Received: 10 November 2021 | Revised: 20 July 2022 | Accepted: 25 July 2022

DOI: 10.1002/we.2777

RESEARCH ARTICLE

WILEY

Evaluating technical and financial factors for commercialising floating offshore wind: A stakeholder analysis

Ben Moverley Smith[1,2] | Robert Clayton[2] | Adriaan Hendrik van der Weijde[3,4] | Philipp R. Thies[5]

[1]EPSRC and NERC Centre for Doctoral Training in Offshore Renewable Energy (IDCORE), School of Engineering, The University of Edinburgh, Edinburgh, UK

[2]Xodus Group, Aberdeen, UK

[3]School of Engineering, The University of Edinburgh, Edinburgh, UK

[4]Netherlands Organisation for Applied Scientific Research (TNO), Gravenhage, The Netherlands

[5]College of Engineering Mathematics and Physical Sciences, University of Exeter, Penryn, UK

Correspondence
Ben Moverley Smith, Xodus Group, Xodus House, 50 Huntly St, Aberdeen AB10 1RS, UK.
Email: ben.moverley-smith@xodusgroup.com

Funding information
UK's Engineering and Physical Sciences Research Council (EPSRC); Natural Environment Research Council (NERC), Grant/Award Number: EP/S023933/1

Abstract

Recently, floating wind has enjoyed much public and governmental attention and is commonly identified as a crucial next step on the route to net zero targets for many countries. However, there is currently a large gap between the scale and readiness-level of devices in the water and the end-of- the-decade aspirational targets of many governments. To facilitate the expansion of the industry, a wider acceptance and agreement of the realistic potential of floating wind and the barriers to the sector's development is required, particularly over this crucial 10-year period, something currently scarce in published literature. In this work, a stakeholder engagement was performed, with subsequent analysis of the results to quantify industry expectations and identify the predominant technical and financial concerns of key stakeholders. The presented results of the work serve to both provide a point of comparison and updated account of industry-based expert views in the near term, with further scientific analysis investigating distinctions between different stakeholder types. Secondarily, the key concerns of industry were analysed and compared with a literature review of recent research effort within floating wind, providing a high-level gap analysis. A knowledge of the gaps can inform future areas for academic enquiry, ensuring the future needs of industry and the focus of research is aligned.

KEYWORDS
challenges, floating wind, stakeholder

1 | INTRODUCTION

Offshore wind is regarded as one of the main routes to reducing the carbon emissions of electricity generation. Recent government announcements from various global regions have demonstrated an increased expectation for offshore wind deployment, both in the coming decade and stretching out to 2050.[1,2] To fulfil such ambitions, countries with deep water-depths around some or all of their coastline, such as the United Kingdom and Japan, will to some extent rely upon the rapid development of a currently nascent technology: floating wind.

Floating offshore wind turbines (FOWTs) can still be regarded as a novel technology, with less than 100 MW of capacity installed globally at the end of 2020.[3] However, numerous studies, along with government ambitions, expect this capacity to increase more than 10-fold over the next decade,[1,3] as the industry moves from small demonstration and pilot projects to larger commercial endeavours. Applying the framework defined in Phaal et al,[4] floating wind technology will therefore undergo a 'gear change', over the next 10 years, as the technology enters a 'growth phase', whereby the emergence of the technology is dominated by market factors. A similar trend can be observed in the fixed wind market.

In order for the industry to progress through the transition from small scale demonstrator units, funded by government and research-body grants, to a commercially viable mass-market technology, several challenges concerned with both the financial and technical aspects of floating wind will need to be overcome. At the same time, it has been shown in other sectors that an alignment of expectations is beneficial in the emergence of new technology, particularly if there is a coherent vision shared amongst different players which then allows for 'institutionalisation' of the new technology.[5,6] Moreover, according to Borup et al,[7] a strongly aligned convergence of expectations on the future of a technology may generate a dynamic of 'promise and requirement', whereby the shared expectation of success leads to concrete actions being taken to fulfil that expectation. This work therefore seeks to provide further detail on both of the factors which will have an impact on the emergent path of floating wind technology in the crucial coming decade: industry expectations and perceived challenges surrounding floating wind technology. We explore both through stakeholder engagement and analysis.

To gauge expectation for the technology over the coming decade, two suitable metrics which can be considered are:

1. the expected level of deployment of floating wind, and
2. the expected cost of energy associated with floating wind.

There are several organisations, both commercially and publicly funded, that have recently made predictions of both the level of deployment for floating wind, and its levelised cost of energy (LCOE). A comparison of recent reports is made in Table 1. The methodologies used to attain such numbers vary by publishing organisation, but broadly follow a similar path that, for the level of deployment, includes resource mapping and policy analysis, and for the levelised cost includes estimation of learning rates for various aspects of floating wind projects. There has been less work done to assess industry perceptions of these values, for instance, via expert elicitation. An expert elicitation survey carried out by Wiser et al. in 2015 did produce estimates for the cost of floating wind in both 2020 and 2030.[8] However, the main focus of that study was on onshore and fixed offshore wind, and the questions for floating wind were asked in relation to these more established wind technologies. In the time since this study, there have been dramatic changes to the offshore wind industry, and floating wind in particular: two floating demonstrator farms have been successfully deployed and are operating with record capacity factors,[9] and the strike price awarded to fixed bottom projects has reduced by more than 70%.[10]

The rapid reduction in the strike price awarded to fixed bottom wind projects is particularly striking and is shown in Figure 1. This reduction happened recently, and it is expected that these changes will have impacted perceptions within the industry. The survey by wiser was therefore repeated in 2020,[11] with results represented and further analysed by the authors in 2022.[12] In both papers, the focus of the work sought to understand the effect of these recent developments on the wind industry as a whole. Although more focus was placed on floating wind as a separate technology, questions were still asked in relation to fixed bottom offshore wind, with an emphasis on the trend of the costs in the long term. Moreover, although there was an large pool of respondents for the survey as whole, less than 25% provided predictions for floating wind in the next 10 years. This present work focuses on the industry perspective and expectations in the nearer term, as the technology moves from demonstrator to commercial level deployment.

The expected deployment level and LCOE for floating wind given by the different sources is shown in Table 1. There is little consensus amongst the expectations provided. Moreover, the projections here are made by enabling institutions within the floating wind sector and may therefore be prone to overoptimism, as enablers have a vested interest in the success of floating wind. One of the aims of our study is therefore to examine whether those perceptions are shared amongst other industry stakeholders.

When identifying and assessing the different challenges that floating wind will need to overcome within the next decade, there are several sources within industry which provide information. Recent reports published by different enabling institutions identifying several different concerns areas are shown in Table 2. At first glance, these concerns can be broadly split into two categories: **financial** concerns about the funding

TABLE 1 Expected levels of UK capacity deployment and LCOE for floating wind in 2030

Source	Expected installed capacity by 2030 (MW)	Expected LCOE in 2030 (£/MWh)
Carbon Trust[3]	1100	N/A
ORE Catapult[13]	57–2130*	62–84*
Wind Europe[14]	N/A	35–50**
Statoil[15]	N/A	35–50**
Expert Elicitation[8]	N/A	79–122*

*Data extracted from graphical sources.
**Conversion form EUR to GBP using exchange rate of 1:0.882.

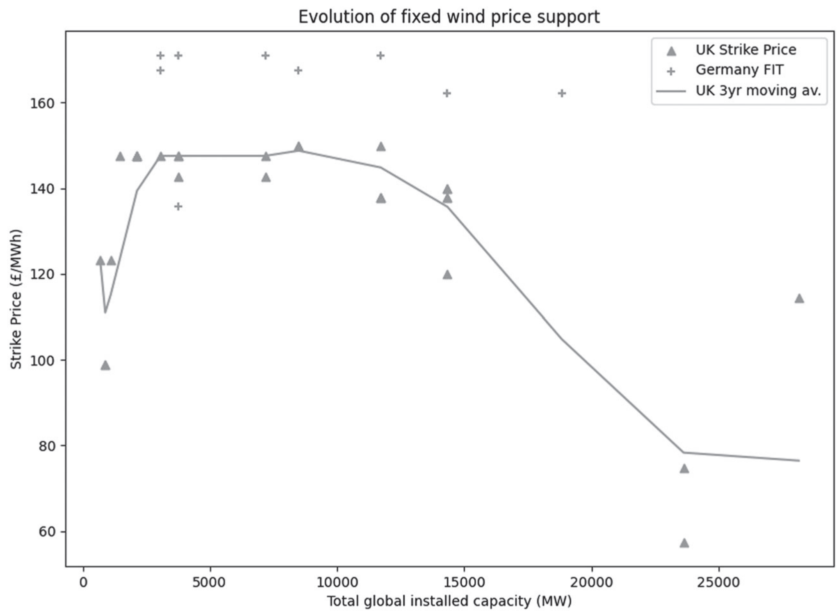


FIGURE 1 Evolution of the strike price awarded to different fixed bottom wind projects with increasing cumulative capacity. Data from publicly available data sources. Prices are in 2012 £

TABLE 2 Main challenges listed in recent industry reports

Report	Type of institution	Main concerns
Floating Wind Summary Report Phase I[16]	Consultancy	Lack of dynamic high voltage cable
		Mooring system design
		Infrastructure availability
Floating Wind Summary Report Phase II[3]	Consultancy	Heavy lift operations
		Lack of dynamic high voltage cable
		Monitoring and inspection challenges
A Bouyant Future[17]	Enabler	Substructure costs
		Dynamic cables
		Proof of concept for TLPs
		Lack of deep water substations
Floating Wind - Risk Analysis Towards Bankability[18]	Investor	Unrealistic estimations
		New due diligence required
		Delays
		System failures

and finance of future floating wind projects and **technical** concerns about the fundamental technological issues which need to be overcome for floating wind farms to operate successfully. As can be seen, there is certain overlap on specific areas, those based in technological challenges. However, there is little information about the relative perceived size of these issues—something which should be considered when determining the route of different research themes. In addition, there is very little information within academic literature about the main technological challenges that are most in need of addressing, despite the abundance of research being carried out. There is, therefore, a danger that research is being performed within academia that does not add value to industry and assist with the development of the technology. In order to prevent this issue, a clear set of research goals are necessary.

This paper therefore seeks to address two main research questions through the use of an opinion survey conducted on different stakeholder groups within the floating wind industry. As noted by the authors of the expert elicitation and analysis mentioned previously,[11,12] elicitations from subject matter experts are 'especially useful when historical data are limited or when future conditions may differ from the past', such as in this nascent industry. In the first instance, the expectations for the future of floating wind amongst different groups will be assessed by considering respondents' expected deployment level of floating wind farms, and the cost reductions projected to occur over the next 10 years. Secondly, the research identifies the current largest perceived risks to the future development of floating wind.

Applying a statistical scientific analysis to the responses identifies a misalignment in outlook between different stakeholder groups, providing key and important insight for those hoping to facilitate collaboration and alignment within industry. To assist with this aim further, we also perform an assessment of concurrent research effort via a literature keyword search to assess whether the main challenges identified by industry are currently being addressed in public-domain research.

In the next section, the design of the engagement is introduced, including a rationale for the research focus and methods. The results section presents descriptive statistics of the responses gathered from the survey, followed by statistical analysis to identify underlying correlation between different respondents. A discussion then follows, during which the results are considered and compared with trends in other industries, and the implications of which are examined. Finally, a conclusion of the work is presented.

2 | METHODOLOGY

2.1 | Data collection

As with other studies into emerging energy industries,[6] the research was performed via a survey, as the floating wind industry is currently too small and nascent for revealed preference data to be available. The determination of the research questions defined in the previous section make up the first step in the methodology used to perform the research, adapted from Groves et al[19] and shown in Figure 2. To address the research questions highlighted earlier, it is necessary to gather stakeholders' opinions on the different topics of expectations for the floating wind industry, and the individual technical and financial concerns of the stakeholder. The method used for the collection of these data was via an online survey. The platform used was Qualtrics, a surveying platform often used in academic research. The platform has the added benefit of being able to capture quantitative responses via different question types, which maintains engagement and can reduce drop-out rates.[20]

To identify the different stakeholder groups, the respondents were first asked about their organisation type. These questions were based around the organisations that respondents worked for, the location in which they worked, and whether they had past experience with floating wind projects. Then, to address the two components of the research question, the survey was broadly split into two sections.

The first section was focused on respondents expectations for floating wind within the coming decade. A focus was placed on projects within the United Kingdom as it is one of the most advanced countries for the technology, and almost all respondents targeted were expected to be familiar with the floating wind landscape within the United Kingdom. Further, by concentrating on one country, it is possible to better understand the estimated progression of floating wind technology whilst controlling for country-specific variation. This time frame was chosen as it coincides with several policy actions taken by the UK government bodies recently, including the announcement of the 1 GW target by 2030, and the announcement of the Scotwind leasing round, through which seabed will be leased on the timescale which will roughly coincide with a 2030 commissioning date. The expectation questions were quantitative, to enable more detailed analysis of the answers, and asked respondents to predict the number of commercial scale (defined as more than 100 MW) floating farms that would be present by 2030, as well as to map out the price reduction for floating wind technologies over the coming decade. As wind turbines are rapidly scaling in size, the addition of a few 12 MW

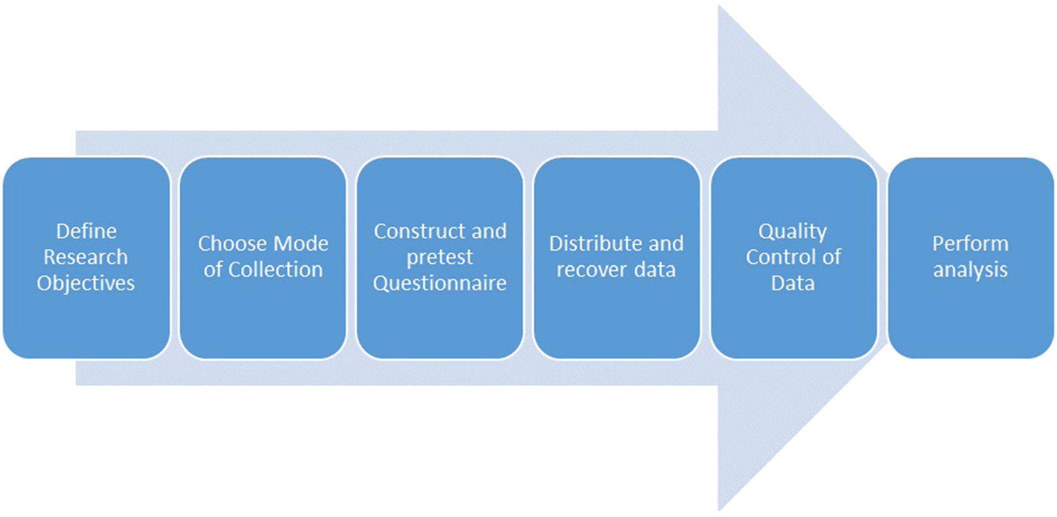


FIGURE 2 Survey methodology adapted from Groves et al.[19]

turbines can make a big difference to a prediction of total installed capacity of a farm. Therefore, we opted to use questions about the *number* of floating farms that people are expecting to be installed before 2030, as opposed to the capacity of those farms. However, to avoid counting existing and proposed pilot projects, the farms to be considered were classed as ‘commercial’, with a provided definition of 100 MW or more to quantify this requirement.

When asking about expected price levels, it is difficult to ask questions directly about the predicted levelised cost of floating wind, as the current levelised cost is not publicly available. What is available is the level of price support that existing projects currently receive, in whatever form, be it strike price, feed-in-tariff or renewable obligation certificates. Questions are therefore framed around this metric for use as a proxy for levelised cost. Received price support represents an upper bound for estimated levelised cost, as no project which produces energy at a higher price than received support would be viable. Additionally, a received price support level estimate provides an easy comparison with existing floating and fixed bottom wind projects, whose received support is readily available from public sources. A similar ambiguity arises around setting the timeframe for the cost estimates. A question such as ‘predict the LCOE in 2030’ does not specify whether that is the price of projects which will be installed in 2030, projects commissioned in 2030, projects receiving revenue in 2030 and so on. Therefore, in order to overcome this issue, it was decided to ask respondents to give an estimation for projects with financial investment decision (FID) in the years 2023 and 2028. These years were chosen as, based on current timelines, they should relate to projects which will be installed in 2025 and 2030 respectively. It again also allows for easy comparison with existing and near future fixed wind farms, the latter of which (as previously mentioned) have recently achieved substantial reductions in their received level of price support, and which would be missed by only comparing with already constructed farms.

Regarding price indexation, prices within the study are monetary values at the time of the survey, that is, 2019. The survey did not ask respondents to account for inflation as the aim was to try to understand the expected cost reduction projections. It should be noted that the 12- and 1-month inflation rates at the time of the study were 1.5% and −0.2%.[21] In the meantime, inflation figures globally have increased substantially, expected to peak at over 10% for Europe and the United Kingdom.[22] Whilst this will influence the absolute cost values, the relative trends from responses will remain valid.

The subsequent section was focused on the major concerns that the different respondents had. To avoid missing any concerns that had not been identified in publicly available reports, the questions in this section were open-ended in nature. This ensured that any concerns that stakeholders had could be captured, and also allowed for a simple identification of the most prevalent concerns through counting the number of mentions. As the concerns that respondents mentioned were expected to cover a diverse range of issues, which cannot be readily compared, it was decided not to ask respondents to rank the concerns that they mentioned but instead just to list the ‘top 3’ concerns. This made the survey easier to complete, without resulting in unnecessary additional work from the respondents.

The survey design was an iterative process, and the questions underwent many design cycles prior to the publication of the survey. Prior to distribution, the survey was tested internally with individuals who held a similar role and with similar experience to the target recipients. The distribution of the survey was performed via numerous channels, including posts on social media sites such as LinkedIn and the UK Energy Research Council, and via more direct emails and direct messaging on the LinkedIn platform to individuals known to be involved in the floating wind industry. In this way, the sampling for the survey can be categorised as convenience sampling. This was necessary due to the size of the floating wind industry—as the industry is currently nascent and small, the population size of individuals working within the floating wind industry does not allow for random sampling. However, as the research aims to identify descriptive trends between stakeholder groups, the lack of random sampling is not prohibitive. The survey was monitored, and results collected by the Qualtrics platform. At the end of the survey, respondents were asked if they would be prepared to take part in a follow-up interview to elaborate on their responses. All participants who indicated that they would be willing to participate in these interviews were subsequently contacted for an interview. Answers given in these interviews are used to inform the discussion section.

Alongside the industry-based survey, to better understand the alignment of industry and the research community, an additional review of published research on the topic of floating wind was undertaken. In order to gauge the level of research effort that different concerns mentioned by respondents were receiving, the proportion of different research papers within the topic of floating wind and with a specific focus on that area were counted. A keyword search of 'floating wind' was performed within the research search engine 'Web of Knowledge',[23] and titles and abstracts from the 500 most relevant research papers (both conference proceedings and journal articles) were collected for further analysis.

2.2 | Data analysis

An initial screening was performed for quality control purposes. The raw data were then collected from the Qualtrics platform.

Analysis of the quantitative answers was performed using Python scripts to produce descriptive statistics and plots. To describe the spread of answers, histograms and box plots were used. Histograms were chosen as they allow an easy determination of the distribution of the data.[24] Box plots were chosen as they are a powerful exploratory data analysis graphic, which show the median, the spread, the skewness and the kurtosis of the underlying data all in one plot. The boxes show the median and the interquartile range (IQR), and the whiskers show the limit of the outliers, calculated as whisker = 1.5 x IQR.[24] Following the exploratory and descriptive analysis, the quantitative data were then further analysed using principal component analysis (PCA). PCA is a method often used as an initial step in multivariate data analysis to identify variance within the data and can be used to group together individuals within a sample who produce similar answers. Briefly, PCA can be described as a linear transformation which reorganises the data points such that the greatest variance within the data becomes the primary axis (or first component). Subsequent components are then the orthogonal axis to the first component. At the simplest level with two variables, PCA is easy to visualise, as it is effectively the line of best fit through the different data points. In two dimensions, this line of best fit, or first principal component, is made up of an x value and a y value. As the number of variables increases, the number to contributions to the principal component also increase. By employing this analysis technique, it is possible to determine any subgroups which exist within the sample of respondents.[25] The PCA analysis was performed using a python script, which imported the open-access scikit-learn package.[26]

Analysis of the technical and financial concerns highlighted by the respondents was performed in NVivo software. NVivo is a common qualitative analysis tool used in multiple disciplines to perform research on text answers.[27] The text answers for all participants was downloaded into the software, and the answers were coded using thematic analysis to identify any common themes. The various codes were then grouped into similar topics. To enable a comparison of the relative popularity and importance of the different topics, the topics were ranked according to the number of mentions that they received from participants.

The analysis of the collected research papers was also performed within the NVivo software. As the aim was to understand the research area of each paper, a thematic analysis of title and abstract was sufficient to identify the main concern under consideration for each. Once all the papers had undergone this analysis, the research areas identified were ranked according to number of papers which focused on that area.

3 | RESULTS

A total of 28 participants took the survey, corresponding to an approximate response rate of 13% from the direct emails and instant messages. The median time for completion for these respondents was 22 min. Of the 28 responses received, 18 were complete responses, and 10 were partial responses. However, the extent of completion of these partial responses was deemed sufficient for analysis.

The breakdown of respondents by organisation type is shown in Figure 3. In order to provide comparison between the different types of respondent, four types were identified. Most of the respondents were either project developers (36%) or worked in role which provided a service to project developers (39%), including consultants, tier one providers and tier two/ specialist providers. All of the technology developers which responded to the survey (7% of total respondents) were designers and developers of floating foundations. The survey was also able to capture the opinions of individuals who worked for non-commercial organisations, such as academia and enabler institutions. An enabler institution is a body, either publicly or privately funded, whose aim is to progress an industry.

3.1 | Expected number of commercial scale floating wind farms

In order to gauge the industry expectations for floating wind in the United Kingdom, the respondents were posed questions on both the number of floating farms that they were expecting to see in the United Kingdom by 2030 and the level of price support that will be required to support

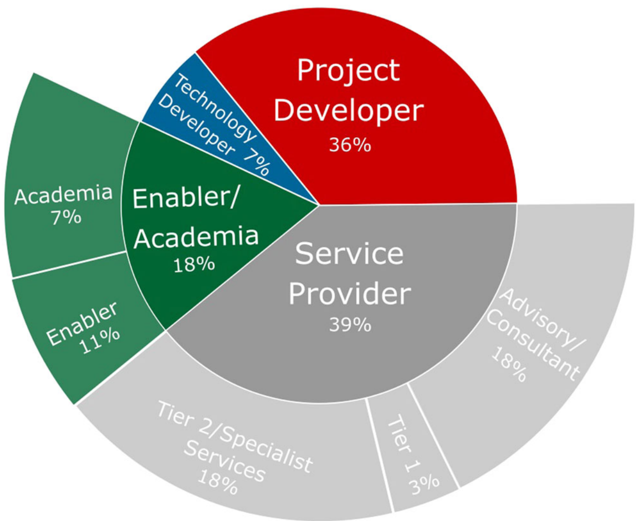
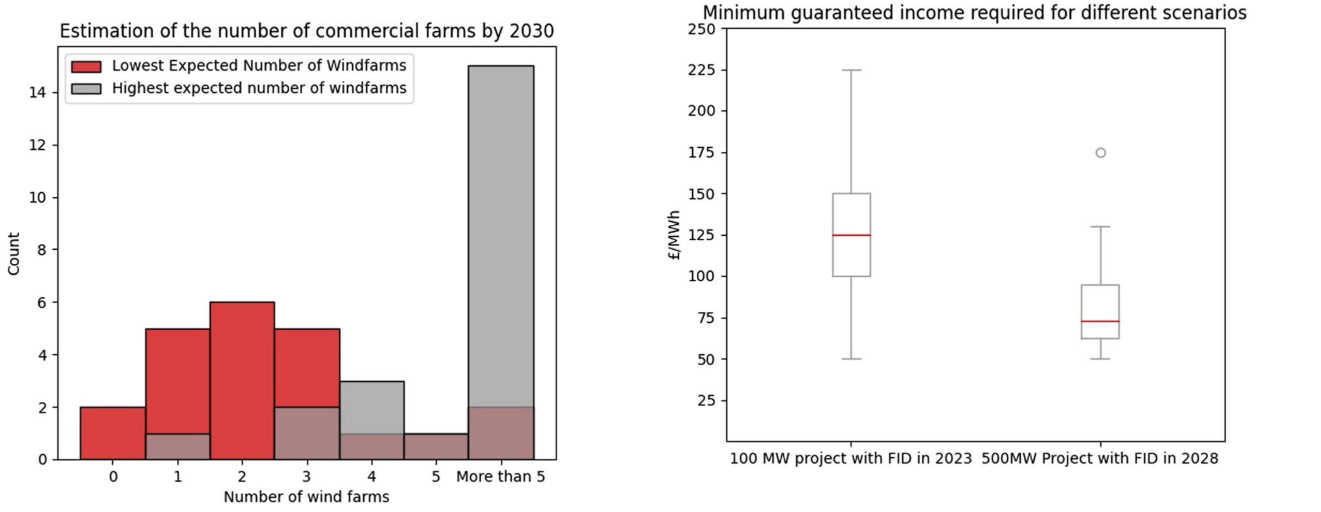


FIGURE 3 Breakdown of respondent by organisation type. Total number of respondents: 28



(A) Expected number of commercial-scale (100MW) floating wind farms in the UK by 2030

(B) Expected strike prices for floating wind in two different scenarios, a 100MW project with FID 2023 and a 500MW project with FID 2028. Prices are 2019£.

FIGURE 4 Respondents expectations for floating wind

floating wind farms in the coming decade. Generally, respondents had a very positive view on both counts, expecting many farms which will only require a small level of price support. When asked about the expected number of commercial scale floating wind farms in 2030, the respondents were optimistic in their predictions, and the results of which are displayed in the bar chart in Figure 4A. The red bars show the distribution of the respondents' reasonable lowest estimate for the number of farms. The distribution is fairly well spread, with a modal response of two commercial wind farms. The grey bars show the distribution of the respondents' high estimate, representing a best-case scenario. The distribution of answers is highly skewed to an answer of more than 5, suggesting consensus around this number of farms in a best-case scenario.

3.2 | Price support levels

Respondents were asked to predict the level of price support that would be required by floating wind projects at different points in the future. The results are shown in the box and whisker plot in Figure 4B. There is a very large spread amongst responses for a small 100 MW project with a final investment decision (FID) in 2023. The median response for this scenario is £125/MWh, with an interquartile range of £100/MWh–£150/MWh. Looking ahead to 2028, there is a more convergent consensus for a larger project in 2028; the median estimate for this scenario is £73/MWh, with an interquartile range of £65/MWh–£100/MWh.

3.3 | Concerns

3.3.1 | Financial concerns

The financial issues raised by the respondents, along with the prevalence of the topics across all respondents' answers are shown in Table 3. The main financial issue that concerned respondents was the cost of components of floating wind farms, with 53% of respondents mentioning the topic. Focusing in on this reveals that the main concern lies in the actual cost of the foundation, specifically the cost of the materials to make the large substructures, and the costs associated with fabrication. Another large issue for the respondents was the cost of finance for floating projects. Numerous stakeholders (47%) mentioned the cost of capital as one of their main financial worries around floating wind projects.

3.3.2 | Technical concerns

The main technical concerns that were highlighted raise topics regarding technical advances needed from fixed wind to floating wind, as can be seen in Table 4. A distinct and repeatedly highlighted concern are dynamic cables, with over 60% of respondents specifically mentioning the technology. In particular, respondents were concerned about the availability and then subsequent reliability of this critical component in floating

TABLE 3 Financial concerns around floating wind farms

Name	%Mention
Cost of components	53%
Cost of capital	47%
Bankability and perceived risk	41%
Securing an income	41%
Supply chain costs and abilities	29%
Fabrication method	29%
Insurance	24%
High number of foundations	18%
External factors	12%
Transmission costs	12%

TABLE 4 Technical concerns around floating wind farms

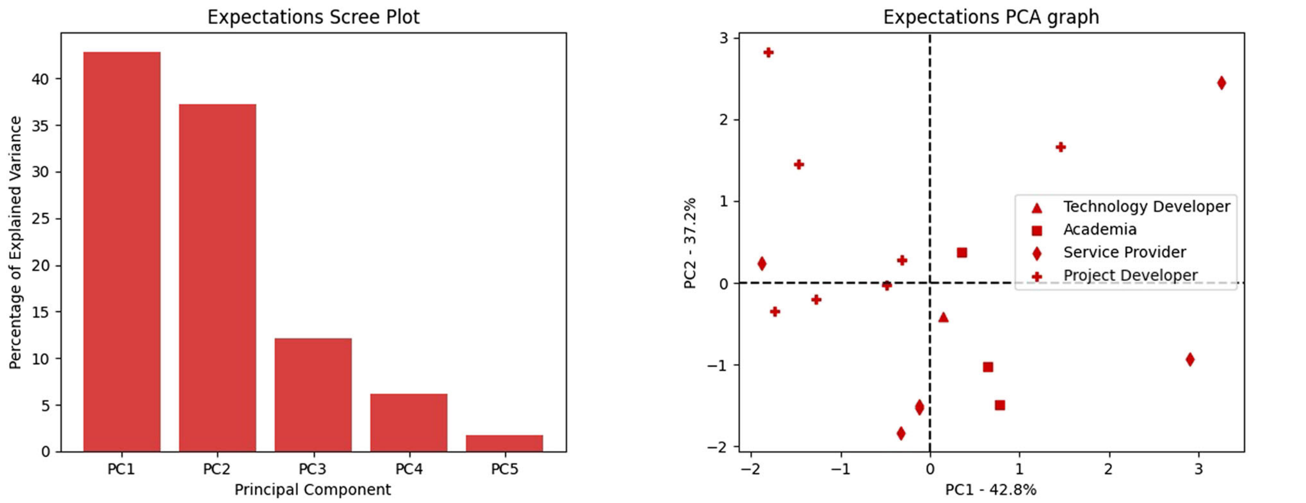
Theme	% Mention
Dynamic cables	61%
Mooring	39%
Supply chain capabilities	33%
Coupled analysis	28%
Turbine related	28%
Engineering design	22%
Nascent technology	22%
O&M	22%
Installation methods	17%
Lack of floating substation	17%
Larger turbines	17%
Too many unproven foundation designs	11%
Lack of holistic approach	6%

farms. Although the dynamic cable technology has been proven in oil and gas applications, the much more dynamic application leads to an increased risk profile for early floating wind developments. Respondents were also concerned about the mooring design for any floating wind farm. Although there is cross-over from oil and gas (O&G) technologies such as floating production and storage offloading (FPSO) units, these structures are normally held in place by numerous anchor lines, with redundancy built into the system. Concerns were raised over whether a similar practice of redundancy would be financially viable in a floating wind farm setting, and if not, how the risk could be accommodated within the project plan.

3.4 | Trends within groups

In order to identify any potential subgroups within the respondents, a PCA analysis was carried out. Two distinct groups were identified within the data, as shown in the scree plot in Figure 5A. The variance amongst the respondents can mainly be described by principal component one (PC1), which accounted for 42.8% of the total variance, and principal component two (PC2), which made up a further 37.2% of the variance seen within the sample. As a large amount of the variance can be described by these two principal components, it indicates that different subgroups exist within the total sample, and individuals within those groups tend to answer in a similar manner. Adding further components would not explain a substantial additional amount of variance, leading to the conclusion that the respondents can be classified into two groups.

The composition of the PC1 and PC2 can be seen in Table 5. The largest component of PC1 was strong negative correlation with answers on whether the UK government would announce any floating specific price support policies, and it was also positively correlated with the expected number of wind farms. Respondents with a positive principal component therefore were not expecting there to be a government support



(A) Scree plot accounting for the variance amongst respondents' answers for questions relating to expectations (B) A PCA graph showing the proportion of principal components making up responses from different respondents

FIGURE 5 PCA analysis of respondents' answers on their expectations for floating wind

TABLE 5 Composition of PC1 and PC2

Question	PC1	PC2
Price support mechanism within the next 2 years?	−0.506	0.134
Lowest expected number of farms	0.497	−0.391
Highest expected number of farms	0.469	−0.371
Strike price: 100 MW project with FID in 2023	0.392	0.578
Strike price: 500 MW project with FID in 2028	0.351	0.598

TABLE 6 Research papers title count

Topic	Academic papers
Numerical modelling of behaviour	139
Model tests	70
Control strategies	48
Mooring system	47
Novel technology	40
Integrated renewable systems	29
Vertical-axis wind turbines	21
O&M	15
Wake	13
Fatigue damage	11

mechanism for floating wind but nevertheless were expecting there to be a significant number of floating wind farms installed by the end of the decade. The largest components of PC2 were the expected strike prices of different future floating wind farms. Respondents with a high PC2 therefore thought that future floating wind farms would require high strike prices.

A graph of PC1 against PC2 can be seen in Figure 5B. The different respondents have been grouped together by organisation type. This analysis reveals that there is a distinction between developers and non-developers, with developers occupying the negative PC1 quadrants and skewed towards a positive PC2. This position suggests that project developers have fairly similar expectations for floating wind and that they are markedly less optimistic than individuals who work in academia or industries which provide services to floating wind developers.

3.5 | Research publications

The literature analysis as described earlier was performed. The top 10 results according to the number of research papers concerned with the topic is shown in Table 6. A large number of papers were concerned with the numerical modelling of floating wind turbines. These papers often were investigating novel coupled analysis of the forces on floating turbines. Similarly, a lot of published floating wind papers have looked at model tank tests of floating foundation designs.

As shown, the majority of published research has been focused on modelling the behaviour of floating wind turbines. This has mainly been focused on efforts to capture the aeroelastic behaviour of wind turbines, and the coupling of the aerodynamic, hydrodynamic and mooring behaviour of the system. From the analysis, it seems that researchers are addressing the mooring concerns of industry, as nearly 10% of all research papers analysed were focused on the topic. However, there was much less of an interest in the dynamic cables for floating wind applications, with only 1% of research papers addressing the topic of electrical infrastructure as a whole.

4 | DISCUSSION

Overall, there is a positive attitude amongst industry professionals on the future of floating wind farms. In particular, there is an ambition in stakeholder views on both the likely number of floating wind farms in the near future, and the levelised cost of energy associated with those farms. When stakeholders were questioned further in one-to-one interviews, the main reasons for the optimism, particularly in the cost reduction, was the cross-over in knowledge between floating wind and the fixed wind industry, as well as the oil and gas industry. Respondents were confident that the mistakes which had been encountered in the fixed wind industry such as grouting connection issues,[28] cable failures,[29,30] installation delays,[31] consenting delays[32] and other issues would not be repeated for the floating wind industry. In this regard, Figure 6 compares the LCOE developments for fixed and floating wind installation with installed capacity.

The grey line shows the LCOE for fixed wind against the total global installed capacity, whilst the red lines show the 10th percentile, median and 90th percentile responses in this piece of work, set against predicted installed capacity. The red triangle represents the current price support received by both the Hywind Scotland and the Kincardine floating wind sites in the United Kingdom. The behaviour of the LCOE expected by respondents in terms of rate of price reduction is similar to that displayed by fixed wind after a cumulative capacity of 15 GW had been installed. Indeed, previous work has shown that the majority of cost reduction in fixed bottom wind can be attributed to learning by deployment.[33] However, as the grey line shows, such rapid reduction in cost only occurred after a rise in price, as wind turbines moved into deeper waters further from shore and encountered unexpected and costly issues.

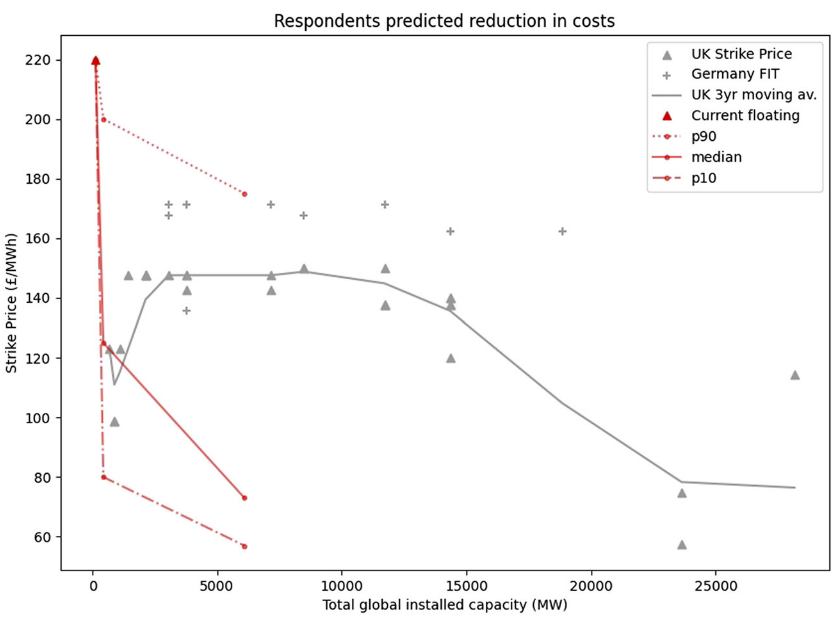


FIGURE 6 Comparison of strike prices: floating wind estimation versus fixed wind history. In order to provide comparison between floating and fixed, the fixed strike prices are marked against the total global installed capacity of offshore wind installed for that year. Floating wind strike price estimates are made against internal estimates of predicted installed capacity

From the responses, it seems apparent that the floating industry does not foresee the same issues being encountered, even though floating farms will also move to deeper water sites which are further from shore and require the use of new and unproven technology, such as floating or sub-sea substations.

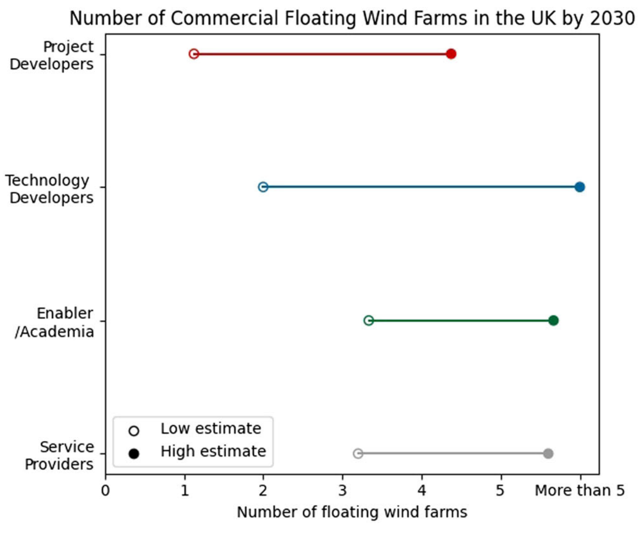
From the follow-on discussions with participants, there are several drivers for the cost reduction. One of which is expected to be the cost reductions brought about by economies of scale, and the serialised production of the floating foundations. This will lead to reduced costs of production per floating foundation, as the fabrication process will become more efficient, reducing the time and money spent on each individual foundation. However, as mentioned previously, the respondents seem very optimistic that the serialised process will happen quickly and result in an immediate and drastic reduction in costs. Comparison with literature on the development of expectations for emerging technologies[7] indicates that there is often temporal variation in the expectations for technologies as they mature. A well-known and simplified visualisation of this is the Gartner Hype cycle, which dictates that every emerging technology follows a path of initial innovation trigger, followed by a peak of inflated expectations with increased publicity and numerous success stories. This surge in optimism then leads to a trough of disillusionment as failures occur and interest wanes, and there is then a recovery in perception of the technology.[34] Arguably, based on the buoyant expectations for floating wind, the technology is on the path to the peak of inflated expectations, with the trough of disillusionment to follow.

4.1 | Variation amongst stakeholders

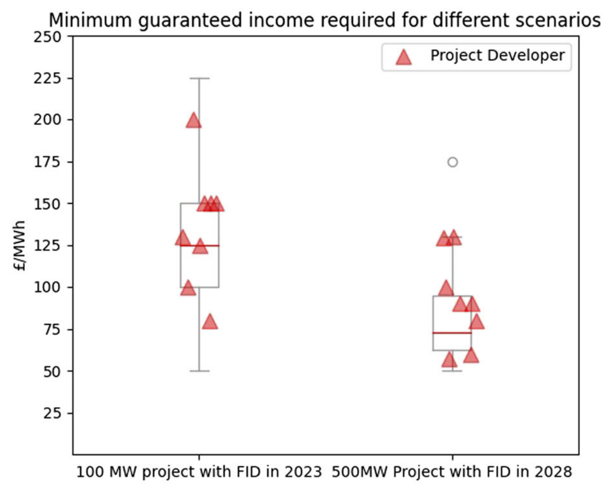
Following from the PCA analysis initially performed, it is interesting to contrast the different stakeholder groups identified by the analysis of their responses to the questions on expected number of floating farms and the cost reduction.

As suggested by the PCA analysis, there is a discrepancy amongst the different groups of the respondents, with the project developers predicting lower number of commercial scale wind farms by 2030, compared to the predictions made by non-developers, Figure 7A. The more conservative answers compared to service providers and enablers reflects the typical attitudes of the different roles. Service providers and academics/enablers have an optimistic view since their role is typically to deal with higher level and conceptual aspects view of a technology; they therefore have a more 'top-down' approach that, depending on the assumptions made, could be quite optimistic. By contrast, project developers are used to dealing with projects on a day-to-day basis and are familiar with the issues that can arise. They therefore take a more ‘bottom-up’ approach and maybe make the estimations based on the technology that they currently deal with and the improvements that are expected in the near future. It may therefore be hard for them to envisage some disruptive innovation which may quickly change the trajectory of floating wind and make it more viable.

When the answers to the question on price support levels are split between developers and non-developers, a difference is similarly observed, as in Figure 7B. The figure shows the developers estimations overlaid on the whole sample distribution and shows most project developers giving answers above the median response, with the median developer responses being £140/MWh and £90/MWh for the two scenarios. Again, this could be suggestive of a more cautious approach taken by developers, perhaps reflecting the fact that many of the developers who



(A) Expected number of commercial-scale (100MW) floating farms, split by respondent type



(B) Expected strike prices for floating wind in two different scenarios, with developers estimations overlaid. Prices in 2019£

FIGURE 7 Respondents expectations for floating wind responded were established companies with experience of dealing with emerging technologies and therefore were aware of the potential issues that might arise as a sector begins to mature.

4.2 | Challenges

The main financial challenge raised by respondents was that of the cost of the components of a floating wind turbine and in particular the cost of the floating foundations. This concern echos findings in other work, which demonstrated that floating wind LCOE was particularly sensitive to the fabrication costs of foundations.[35] Other important issues mentioned were the cost of capital associated with floating projects and the 'bankability' of different concepts. These concerns draw attention to a challenge that was highlighted by multiple respondents in further interviews, namely, the choice (or lack thereof) of foundations for projects. The foundations currently used in floating projects are building up a successful track record and developing strong partnerships with turbine suppliers and are therefore considered to be the most bankable choice when project developers select foundations for their projects. However, such early designs are, due to their nature, conservative and costly. In order to reduce the foundation costs, competition is required from disruptive new designs that have the potential for much cheaper material and fabrication costs, such as the Tetra-spar design by Stiesdal.[36] However, up to now, project developers have been unlikely to opt for such cost-reducing designs as they do not have the crucial time in the water which project lenders and project underwriters require.

The two main technical challenges highlighted by the respondents concerned dynamic cables and mooring design for floating wind farms. Both of these technical issues are already dealt with in the oil and gas industry, as umbilical cables and mooring arrangements are both features of floating structures in this sector. However, the way in which they will be deployed within floating wind is markedly different. Additionaly, for the mooring design, although similar mooring technology will be used for floating wind turbines as is used for O&G platforms, the risk profile will be very different. In O&G applications, floating structures such as floating production storage and offloading installations (FPSOs) have multiple anchors attached from many directions. As such, there is redundancy built into the system, as the failure of a single mooring line does not lead to catastrophic failure of the system. In a floating wind setting, early designs show a minimum number of mooring lines per are being used, in order to cost-optimise project designs. As mooring lines currently fail at a rate of once per 5 years for FPSOs, which is shorter than a wind farm service life,[37] the concern is understandable.

5 | CONCLUSION

Through engagement with key stakeholders along the value chain of the floating wind industry, a stakeholder analysis has been performed. The aim was to understand the current perceptions regarding market development in the United Kingdom and the current challenges. The results of this analysis can be summarised by five key findings:

1. Throughout the industry, there is a very optimistic view on the future of floating wind in the United Kingdom, both in terms of the scale of deployment and the reduction in the LCOE of floating wind.

Stakeholders almost unanimously felt that floating wind would take numerous learnings from both the oil and gas and fixed offshore wind industries. Most importantly, stakeholders expressed that floating wind will see a swift cost reduction. In light of the offshore wind LCOE development, this might be overly optimistic but shows the potential for floating wind manufacture and deployment to scale effectively. These projections should allow alignment in expectations between industry and policy makers.

2. The largest financial concern amongst respondents was the cost of the structure, closely followed by concerns around the cost of capital and bankability. Conventional mitigation measures for these concerns are causing conflicting objectives.

For floating wind to become a viable technology, costs must be reduced across projects, in particular the construction costs of the foundation. A primary route for this reduction is by bringing new and innovative designs into the market. However, in order for these designs to be used, they need investor confidence, which only comes with previous projects. The industry is therefore currently focused on a handful of incumbent and costly designs. This will need to be overcome if the previously mentioned rapid reduction in price is to be achieved.

3. Dynamic cables are the most ubiquitous perceived risk for future floating projects.

The majority of respondents mentioned dynamic cables as a concern, indicating that it is a challenge felt across the industry. Although the technology has in principal been used in other settings such as oil and gas applications, it is still felt to be an unproven technology within the floating wind industry. This concern could be addressed by specific policy initiatives.

4. There is a currently a gap between some of the topics being researched and the topics which industry needs addressed.

In particular, as mentioned in point 3, dynamic cables and their reliability are a major issue for industry and represent a challenge on the way to commercialising floating wind. However, of the 500 research papers reviewed, less than 1% were focussed on such a topic. More should therefore be done to align research effort with industry requirement.

5. There is a disparity between perceptions of different industry stakeholders. Especially when trying to estimate the future of the floating wind industry, there is an apparent difference between project developers and other stakeholders such as service providers. This result is a reminder that is necessary to frame market perceptions and outlooks within the stakeholder context.

In conclusion, this work has identified a number of aspects that can be solved through continued collaboration between research and industry, as well as continued economic, political and regulatory support. All floating wind stakeholders should be wary of the Hype cycle concept, in order to not overly inflate expectations beyond what is reasonable, avoiding a deep trough of disillusion. However, with correct support and directed research focus, floating wind does have the capability to become a commercial reality and provide cost effective low carbon energy.

ACKNOWLEDGEMENTS

Funding is acknowledged from the UK's Engineering and Physical Sciences Research Council (EPSRC) and Natural Environment Research Council (NERC) for the Industrial CDT in Offshore Renewable Energy (EP/S023933/1).

CONFLICT OF INTERESTS

The authors declare no potential conflict of interests.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/we.2777.

ORCID

Ben Moverley Smith https://orcid.org/0000-0001-5375-0663
Philipp R. Thies https://orcid.org/0000-0003-3431-8423

REFERENCES

1. HM Government. The Ten Point Plan for a Green Industrial Revolution. Tech. Rep., HM Government; 2020. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf
2. Japan Wind Power Association. Jwpa report; 2020. http://jwpa.jp/page_301_englishsite/jwpa/detail_e.html
3. Carbon Trust. Floating Wind Joint Industry Project - Phase II Summary report; 2020. https://www.carbontrust.com/resources/floating-wind-joint-industry-project-phase-2-summary-report
4. Phaal R, O'Sullivan E, Routley M, Ford S, Probert D. A framework for mapping industrial emergence. *Technol Forecast Social Change*. 2011;78(2):217-230.
5. Swanson EB, Ramiller NC. The organizing vision in information systems innovation. *Organiz Sci*. 1997;8(5):458-474. http://www.jstor.org/stable/2635216
6. Elliott K, Smith HCM, Moore F, van der Weijde AH, Lazakis I. Environmental interactions of tidal lagoons: A comparison of industry perspectives. *Renew Energy*. 2018;119:309-319.
7. Borup M, Brown N, Konrad K, Van Lente H. The sociology of expectations in science and technology. *Technol Anal Strategic Manag*. 2006;18(3-4):285-298.
8. Wiser R, Jenni K, Seel J, et al. Expert elicitation survey on future wind energy costs. *Nat Energy Anal*. 2016;1(10):1-8.
9. Smith AZP. UK offshore wind capacity factors. https://energynumbers.info/uk-offshore-wind-capacity-factors. Accessed[08/03/2021].
10. Evans S. Analysis: Record-low price for uk offshore wind cheaper than existing gas plants by 2023. Carbon Brief; 2019. https://www.carbonbrief.org/analysis-record-low-uk-offshore-wind-cheaper-than-existing-gas-plants-by-2023
11. Wiser R, Rand J, Seel J, other. Expert elicitation survey predicts 37% to 49% declines in wind energy costs by 2050. *Nat Energy*. 2021;6:555-565.
12. Beiter P, Rand JT, Seel J, Lantz E, Gilman P, Wiser R. Expert perspectives on the wind plant of the future. *Wind Energy*. 2022;25(8):1363-1378. doi:10.1002/we.2735
13. ORE Catapult. Floating Offshore Wind: Cost Reduction Pathways; 2021. https://ore.catapult.org.uk/wp-content/uploads/2021/01/FOW-Cost-Reduction-Pathways-to-Subsidy-Free-report-.pdf
14. Europe W. Floating Offshore Wind Energy: A Policy Blueprint for Europe. *Position Paper*. 2018:10.
15. Statoil. World's first floating wind farm has started production; 2017. equinor.com/en/news/worlds-first-floating-wind-farm-started-production.html
16. Carbon Trust. Floating Wind Joint Industry Project - Phase I Summary; 2018. https://www.carbontrust.com/media/675868/flw-jip-summaryreport-phase1.pdf
17. Proskovics R, Smart G. A Buoyant Future. *Windtech Int*. 2017;13(4):106-108.
18. Weber C, Ardoise G, Guzzetti M. Floating wind - Risk analysis towards bankability. Presentation. Green Giraffe; 2018.

19. Groves RM, Fowler FJ, Couper Jr MP, Lepkowski JM, Singer E, Tourangeau R. Lifecycle of a survey from a design perspective. *Survey methodology*. Hoboken, New Jersey: Wiley; 2009:41-49.
20. SurveyAnyplace. Overview of different question types. https://help.surveyanyplace.com/en/support/solutions/articles/35000048750-overview-of-different-question-types
21. Office for National Statistics. Consumer price inflation, UK: December 2019; 2020. https://www.ons.gov.uk/economy/inflationandpriceindices/bulletins/consumerpriceinflation/december2019
22. Monetrary Policy Committee. Monetary policy report. Tech. Rep., London, Bank of England; 2022.
23. Clarivate. Web of Science. https://clarivate.com/webofsciencegroup/solutions/web-of-science/. Accessed [11/3/2021].
24. Reimann C, Filzmoser P, Garrett RG, Dutter R. Graphics to Display the Data Distribution. *Statistical data analysis explained: Applied environmental statistics with R*: Wiley; 2008:29-50.
25. Reimann C, Filzmoser P, Garrett RG, Dutter R. Principal Component Analysis and Factor Analysis. *Statistical data analysis explained: Applied environmental statistics with R*: Wiley; 2008:211-232.
26. Pedregosa F, Varoquaux G, Gramfort A, other. Scikit-learn: Machine learning in Python. *J Machine Learn Res*. 2011;12:2825-2830.
27. Nvivo. About NVivo. https://help-nv.qsrinternational.com/20/win/Content/about-nvivo/about-nvivo.html
28. Dallyn P, El-Hamalawi A, Palmeri A, Knight R. Prediction of Wear in Grouted Connections for Offshore Wind Turbine Generators. *Structures*. 2017;10:117-129.
29. Lawler R. Cables for offshore wind - steady as she goes. *Materials World Magazine*. 2014;i:24-25. www.iom3.org/news/cables-offshore-wind-steady-she-goes?c=621
30. Boehme T, Robson DJ. Offshore wind farm cabling: Incidents and required learning. *Proc Instit Civil Eng: Forensic Eng*. 2012;165(4):185-197.
31. Lacal-Arántegui R, Yusta JM, Domínguez-Navarro JA. Offshore wind installation: Analysing the evidence behind improvements in installation time. *Renew Sustain Energy Rev*. 2018;92:133-145.
32. Gibson E, Howsam P. The legal framework for offshore wind farms: A critical analysis of the consents process. *Energy Policy*. 2010;38(8):4692-4702.
33. Elia A, Taylor M, Ó Gallachóir B, Rogan F. Wind turbine cost reduction: A detailed bottom-up analysis of innovation drivers. *Energy Policy*. 2020;147:111912. https://www.sciencedirect.com/science/article/pii/S0301421520306236
34. Gartner. Hype Cycle. https://www.gartner.com/en/research/methodologies/gartner-hype-cycle
35. Lerch M, De-Prada-Gil M, Molins C, Benveniste G. Sensitivity analysis on the levelized cost of energy for floating offshore wind farms. *Sustain Energy Technol Assess*. 2018;30:77-90. doi:10.1016/j.seta.2018.09.005
36. Borg M, Walkusch Jensen M, Urquhart S, Andersen MT, Thomsen JB, Stiesdal H. Technical definition of the tetraspar demonstrator floating wind turbine foundation. *Energies*. 2020;13(18):4911. https://www.mdpi.com/1996-1073/13/18/4911
37. Brindley W, Cornley A. North sea mooring system: How reliable are they? *Offshore Eng*. 2014;39(11):58-61.

How to cite this article: Moverley Smith B, Clayton R, AH van der Weijde, Thies PR. Evaluating technical and financial factors for commercialising floating offshore wind: A stakeholder analysis. *Wind Energy*. 2022;1-14. doi:10.1002/we.2777