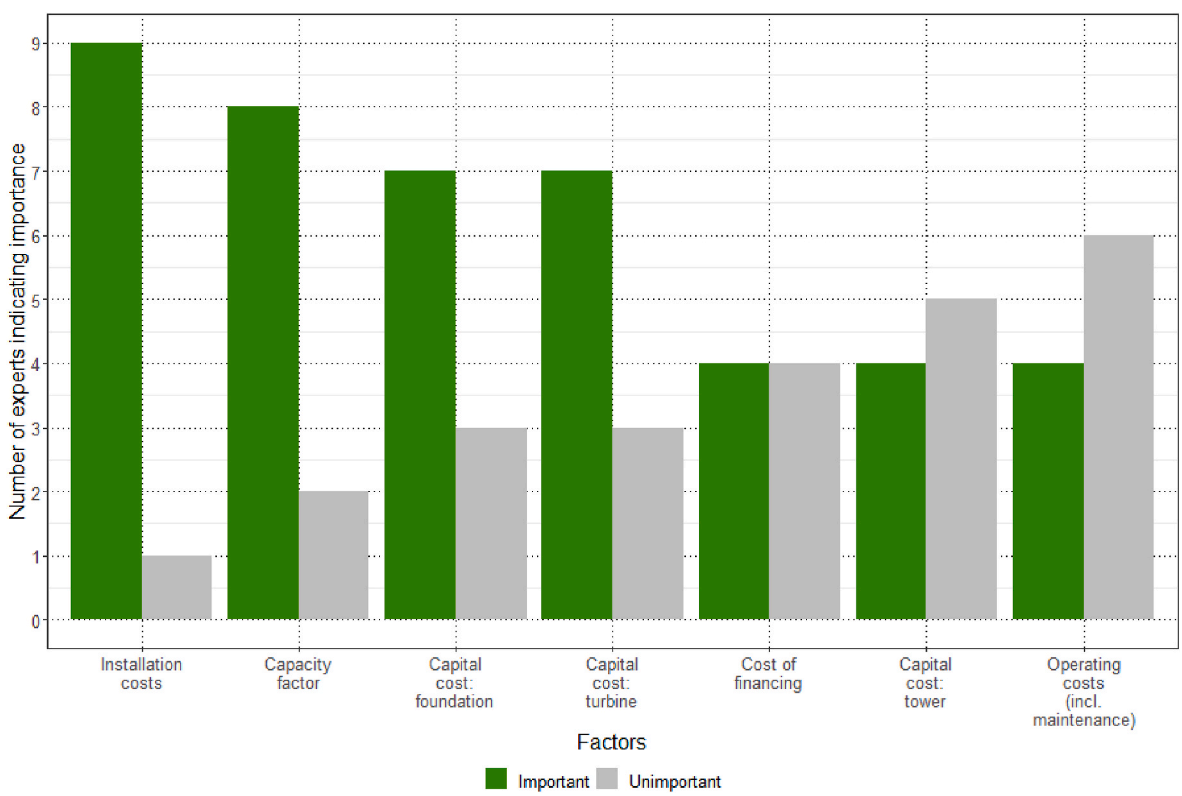

Fig. 3. Factors contributing to cost declines in fixed-bottom technologies by 2030.

falls in the LCOE for fixed-bottom offshore wind were capital costs for turbines and foundations. There was less agreement about the importance of falling financing costs, and the costs of capital for towers. Fewer experts also identified falling operating and maintenance costs as important, suggesting an expectation that increased deployment will reduce installation costs but may not contribute to falling operating and maintenance costs.

The third group of questions asked respondents to identify policies they believe will contribute to reducing the LCOE for fixed-bottom offshore wind technologies, in the near-term to 2030 (Fig. 4), and after 2030 (Fig. 5). Respondents were able to choose up to three policy types that in their view were most important in supporting reductions in LCOE.

As Fig. 4 shows, near-term policies identified as most important were the introduction of a regulatory one-stop-shop or regulatory streamlining and the creation of policy targets suggesting the importance of reducing regulatory risks in supporting reductions in the LCOE of fixed-bottom offshore wind. There was less unanimity, although still

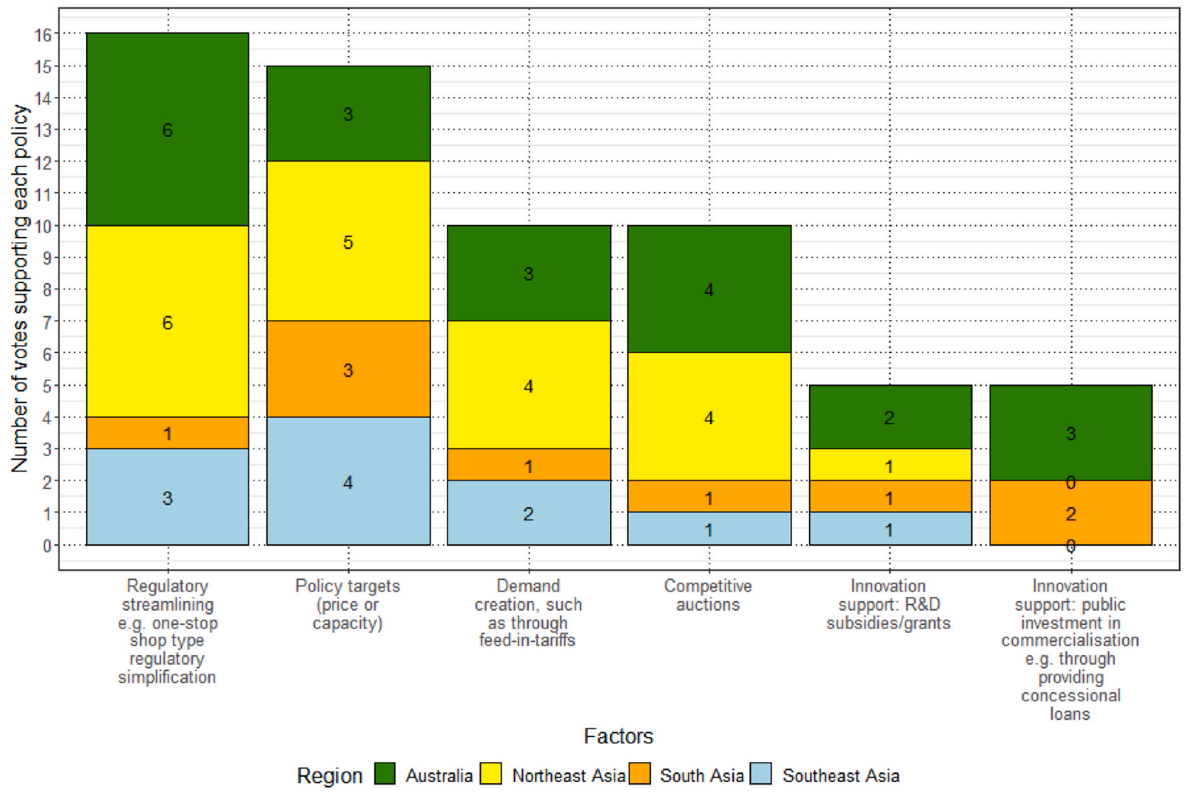

Fig. 4. Policies identified as contributing to reducing the LCOE for fixed-bottom technologies up to 2030.

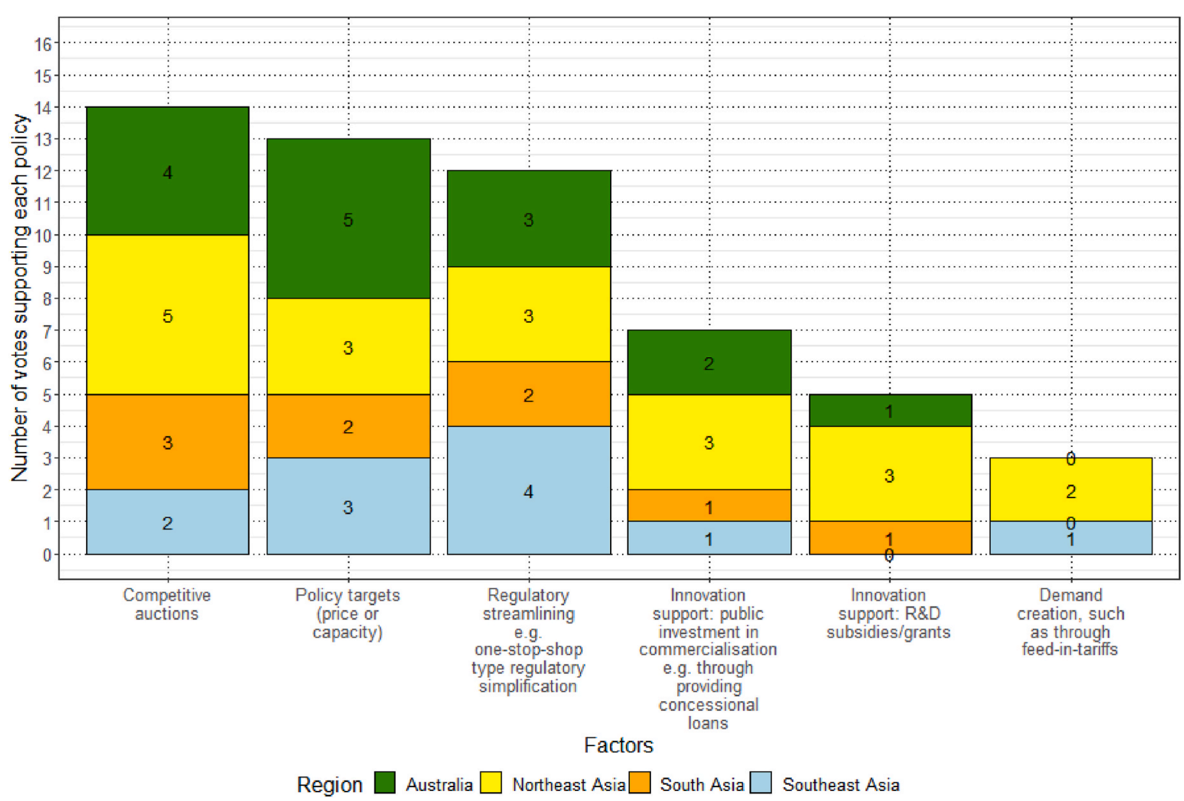

Fig. 5. Supportive policies for reducing LCOE for fixed-bottom technologies after 2030.

considerable support for, the continued provision of economic incentives such as the use of feed-in-tariffs, and the use of competitive auctions in the near-term. Innovation support was seen as less important, underlining the maturity of the technology.

After 2030, on the other hand, respondents saw the use of economic incentives as less important, which is consistent with views that the

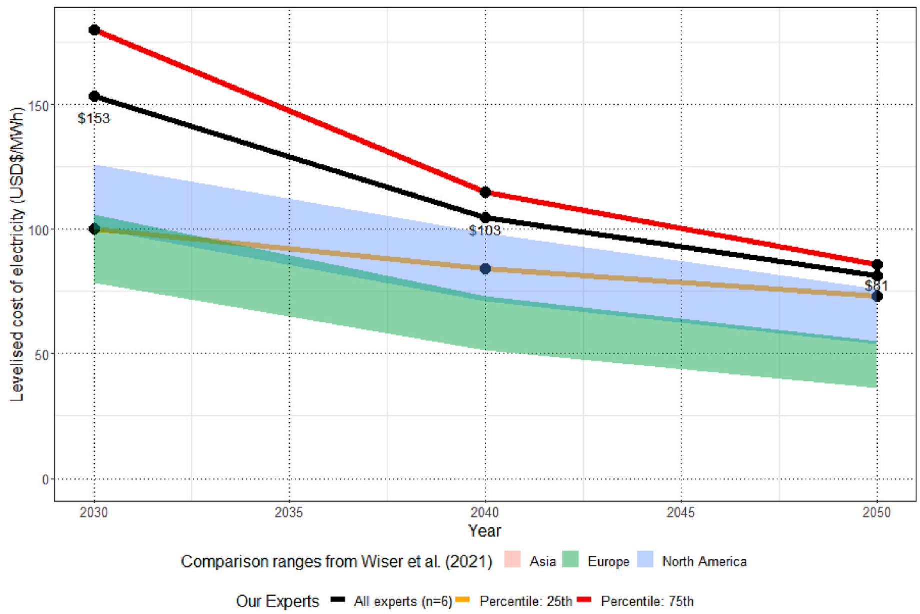

Fig. 6. LCOE for newly installed floating projects – average by region.

LCOE of fixed-bottom offshore wind will fall over time (Fig. 5). In addition, there was greater support for the use of competitive auctions after 2030 compared to beforehand. Together, this suggests an understanding among some experts that policies supporting fixed-bottom offshore wind should be sequenced, with renumeration support in the near-term giving way to the use of competitive auctions. The importance of policy targets and regulatory streamlining was emphasized both before and after 2030, suggesting support for governments to continue to de-risk offshore wind through providing policy certainty.

4.2. Floating offshore wind technologies

The same elicitation approach was used for self-identified experts in floating offshore wind technologies, who were asked to provide an estimate for the LCOE of floating wind projects. The initial year experts were asked to provide estimates for was changed to 2030, reflecting the fact that floating offshore wind technologies remain at a lower technology readiness level compared to fixed-bottom floating technologies. Percentage reductions they were asked to provide were set to 2040 and 2050.

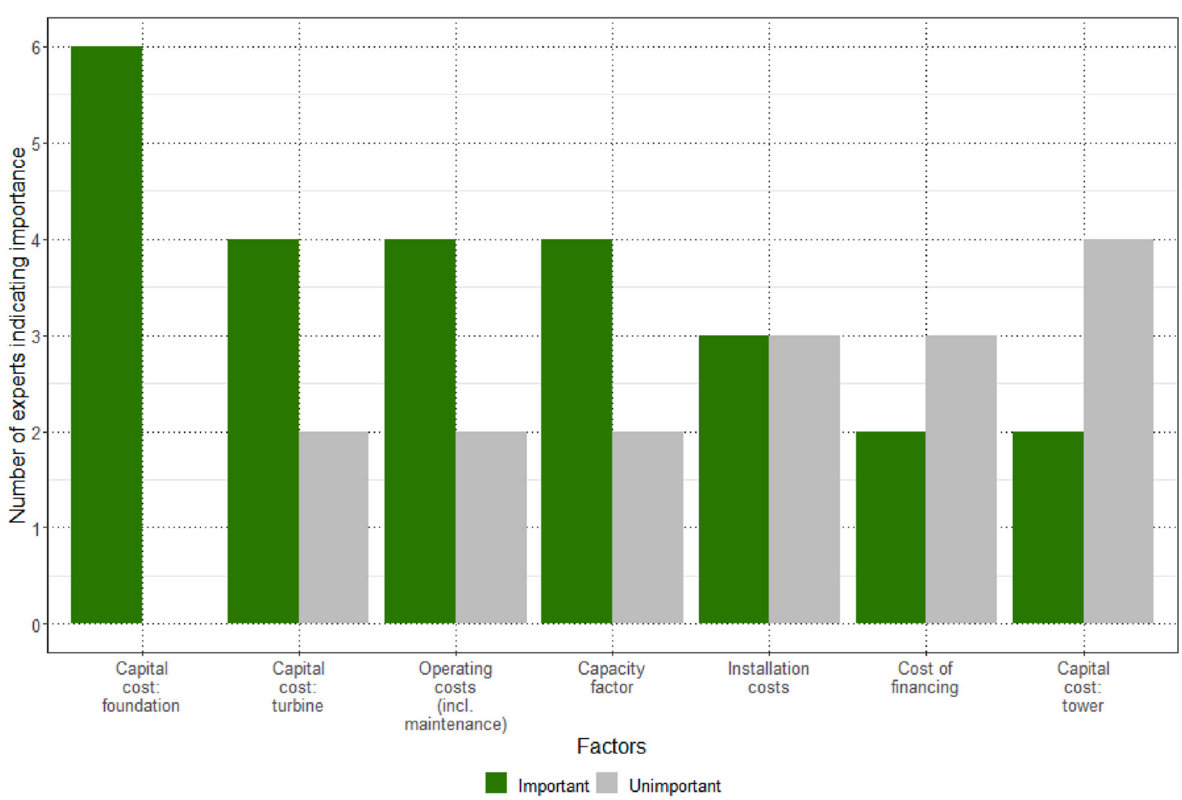

Fig. 7. Factors contributing to cost declines in floating technologies by 2030.

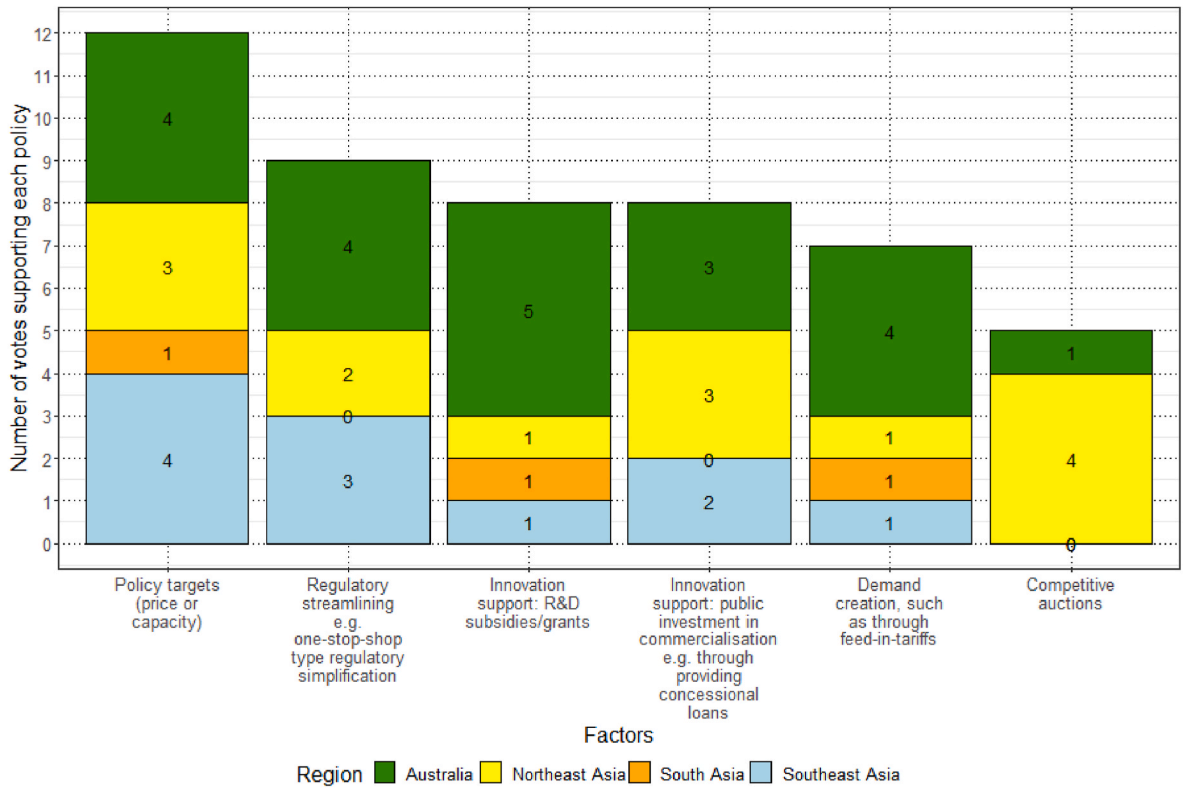

Fig. 8. Supportive policies for reducing LCOE for floating technologies up to 2030.

The estimates provided by experts for floating offshore wind are shown in Fig. 6, with auction results not reported due to the limited number of auctions held that are specific to floating offshore wind technologies (Jansen, 2022). There was an average estimate of USD153/MWh for 2030, USD104/MWh for 2040, and USD81/MWh for 2050. Thus, mean long-term expectations of the LCOE for floating offshore wind followed those of fixed-bottom technologies, implying an expectation of larger falls in LCOE over time, given the higher initial assessment for 2030. There were a smaller number of respondents for floating offshore wind, which increases the possibility that results may be influenced by individual biases. We also note that estimates for Northeast Asia where higher in 2030 compared to estimates for Australia.

In Fig. 6 we compared the estimates of our experts to those in Wiser et al. (2021), which did not have any experts responding for floating offshore wind in the Asia-Pacific. Responses were higher than provided in Wiser et al. (2021) for fixed-bottom offshore projects in North America in 2030, converging to the 75th percentile estimates (i.e. $81/MWh compared to $76/MWh).

For floating offshore wind technologies, the key factors identified as important in lowering the LCOE were reductions in the costs of foundations and turbines (Fig. 7). Views were mixed in relation to financing costs, which is a similar result produced for fixed-bottom technologies, and the capital cost of the tower was also seen as less important in supporting reductions in LCOE for floating offshore wind.

With regards to policies, the creation of policy targets and regulatory streamlining, was again understood to be important in the near-term for reducing the LCOE of floating offshore technologies (Fig. 8). In contrast to fixed-bottom technologies, innovation support in the form of subsidies for research and development, and support for demonstration projects, were identified as important in the near term for floating technologies, but less important for fixed-bottom offshore wind. Aggregate support for innovation was judged less important after 2030 than the need for clear signaling of a project pipeline through the establishment of policy targets. The role of competitive auctions increased in importance according to experts as a strategy for reducing the LCOE for floating offshore technologies (Fig. 9). Taken together, this suggests overall support for a sequenced suite of policies in the case of floating offshore wind, beginning with support for research, development, and deployment, in the near term, and moving forward to the introduction of auctions as a way of driving down the LCOE for floating technologies over time. In all cases a clear commitment from governments such as by establishing long-term targets for offshore wind deployment was judged as important.

5. Conclusion and policy implications

Offshore wind power has the potential to play an important role in helping to decarbonize energy systems in the Asia-Pacific region, but it is important for the cost of electricity to fall so the technology becomes more competitive against emissions-intensive power generation. Data shows that the technology costs of fixed-bottom offshore wind technologies has fallen globally since around 2010 (IRENA, 2021), however there is uncertainty about future cost pathways. There is also uncertainty about the long term cost of electricity generated by floating offshore wind, which is at a lower level of technological readiness compared to fixed-bottom offshore wind.

We used an expert elicitation in order to understand views of experts in the Asia-Pacific region about the future cost pathway for fixed-bottom and floating offshore wind technologies. We also asked experts about their views of policies that would support cost declines for offshore wind technologies. Experts shared the opinion that they expect the LCOE for both fixed-bottom and floating offshore wind technologies to continue to fall into the future. The mean expectation for newly installed fixed-bottom offshore wind technology cost reductions was 38% between 2025 and 2040, resulting in an average LCOE of USD72/MWh by 2040. For floating offshore wind, initial expectations for the LCOE were higher than for fixed-bottom platforms, with a mean assessed cost of USD153/

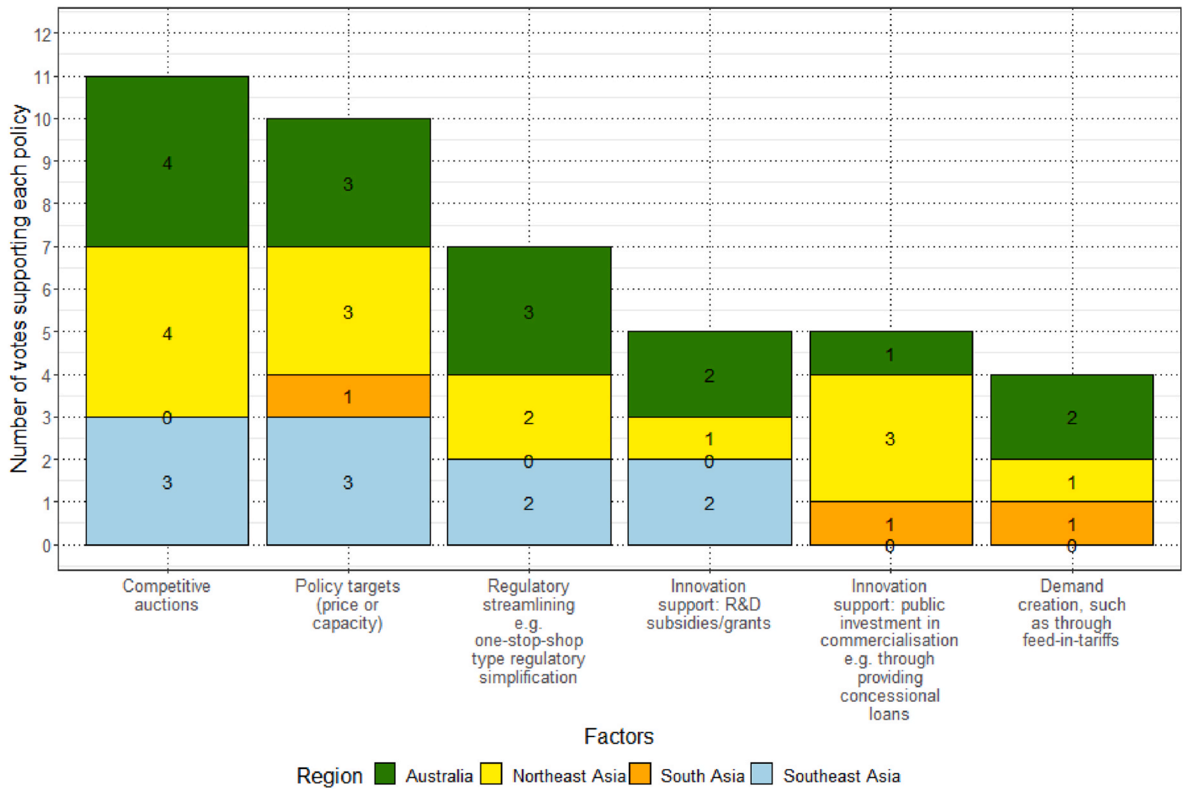

Fig. 9. Supportive policies for reducing LCOE for floating technologies after 2030.

MWh in 2030 for newly installed projects, against USD116/MWh in 2025 for newly installed fixed-bottom offshore projects. Assessed expectations for the long run cost of floating technologies, on the other hand, were similar to fixed-bottom offshore, reaching USD81/MWh by 2050. This suggests a broad expectation that floating offshore wind will approach competitiveness with fixed-bottom installations in the long run following a reduction in LCOE of around 47% between 2030 and 2050.

The assessed average change for fixed bottom and floating offshore wind is of a similar magnitude to that of Wiser et al. (2021), which finds expectations of a reduction in LCOE for fixed-bottom offshore wind of 35% and 49% by 2030 and 2050 respectively relative to 2019 baseline values in their median scenario, and a mean reduction of 17% by 2030 and 40% by 2050 for floating offshore wind. The long-run estimate in this study for the LCOE of floating offshore wind is similar to that of North America in Wiser et al. (2021), where experts estimated an LCOE of US$73.61/MWh in 2050. It nevertheless remains significantly higher than for Europe, which produced a median estimate of $44.78/MWh.[4] Interestingly, the estimates produced in this study are higher than those for some realized competitive auction outcomes in some European markets (Jansen et al., 2020).[5]

A plausible explanation for the difference in long-run estimates between Europe and the Asia-Pacific is the use of expert elicitation, where cognitive biases can affect estimates. Availability heuristic may be a factor for offshore wind, for example, where current information about higher regional costs has the effect of biasing estimates about future outcomes, compared to Europe where expectations are anchored by realized competitive auction outcomes. We did not include subsidiary questions asking experts about why their expectations might differ from that of other markets, making this is an important area for future research.

For fixed-bottom offshore wind, respondents were in relative agreement in identifying falling installation and capital investment costs for turbines and foundations as important contributors to cost reductions, along with increased capacity factors. This is consistent with findings presented by the International Energy Agency (2019, 12), and suggests expectations that innovation will continue to be an important factor in determining the future LCOE for fixed-bottom offshore wind technologies. There was relatively less agreement, on the other hand, about the importance of the cost of financing and reductions in costs for operations and maintenance (O&M) in contributing to LCOE reductions. In Europe, recent research shows falling costs of capital has contributed to lower LCOEs for renewable energy technologies. The LCOE for offshore wind has also been found to be sensitive to the costs of capital (Egli, 2020; Egli et al., 2018; Hirth and Jan Christoph, 2016; Timilsina, 2021). Most data thus far is drawn from European markets, and this result points to the need for further research to understand factors affecting the LCOE for offshore wind in the Asia-Pacific region. Responses from experts also differed between markets, suggesting that it may be important to take into account possible heterogeneity in financing methods. This is also the case for expectations for the contribution of O&M cost, which have fallen for renewable energy technologies in Europe (Steffen et al., 2020).

For floating offshore wind, there was unanimity amongst the smaller number of experts responding to this section of the expert elicitation study that falling foundation costs would be an important determinant of falling LCOEs for the technology. Other factors over which there was relative agreement were turbine costs, capacity factor, and operating and maintenance costs, with the latter possibly reflecting differences in the assessment of the overall importance of O&M for floating offshore wind technologies. There was less agreement about the importance of the cost of financing, implying expert assessments of the relatively less important role of financing in reducing the LCOE was not tied to a particular offshore wind technology platform.

[4] No estimate for the LCOE of floating offshore wind is provided for the Asia-Pacific in Wiser et al. (2021).

[5] We thank an anonymous reviewer for emphasizing this point to us.

Reponses to questions about which policy settings would be effective in reducing the LCOE of offshore wind showed high levels of support for regulatory streamlining and policy targets for both fixed-bottom and floating offshore wind technologies. While deployment targets have been established by governments in a number of Asia-Pacific markets, the focus on policy certainty is consistent with research on European markets which finds increased policy credibility reduced investment risk for renewable energy technologies (Egli, 2020). For fixed-bottom offshore wind, a greater number of experts supported the provision of economic incentives such as renumeration schemes in the near-term, and more experts supported the use of competitive auction processes in the longer-term. This suggests support among some experts for the sequencing of policy support for offshore wind. It also concords with findings that competitive allocation processes have been effective in lowering the technology costs of offshore wind, although there are differences in auction design that must be taken into consideration (Jansen et al., 2020). In the Asia-Pacific, for example, the use of LCRs in support of local manufacturing in the Taiwanese offshore wind sector has been criticized Gao et al. (2021a), and the inclusion of LCRs in solar PV auctions in India was found to increase auction bid prices by 5.3–5.9% relative to auctions without LCRs (Probst et al., 2020). A second issue raised by this result is the need for governments to provide policy certainty while also revising policy settings to support the reductions in the LCOE for offshore wind.

Experts responding to questions on floating offshore wind also nominated policy targets and improved regulatory streamlining to reduce technology costs in the near-term, suggesting policy certainty and credibility broadly matters for offshore wind technologies. It is notable that in Northeast Asia there was a similar level of support for the use of competitive auctions for floating offshore wind as there was for fixed-bottom offshore wind as a strategy for reducing technology costs, although this view was not held by experts across the region. In contrast, there was agreement that support for research, development, and deployment measures targeting floating offshore wind is warranted, reflecting the comparatively less mature stage of the technology. As with fixed-bottom offshore wind, a greater number of experts supported the use of competitive auctions in the longer-term than in the near-term, suggesting the usefulness of sequencing policy support for offshore wind across technologies platforms.

The study results suggest a number of policy recommendations. Qualitative evidence from Egli (2020) shows policy credibility may increase over time as investors gain more knowledge about the intentions of policymakers in local markets. The emphasis of experts on the importance of regulatory streamlining and the use of policy targets suggests, however, that governments should improve policy certainty and credibility. This is particularly important given the heterogeneity of systems of economic and regulatory governance in the Asia-Pacific region, and differences in the approaches adopted by regional governments to supporting offshore wind.

Second, our results suggest it is important for governments to develop different policy settings for fixed-bottom and floating offshore wind technologies. While competitive tendering processes are identified as important for both, the results suggest floating offshore wind would benefit from sequencing, with competitive auction processes introduced in the medium-term, although the results also suggest there are differences across different markets within the region that require investigation. An important exception is Northeast Asia, where experts supported the near term introduction of competitive auctions for floating offshore wind. The results also suggest there is an opportunity for policy learning from Europe, which has seen the shift from the use of administrative price supports to competitive auctions help reduce technology costs. Finally, in the near term, policy support for research, development and deployment for will floating offshore wind technologies will remains important to lower technology costs in the region.

There are a number of limitations of the paper, as well as avenues for future research. Expert elicitations tend to have small sample sizes, and rely on selecting a qualified and diverse group of experts to increase confidence that the judgments provided are authoritative and representative. There is nevertheless the possibility that the results are biased by idiosyncrasies associated with small numbers. The expert elicitation study reported here presents results for the Asia-Pacific region has a larger number of respondents from the region than comparable studies. The results could nevertheless be complemented by more detailed and context-specific analyses from individual markets within the region.

In terms of future research, policy frameworks supporting offshore wind power deployment are well documented for European markets, centered on renumeration schemes and auction design (Jansen et al., 2020). While there are a number of individual country studies for some Asia-Pacific markets (Do et al., 2022; Gao et al. 2021; Li, 2022; Li and Xu, 2019; Liao et al., 2021; Mani and Dhingra, 2013; Park and Kim, 2019), there remains a lack of information on the design and effectiveness of policy frameworks used by governments in the Asia-Pacific region to support offshore wind power. Future research could examine the design and effects of renumeration schemes and auctions on the cost of offshore wind across different Asia-Pacific markets. Finally, results reported in this expert elicitation suggest support for a sequential approach to policy design in which auctions are introduced in more mature markets for offshore wind. Data used in the study were collected prior to supply chain challenges in global offshore wind markets, which led some developers to argue low auction price outcomes are inconsistent with rising equipment costs (Millard, 2023), and future research could examine the sensitivity of the policy responses reported here to changes in costs for offshore wind.

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Credit author statement

Llewelyn Hughes: Conceptualisation, Methodology, Writing – original draft, Writing – review & editing Thomas Longden: Conceptualisation, Methodology, Writing – review & editing.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2023.113842.

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