U.S. Offshore Wind Energy Noise Reduction Questionnaire Results and Recommendations

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Overview

At the direction of the U.S. Department of Energy's Wind Energy Technologies Office (WETO), the National Renewable Energy Laboratory (NREL) and the Pacific Northwest National Laboratory (PNNL) distributed an online questionnaire to gather feedback on research and development priorities regarding underwater noise associated with fixed-bottom offshore wind turbine installations in U.S. waters.

For background, NREL and PNNL, the project team, hosted a virtual workshop in December 2022 to gather initial input on noise reduction strategies and recommendations for research and development (see the workshop report[1] for more information). The Bureau of Ocean Energy Management's Proposed Quieting Performance Target was also presented at the workshop as reference to the scale of noise reduction being considered. To refine and enhance the results of the workshop, the project team distributed a brief questionnaire in May 2023 (Appendix A) to the workshop invitees, 255 potential respondents. In total, 46 respondents completed the questionnaire, and most respondents identified as an *Environmental Scientist or Researcher*, *Government Representative*, or an *Offshore Wind Project Developer*.

The 12 questions in the questionnaire were developed in discussions by the project team and informed by guidance from DOE WETO. The research and development themes resulting from the initial workshop informed the six topics presented in the questionnaire: data access, standardization, and model consistency; research, development, and deployment (RDD) of alternative foundation types, RDD of new monitoring strategies and technologies; RDD of noise abatement and mitigation technologies (including alternative installation techniques); research to assess disturbance on marine species and habitats; and supply chain and infrastructure improvements.

This report summarizes the results of the questionnaire and provides recommendations to WETO on research and development priorities.

[1] Green, Rebecca, Hayley Farr, Kendra Ryan, Genevra Harker-Klimes, Joseph Haxel, and Michael Richlen. 2023. *U.S. Offshore Wind Energy Noise Reduction Associated With Installation of Fixed-Bottom Foundations: Workshop Report*. Report by NREL and PNNL for the U.S. Department of Energy Wind Energy Technologies Office. https://tethys.pnnl.gov/publications/us-offshore-wind-energy-noise-reduction-associated-installation-fixed-bottom.

Results

This section summarizes the responses to each of the 12 questions on the questionnaire.

1. What is your role?

As shown in Figure 1, of the 46 respondents, 10 respondents (21.7%) identified as an *Environmental Scientist or Researcher*, 10 (21.7%) identified as a *Government Representative*, 9 (19.6%) identified as an *Offshore Wind Project Developer*, 6 (13.0%) identified as a *Noise Mitigation/Abatement Technology Developer*, 5 (10.9%) identified as an *Environmental Consultant*, 1 (2.2%) identified as an *Offshore Wind Foundation Developer*, and 1 (2.2%) identified as a *Contractor*. Four (13.0%) respondents identified as *"Other,"* which included NGO representatives, a developer of long-duration environmental monitoring vessels, and a non-environmental consultant. None of the respondents identified as a *Supply Chain Representative*.

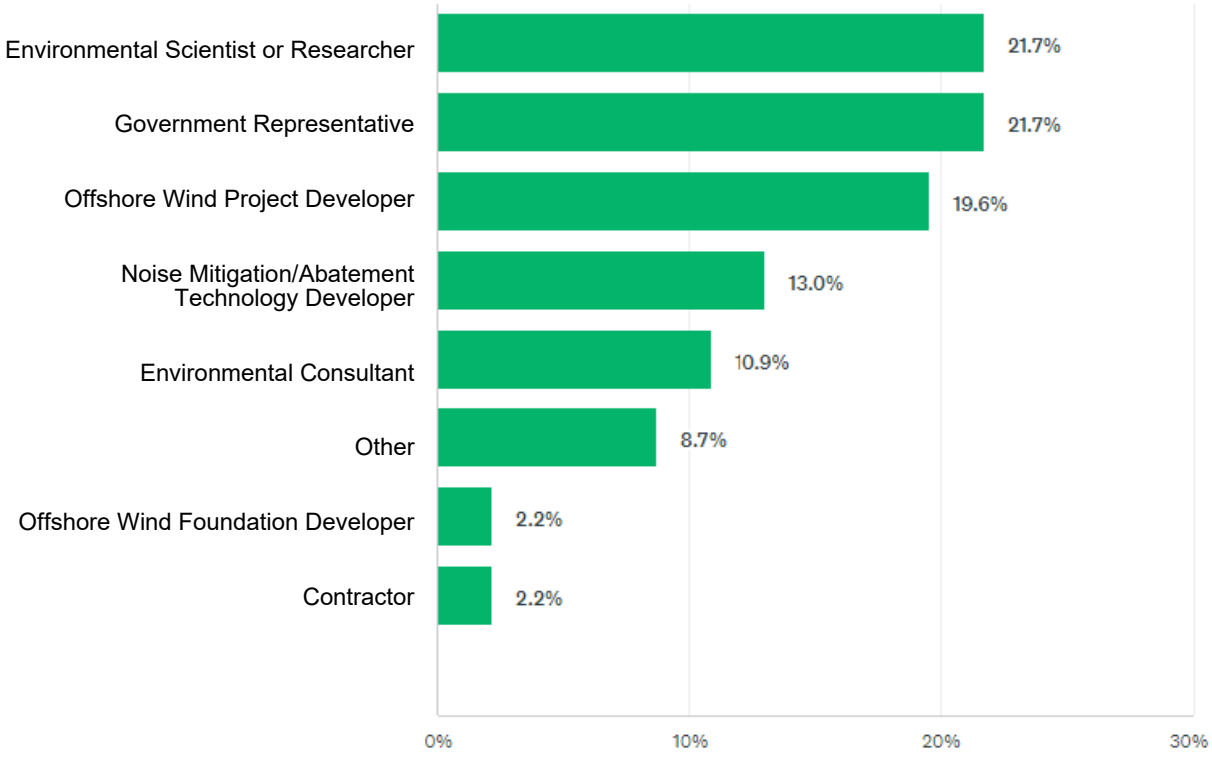

Figure 1: Distribution of self-identified roles of respondents.

2. **What are the highest priority noise reduction needs to be addressed <u>in the short term (to achieve successful deployment targets by 2030)</u>? Please rank in order of priority from highest priority to lowest priority.**

For Question 2, respondents were asked to rank six topics that could address noise reduction needs in the short term (to achieve successful deployment targets by 2030) from highest priority (#1) to lowest priority (#6). Forty-four respondents answered the question and two did not answer the question. Figure 2 shows the percentage distribution of responses for each need in the short term. The average score for each need is also presented below (lowest score = highest priority).

Research, development, and deployment (RDD) of noise abatement and mitigation technologies (including alternative installation techniques) ranked the highest priority with an average score of 2.4 and 84.8% of respondents scoring it as first, second, or third. *Research to assess disturbance on marine species and habitats* ranked second with a score of 2.8 and 67.4% of respondents scoring it as first, second, or third. *RDD of new monitoring strategies and technologies* ranked third with a score of 3.3 and 45.6% of respondents scoring it as first, second, or third. Although *data access, standardization, and model consistency* ranked fourth with an average score 3.5, more respondents (50%) ranked it as first, second, or third than *RDD of new monitoring strategies and technologies*. *RDD of alternative foundation types* ranked fifth with a score of 4.0 and 34.8% of respondents scoring it as first, second, or third. Finally, *supply chain and infrastructure improvements* ranked last with a score of 5.0 and 17.4% of respondents scoring it as first, second, or third.

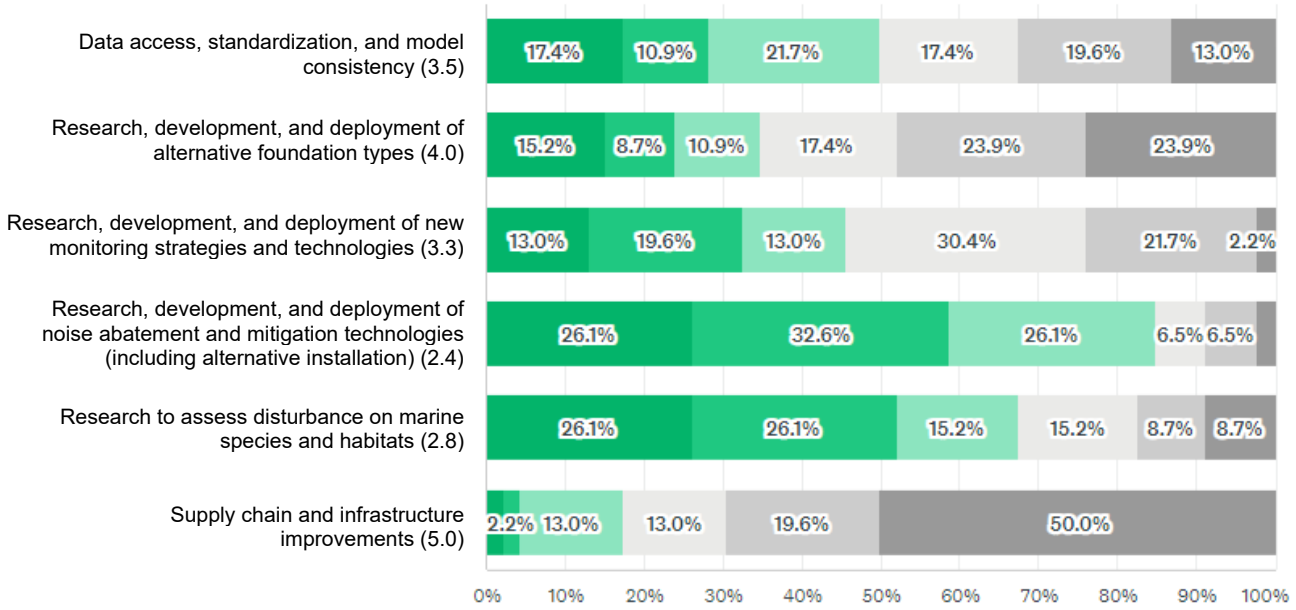

Figure 2: Distribution of highest priority noise reduction needs in the short term (dark green represents highest priority; dark gray represents lowest priority). The average score is noted next to the topic.

3. **What are the highest priority noise reduction needs to be addressed <u>in the long term (to achieve successful deployment targets by 2050)</u>? Please rank in order of priority from highest priority to lowest priority.**

For Question 3, respondents were asked to rank six topics that could address noise reduction needs in the long term (to achieve successful deployment targets by 2050) from highest priority (#1) to lowest priority (#6). Forty-four respondents answered the question and two did not answer the question. Figure 3 shows the percentage distribution of responses for each need in the long term. The average score for each need is presented below (lowest score = highest priority).

Research to assess disturbance on marine species and habitats and *RDD of alternative foundation types* tied for highest priority in the long term, with scores of 3.0 and 56.8% of respondents scoring them as first, second, or third. However, 27.3% of respondents ranked *research to assess disturbance on marine species and habitats* as first, while only 18.2% of respondents ranked *RDD of alternative foundation types* as first. *RDD of noise abatement and mitigation technologies (including alternative installation techniques)* ranked next in priority with an average score of 3.1 and 56.9% of respondents scoring it as first, second, or third. *Data access, standardization, and model consistency* ranked next with an average score of 3.3 and 54.5% of respondents scoring it as first, second, or third. *RDD of new monitoring strategies and technologies* ranked next with a score of 3.8 and 36.4% of respondents scoring it as first, second, or third. Although *supply chain and infrastructure improvements* ranked last with an average score of 4.0, more respondents (38.6%) ranked it as first, second, or third than *RDD of new monitoring strategies and technologies*.

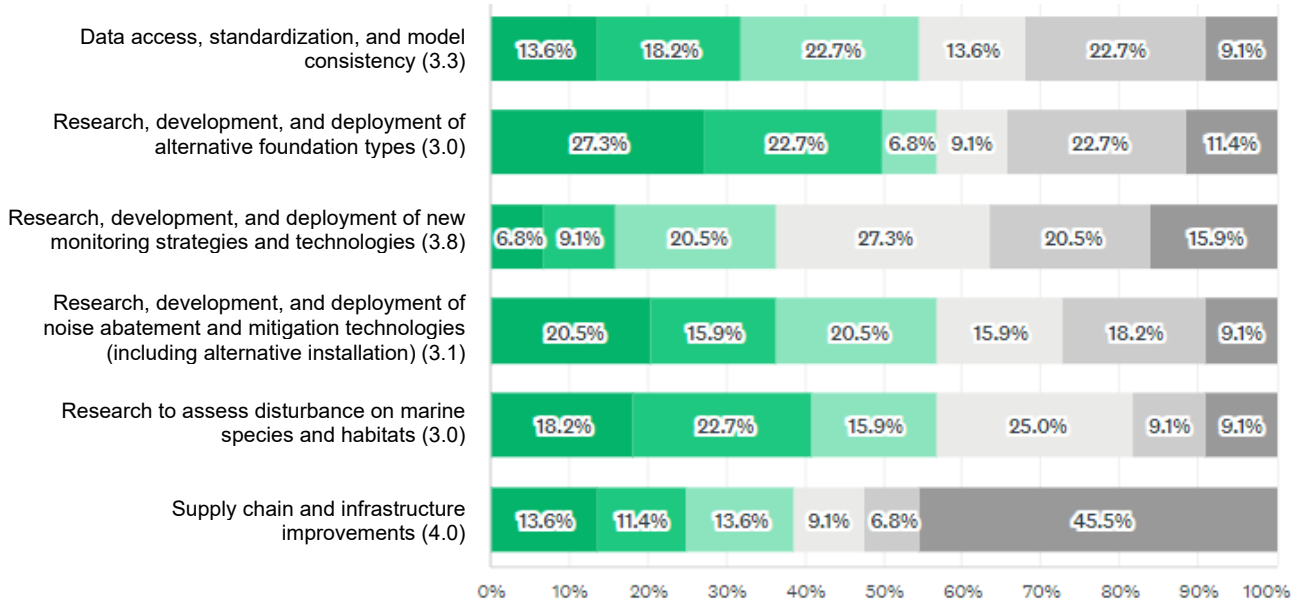

Figure 3: Distribution of highest priority noise reduction needs in the long term (dark green represents highest priority; dark gray represents lowest priority). The average score is noted next to the topic.

4. **What level of impact could be achieved with <u>$1–$10 million</u> and <u>$10–$20 million</u> if directed to support noise reduction R&D needs?**

For Question 4, respondents were asked to assess the potential impact of investing $1–$10 million and $10–$20 million in six noise reduction research and development topics by assigning a value of 1 (highest impact) to 5 (lowest impact). Forty-four respondents answered the question and two did not answer the question. Unlike Questions 2 and 3, impact levels were not ranked (i.e., a respondent could answer that investment in two different research needs were equally impactful). Figures 4 and 5 show the percentage distribution of responses for each need. The average score for each need is presented below (lowest score = highest priority).

$1–$10 million

Data access, standardization, and model consistency ranked highest in impact with an average score of 2.0 and 65% of respondents assigning a score of 1 or 2. *Research to assess disturbance on marine species and habitats* ranked second with an average score of 2.5, with 53.7% of respondents assigning a score of 1 or 2. *RDD of new monitoring strategies and technologies* ranked third with an average score of 2.6 and 47.5% of respondents assigning a score of 1 or 2. *RDD of noise abatement and mitigation technologies (including alternative installation techniques)* ranked fourth with an average score of 2.7 and 45% of respondents assigning a score of 1 or 2. *Supply chain and infrastructure improvements* and *RDD of alternative foundation types* tied for last with average scores of 3.8, but 10.8% of respondents assigned a score of 1 or 2 for *supply chain and infrastructure improvements*, and only 7.7% assigned a score of 1 or 2 for *RDD of alternative foundation types*.

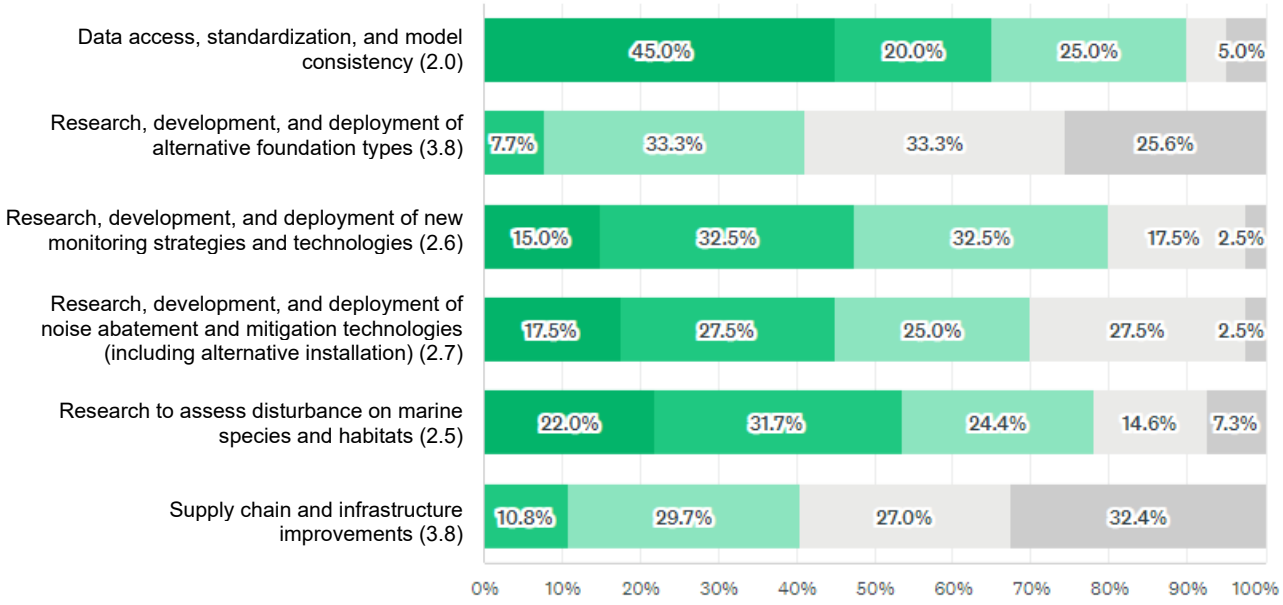

Figure 4: Distribution of perceived impact of $1–$10 million in various noise reduction research and development needs (dark green represents highest impact (1) and dark gray is lowest impact (5)). The average score is noted next to the topic

$10–$20 million

RDD of noise abatement and mitigation technologies (including alternative installation techniques) and *research to assess disturbance on marine species and habitats* tied for highest impact with average scores of 1.7, but 87.2% of respondents assigned a score of 1 or 2 for *RDD of noise abatement and mitigation technologies (including alternative installation techniques)*

while 85% assigned a score of 1 or 2 for *research to assess disturbance on marine species and habitats*. *Data access, standardization, and model consistency* ranked next with an average score of 1.8 and 71.1% of respondents assigning a score of 1 or 2. *RDD of new monitoring strategies and technologies* ranked next with an average score of 1.9, but more respondents (74.4%) assigned a score of 1 or 2 than they did for *data access, standardization, and model consistency*. *RDD of alternative foundation types* ranked next with an average score of 2.5 and 57.9% of respondents assigning a score of 1 or 2. Finally, *supply chain and infrastructure improvements* ranked last with an average score of 2.8 and 43.2% of respondents assigning a score of 1 or 2.

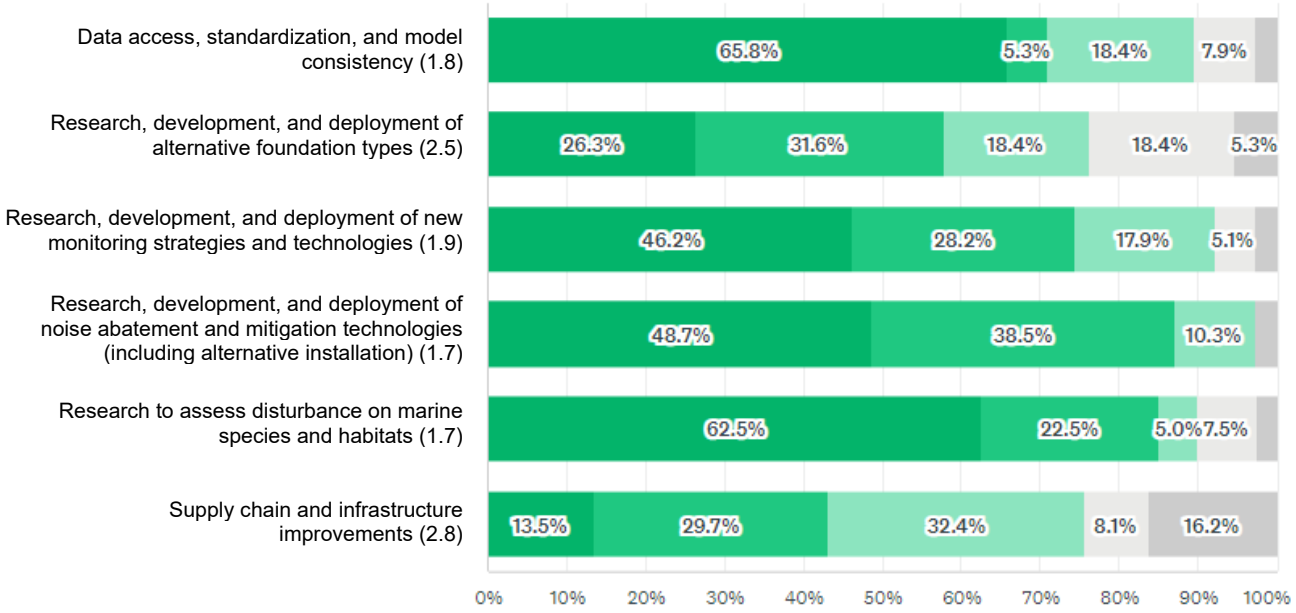

Figure 5: Distribution of perceived impact of $10–$20 million in various noise reduction research and development needs (dark green represents highest impact (1) and dark gray is lowest impact (5)). The average score is noted next to the topic

5. Which of the following <u>noise abatement and mitigation technologies</u> are most promising for reducing the noise associated with the installation of fixed-bottom foundations? Please select your top three choices.

For Question 5, 44 respondents selected three choices for the most promising noise abatement and mitigation technologies and 2 respondents did not answer the question. The noise abatement and mitigation technology options presented in the questionnaire were informed by the workshop outcomes. Figure 6 shows that *bubble curtains (e.g., single, double, enhanced)* received 24 votes (54.5%), *new hammer technologies (e.g., PULSE®, MENCK Noise Reduction Unit)* received 21 votes (47.7%), the *Hydro Sound Damper* received 18 votes (40.9%), *resonator systems (e.g., AdBm Noise Mitigation System)* received 16 votes (36.4%), *modified pile driving (e.g., smaller pile diameter, reducing tip resistance and friction)* received 11 votes (25.0%), *noise mitigation screens (e.g., IHC Offshore Systems)* received 11 votes (25.0%), and *prolongation of the impulse duration (e.g., BLUE piling)* received 11 votes (25.0%). There were also 10 votes (22.7%) for *other*. The “other” responses include:

- Using alternative foundations not requiring pile driving or using combinations of technologies.
- We should be moving away from monopiles and fixed installation.

- Suction pile foundations.
- Noiseless installation techniques such as those used with GBS foundations.
- European data indicates combination of near- (e.g., HSD, AdBm) and far-field (e.g., bubble curtain) treatments produces the best noise reduction. We think new hammer technologies/modified pile driving show promise, but we haven't seen data on their effectiveness to feel comfortable including them in this selection (see Q6).
- Double-walled pile driving.
- Vibro driving.
- Tools/techniques that liquify the soil (e.g., vibratory/jetting).
- Subsea quieter.
- Time-of-year restrictions and effective monitoring.

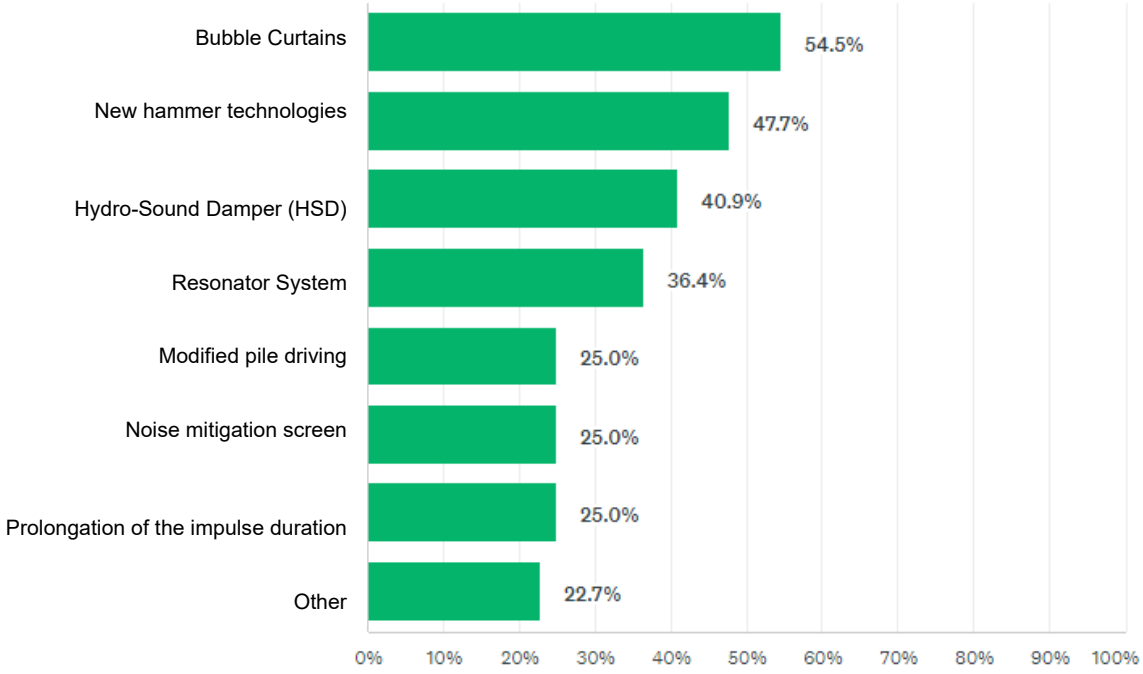

Figure 6: Most promising noise abatement mitigation technologies for use in fixed-bottom installations.

6. For the noise abatement and mitigation technologies you selected above, what is the highest priority R&D need?

For Question 6, 32 respondents provided the highest priority research and development needs, and 14 respondents did not answer the question. The responses are provided below and grouped according to technology. Some respondents commented on more than one technology, so more than 32 comments are below.

Bubble Curtains

- Enhanced bubble curtains need demonstration testing (at scale and in representative installation conditions).
- Enhancements that optimize power usage for bubble curtain solutions (e.g., reduce power usage, increase robustness).
- Adaptation of system configuration to be able to achieve good noise reduction in water depth >40 m.

- Development and real offshore tests of the enhanced Big Bubble Curtain (BBC).
- Increase the amount of BBC suppliers and have well-experienced suppliers.
- Habituation by marine species to the presence of bubble curtains.

New Hammer Technologies

- New hammer technologies, blue piling, and other modifications have the potential to reduce low-frequency sound/transmission of sound/vibrations through the substrate and should be combined with a near- and far-field noise abatement system.
- New hammer technologies [two responses].

Hydro Sound Damper (HSD)

- Further optimization of HSD systems.
- Noise mitigation systems and damping systems.
- Is there any possibility to increase the noise reduction <100 Hz?

Resonator System

- Am not an expert but from past experience developing vibrating corers, the resonator system appears to have potential.
- Demonstrations on how resonator systems can be optimized for hammer quieting would benefit the entire industry as well as the environment.
- Deployment of resonator system.
- AdBm [noise mitigation system].

Modified Pile Driving

- For modified pile driving we need to have the spectral data measured in the field to understand how the noise mitigation technologies should adjust to work optimally for them.
- Modification to pile driving and pile driving equipment to reduce noise generated.

Noise Mitigation Screen (NMS)

- How to scale the NMS with increasing pile diameter and water depth with respect to weight, size, and vessel capacity.

Prolongation of the Impulse Duration

- Prolongation of the impulse duration.
- Blue piling.

Other

- Design code is based upon hammering (need to expand for alternative and hybrid installation techniques).
- Demonstration/pilot testing of alternative and hybrid installation techniques.
- Involvement of all included parties.
- Should be informed by a review to determine which technologies have greatest promise in reducing the generation and propagation of low-frequency noise.
- Effects on environment, noise measurements and evaluation/comparison with other installation technologies (impact driving).
- This is hard to answer because there are several components of noise to consider (i.e., in water and sound that enters the sediment and comes back). There is also a frequency (kHz) component to think about, so it may depend on what taxa is of greatest concern.

- Investigating new technologies that are quieter and reduce the noise impact to marine life, while also being robust and quick. Reducing the time that sound is going into the water would reduce potential impacts.
- Demonstrating the efficiency of the novel methodologies through full-scale offshore testing, which is accompanied by independent (third-party) noise measurements and modeling.
- Focus should be on technologies that already show some promise at the R&D level that can be scaled up quickly and be cost-effective.
- Frequency-dependent studies i.e., which frequencies are abated and alignment with key priority species. For example, in Europe, bubble curtains are very effective because they reduce sound levels at higher frequencies; this may be less relevant for baleen whales in U.S. waters.
- How the supply chain in the United States can be improved and brought to European Union/Asian standards (with respect to product quality and cost level).
- The highest need is a regulatory requirement that demands much more abatement. The developers and contractors will do what they must.
- Adaption to U.S. conditions such as tide.
- Getting the most effective methods, particularly concerning reducing exposure to low-frequency-hearing animals available and used ASAP.
- Better planning of locations of wind developments away from critical habitats, ESA [Endangered Species Act] species, and high-value resource areas.
- Systems that can maximize low-frequency decibel reduction significant enough to bring distances down to observable areas for baleen whales and fish and broadband reductions elsewhere.
- Adjusting the systems to increase the low-frequency (<500 Hz) sound abatement.

7. Which of the following alternative foundation types is most promising for reducing the noise associated with installation of offshore wind turbines?

For Question 7, 42 respondents selected a promising alternative foundation type, and 4 respondents did not answer the question. In total, *suction buckets* received 20 votes (47.6%), *gravity-based foundations* received 8 votes (19.0%), *jacket foundations* received 8 votes (19.0%), and *shallow water floating foundations* received 4 votes (9.5%). There were also 2 votes (4.8%) for *other*. The responses are summarized in Figure 7. The “other” responses include:

- Suction bucket tripods.
- Technologies that don't require impact pile driving or could be installed with low noise but still are robust enough to withstand environment.

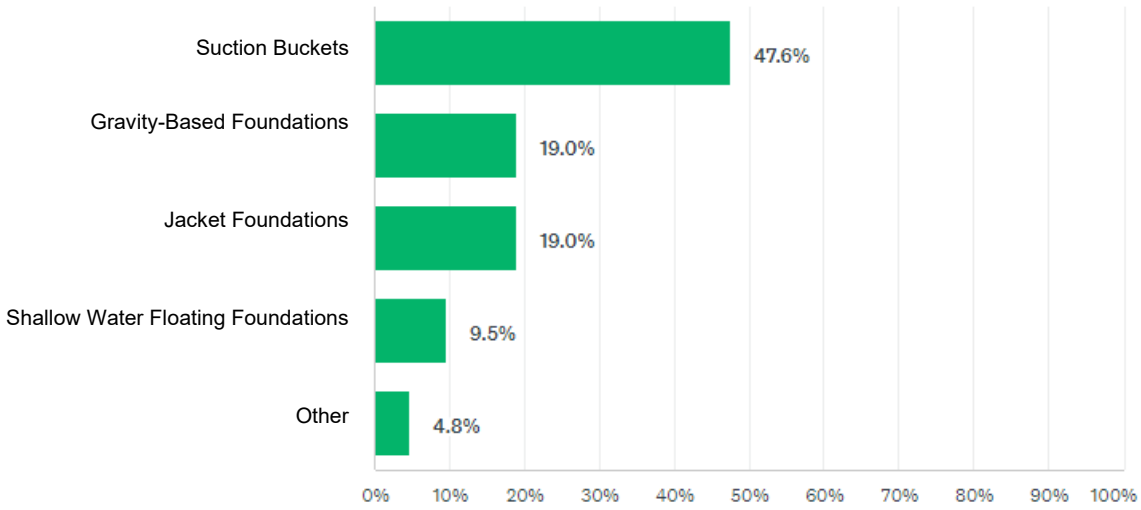

Figure 7: Alternative foundation types promising for reducing noise.

8. For the alternative foundation type you selected above, what is the highest priority R&D need?

For Question 8, 30 respondents detailed the highest priority need and 16 respondents did not answer the question. The responses are provided below and grouped according to foundation type.

Suction Buckets

- Suction buckets and gravity-based seem like best options for R&D in shallow water.
- Shallow water stability of the suction bucket.
- Install ability in layered soils, optimization of steel structures (cost reduction), and mass fabrication of substructures.
- Installation feasibility in layered soils.
- Identification of the conditions where this alternative foundation can be used and research into whether the technology can be modified to be used in a wider range of conditions.
- Testing and deployment in U.S. waters, supply chain establishment, if needed.
- Feasibility of suction bucket jackets for larger turbines and different ground conditions
- Supply chain development. How can we make this technology more economically available and desirable to offshore wind developers and states in contracting?
- Sound verification measurements during installation (i.e., is this a quieter foundation), technology development to reduce bucket size.
- Suction monopile to reduce costs.
- Enhancements on reliable jacket suction buckets so that costs and installation time can be reduced.
- How to improve U.S. fabricators' capacity to be able to produce large steel or concrete structures of the size of a typical jacket (100 m height/2,500 t).
- Motivation.
- Proof of concept for large turbines for conditions on the U.S. East Coast continental shelf to reduce perceived risk from an engineering standpoint, which seems to be what is preventing adoption and investments.

- Technical feasibility in different environments, stability, and supply chain in the U.S.

Gravity Based

- Possibility to use gravity-based structure (GBS) foundations with no need for seabed preparations as has been the case often with GBS structures for oil and gas.
- Potential use in deeper waters than is now possible.

Jacket Foundations

- Integration of noise mitigation into piling template.
- To find a method of construction that is more competitive than the actual way of manufacturing jackets.
- Cost optimization of the jackets to make it more comparable to monopiles (e.g., supply chain).
- Fabrication/automation, supply chain improvements.
- Jackets still require pile driving (so I am not sure why they are being considered?). It would be helpful to have a better understanding of when monopiles vs. jackets can be used.

Shallow Water Floating Foundations

- Deconflicting competing space uses.
- Stability for very large turbines being proposed.

Other

- Suction bucket tripods: fatigue analysis and fabrication/industrialization.
- Determining alternate foundations that don't increase risk of animal entanglement while also being quieter to install and potentially require less equipment.

9. What is the highest priority environmental research focus to better understand and assess underwater noise and associated mitigation effects on species and habitats?

For Question 9, 45 respondents selected a highest priority environmental research focus, and one respondent did not answer the question. Figure 8 shows *determining hearing thresholds and potential impacts for key marine species* received 21 votes (46.7%), *better understanding the potential effects of particle motion* received 11 votes (24.4%), and *disturbance to benthic habitats through use of alternative foundations* received 5 votes (11.1%). There were also 8 votes (17.8%) for *other*. The “other” responses include:

- Better understanding the context-dependent likelihood of behavioral responses and the consequences to populations.
- Behavioral impacts, including foraging disturbance and energetic consequences on individuals.
- There is nothing about understanding behavioral impacts of noise as an option. Also is this question just focused on construction or does it also consider operation? There is also the issues of multiple wind farms being constructed at the same time (i.e., cumulative effects during both construction and operation).
- Population consequences of disturbance and understanding of behavioral and physical response and how that does or does not affect fitness.
- Determining hearing thresholds and potential impacts for key marine species with regard to comparison on impact vs. vibro installation.

- Understanding the effects of noise during operations.
- Understanding whether there could be a more functional target/zone for sound propagation and verification that can be established (like European regulations) that then allows developers to progress technologies and techniques to meet that standard. Research to understand/align around a functional target would be extremely beneficial.
- High investment in situ monitoring of dozens of species of interest as first projects are deployed. Don't need more models.

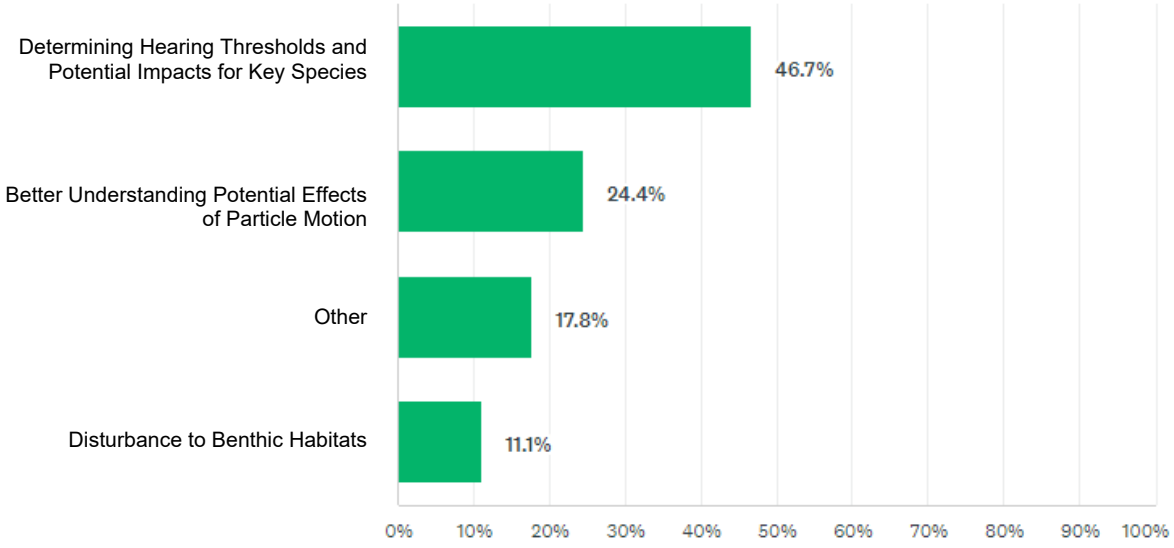

Figure 8: Highest priority environmental research focal areas.

10. With regard to underwater noise requirements for permitting and authorization, what is the highest priority need related to data access, standardization, and model consistency?

For Question 10, 45 respondents selected a highest priority need related to data access, standardization, and model consistency and one respondent did not answer the question. Figure 9 shows *data access, sharing, and transparency* received 16 votes (35.6%), *standardization of data collection and modeling* received 13 votes (28.9%), *model development and validation* received 12 votes (26.7%), and adva*nces in efficiency for processing and analysis of large data sets (archival and real-time)* received 2 votes (4.4%). There were also 2 votes (4.4%) for *other*. The "other" responses include:

- It's three of these: data access, sharing, transparency AND standardization AND validation of predictive models.
- I am not sure what kind of data are being mentioned here? Data for modeling sound, data for detecting taxa in the area? Sorry, I am not sure how to answer this.

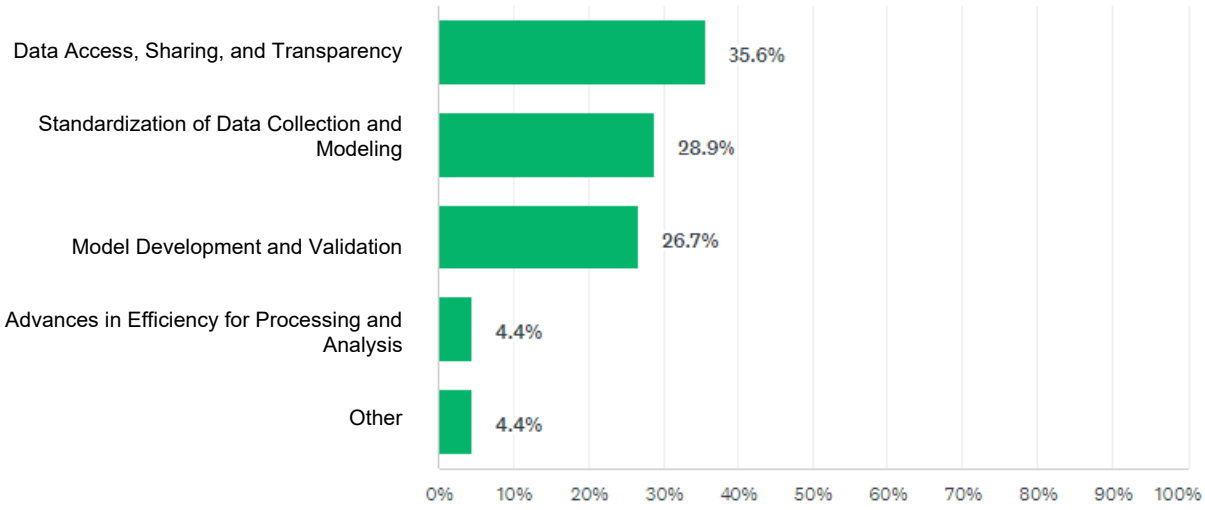

Figure 9: Highest priority need related to data access, standardization, and model consistency.

11. What is the highest priority need related to supply chain and infrastructure improvements to facilitate access to technologies and alternative foundations in the U.S.?

For Question 11, 44 respondents selected the highest priority need related to supply chain and infrastructure improvements and two respondents did not answer the question. The improvement options presented in the questionnaire were derived from the workshop outcomes. Figure 10 shows *access to and availability of noise abatement and monitoring technologies* received 14 votes (31.7%), *increased production capacity for alternative foundation material types* received 13 votes (29.5%), *increased specialized vessel availability* received 10 votes (22.7%), and *port improvements* received 5 votes (11.4%). There were also 2 votes (4.5%) for *other*. The “other” responses include:

- Type certification.
- All the above.

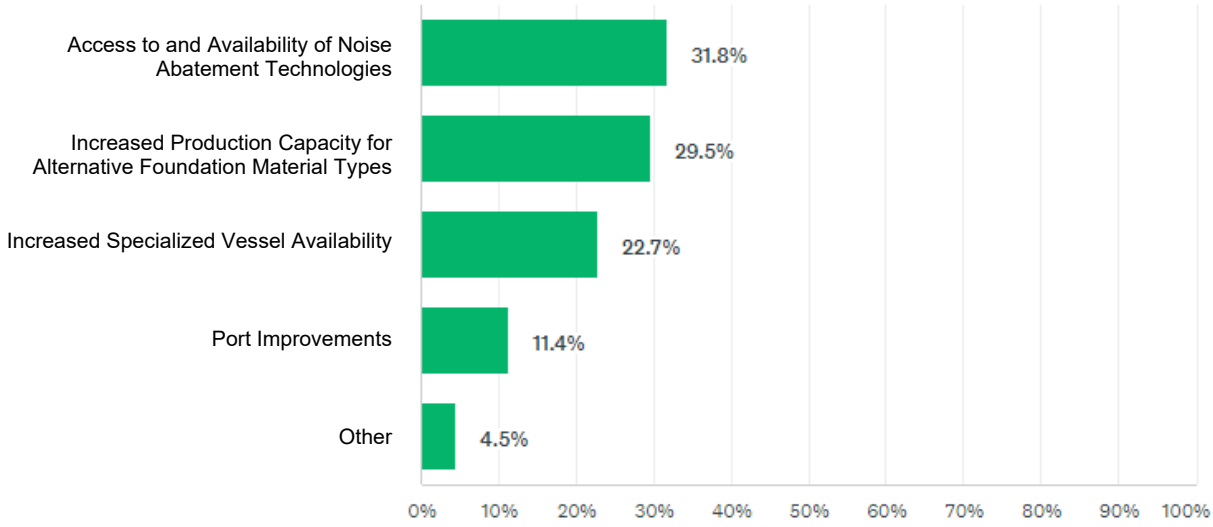

Figure 10: Highest priority need related to supply chain and infrastructure improvements.

12. If you would like to provide any additional feedback related to underwater noise reduction, please do so below.

For Question 12, 13 respondents provided additional feedback and 33 respondents did not answer the question. The responses are provided below and grouped according to topic area.

<u>Environmental</u>

- Need ongoing environmental monitoring during baseline, installation, operation and decommissioning.
- Updated behavioral thresholds/criteria for sound exposure would be most useful, particularly for marine mammals. Removal of outdated dB RMS [decibel root mean square] thresholds for impulsive sources would also improve the accuracy of noise impact assessment.
- Although not directly a noise abatement, I think we have not looked sufficiently at offset mitigation where noise is not avoidable. It is important to conduct some research on what offsets might be biologically substantive for protecting affected species.
- Apologies, but it is not possible to answer these questions in a general way. The actual issues with noise are highly project-specific, relating to what sensitive species are in the area, and what options and alternatives are technically possible for mitigation.

<u>Research & Development</u>

- Using combinations of near-field and far-field noise mitigation methods for improving results.
- [Company A] is developing an active noise cancellation system for ships that if successful could be adapted to cancel coherent very low-frequency noise emitted by operational turbines.
- Establish different levels of sensitivity dependent upon location or season.
- Promote the use of noiseless foundation solutions, such as GBS, which shall remain noiseless regardless of offshore wind turbine generators fast growth. Does it make sense to invest largely on piling noise mitigation measures that will hardly keep up with

the evident trend toward larger wind turbines. A solution that cannot be efficiently scaled is no solution for offshore wind.

Regulatory

- Government acoustic regulations should be written to encourage the use of less impactful installation methods.
- Monopiles are currently categorized as “manufactured product” in Inflation Reduction Act guidance while suction bucket jackets (SBJs) are "steel/iron"—this makes it highly beneficial to projects to choose the “louder” monopiles versus SBJs. Thinking through the financial and performance-based incentives and targets for developers on these technologies is critical, otherwise there will be little appetite for progressing on the deployment side.
- Appreciate the research and development focus here, but it is the regulatory drivers that are the biggest obstacle to progress. If the regs allow status quo, then that’s what we will get. $20 million is a drop in the bucket. Set a high bar and let industry figure out how to meet it.

Data

- More and easier data access, sharing, and transparency would help a lot.

General Comments

- We intentionally chose the same answers for Q2 and Q3, because we feel the short-term investments will also solve the issue in the long term.
- I think any of the above that can make things quieter should be a priority (i.e., it is hard to really rank any of these because they could all make a difference).

Summary

Respondents

The project team distributed the questionnaire to 255 potential respondents, identified from the December 2022 workshop list. In total, 46 respondents completed the survey, the majority of whom identified as an *Environmental Scientist* or *Researcher*, *Government Representative*, or an *Offshore Wind Project Developer*. This bias may have influenced the results of the questionnaire. For example, none of the respondents identified as *Supply Chain Representatives*, and *supply chain and infrastructure improvements* consistently ranked lower than others. Similarly, 15 (32.6%) respondents identified as either an *Environmental Scientist/Researcher* or *Environmental Consultant*, and *research to assess disturbance on marine species and habitats* ranked higher in impact and priority than other topics. This may reflect the need's importance to respondents in the environmental field rather than its importance to a broader stakeholder group.

Analysis

Questions 2 and 3 asked respondents to rank six topics that could address noise reduction needs in the short and long term from highest priority (#1) to lowest priority (#6). Similarly, Question 4 asked respondents to assess the potential impact of investing $1–$10 million and $10–$20 million in the same six noise reduction research and development topics by assigning a value of 1 (highest impact) to 5 (lowest impact). The average scores calculated for each noise reduction need in Questions 2–4 are summarized in Figure 11. The noise reduction needs with the lowest average scores are the highest priority and highest impact.

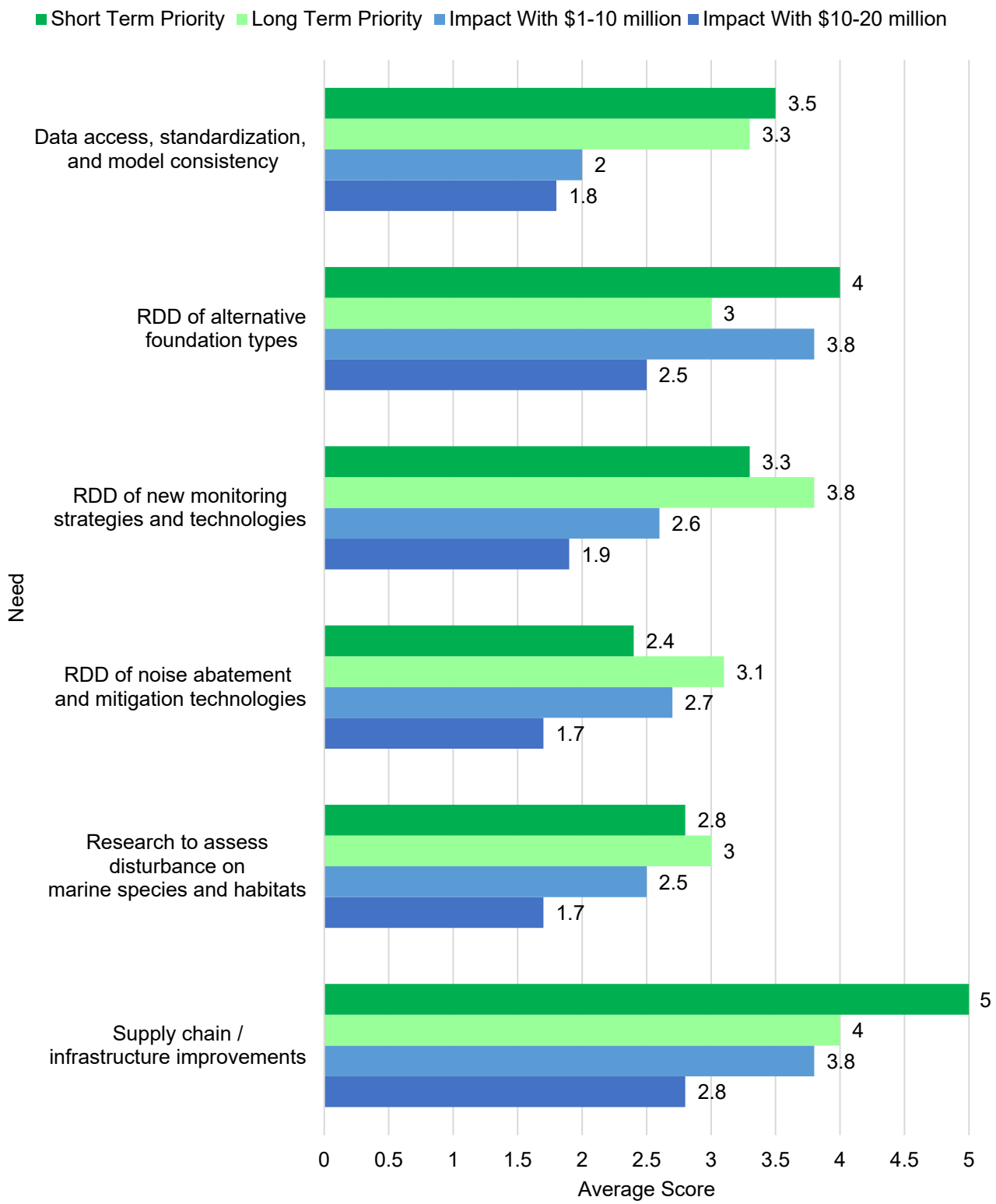

Figure 11: Summary of priority and funding impact for noise reduction research needs. Lower scores are higher priority/impact.

Overall, *RDD of noise abatement and mitigation technologies (including alternative installation techniques)* ranked highest priority in the short term and tied with *research to assess disturbance on marine species and habitats* for highest impact with an investment of $10–$20 million. *Research to assess disturbance on marine species and habitats* also tied with *RDD of alternative foundation types* for highest priority in the long term, with scores of 3.0 and 56.8% of respondents scoring them as first, second, or third. However, *RDD of noise abatement and mitigation technologies (including alternative installation techniques)* ranked closely behind with an average score of 3.1 and 56.9% of respondents scoring it as first, second, or third, suggesting all three needs are approximately equal in priority in the long term.

The results from Questions 5–9 provide additional details on these priorities. For example, the most promising noise abatement and mitigation technologies for reducing the noise associated with the installation of fixed-bottom foundations were *bubble curtains (e.g., single, double, enhanced)* (54.5%), *new hammer technologies (e.g., PULSE®, MENCK Noise Reduction Unit)* (47.7%), and the *Hydro Sound Damper* (40.9%). The most promising alternative foundation type for reducing the noise associated with installation of offshore wind turbines were *suction buckets* (47.6%). Respondents also identified the need to understand the technical feasibility of suction buckets in different environments and soil conditions, stability with larger turbines, and supply chain in the United States. Finally, the highest priority environmental research focus to better understand and assess underwater noise and associated mitigation effects on species and habitats was *determining hearing thresholds and potential impacts for key species* (46.7%).

Data access, standardization, and model consistency ranked highest impact with an investment of $1–$10 million and received the largest proportion of highest priority rankings (1) than any other need for both $1–$10 million (45%) and $10–$20 million (65.8%). Regarding underwater noise requirements for permitting and authorization, the highest priority need was *data access, sharing, and transparency* (35.6%) (Question 10). *Standardization of data collection and modeling* (28.9%) and *model development and validation* (26.7%) ranked second and third, respectively.

Supply chain and infrastructure improvements consistently ranked amongst the lowest priority and lowest impact need. Nonetheless, the highest priority need related to supply chain and infrastructure improvements to facilitate access to technologies and alternative foundations in the U.S. was *access to and availability of noise abatement and monitoring technologies* (31.7%) (Question 11). *Increased production capacity for alternative foundation material types* (29.5%) and *increased specialized vessel availability* (22.7%) ranked second and third, respectively.

Recommendations

The results of the questionnaire identified several research and development priorities for reducing underwater noise associated with fixed-bottom offshore wind turbine installation in U.S. waters. *RDD of noise abatement and mitigation technologies* and *research to assess disturbance on marine species and habitats* were both high priorities in the short and long term and would be most impactful with an investment of $10–$20 million. Examples of research in these areas in the workshop report substantiate the comments from respondents in the questionnaire. The questionnaire results serve to further refine the topic areas to prioritize.

Additionally, resources focused on *data access, standardization, and model consistency*, such as efforts to improve and develop sound propagation models, including the incorporation of mitigating measures, would have a high impact at either funding level.

Appendix A: Questionnaire

The purpose of this questionnaire is to gather feedback from industry and other stakeholders on **the research and development (R&D) priorities for reducing underwater noise associated with fixed-bottom offshore wind turbine installation** in U.S. waters. The questionnaire features 12 questions and should take less than 10 minutes of your time.

1. What is your role? **Select one.**
    - Offshore Wind Project Developer
    - Offshore Wind Foundation Developer
    - Noise Mitigation/Abatement Technology Developer
    - Environmental Scientist or Researcher
    - Environmental Consultant
    - Government Representative
    - Supply Chain Representative
    - Contractor
    - Other (please specify)

To help facilitate the United States' goal of 30 GW by 2030 and over 110 GW by 2050...

2. What are the highest priority noise reduction needs to be addressed in the short term (to achieve successful deployment targets by 2030)? Please rank in order of priority from highest priority to lowest priority. **Forced ranking 1-6 (1 is highest priority, 6 is lowest priority).**
    - Data access, standardization, and model consistency
    - Research, development, and deployment of alternative foundation types
    - Research, development, and deployment of new monitoring strategies and technologies
    - Research, development, and deployment of noise abatement and mitigation technologies (including alternative installation techniques)
    - Research to assess disturbance on marine species and habitats
    - Supply chain and infrastructure improvements

3. What are the highest priority noise reduction needs to be addressed in the long term (to achieve successful deployment targets by 2050)? Please rank in order of priority from highest priority to lowest priority. **Forced ranking 1-6 (1 is highest priority, 6 is lowest priority).**
    - Data access, standardization, and model consistency
    - Research, development, and deployment of alternative foundation types
    - Research, development, and deployment of new monitoring strategies and technologies
    - Research, development, and deployment of noise abatement and mitigation technologies (including alternative installation techniques)
    - Research to assess disturbance on marine species and habitats
    - Supply chain and infrastructure improvements

4. What level of impact could be achieved with $1–$10 million and $10–$20 million if directed to support noise reduction R&D needs? **Scoring each in terms of 1 (high impact) to 5 (low impact).**

- Data access, standardization, and model consistency
- Research, development, and deployment of alternative foundation types
- Research, development, and deployment of new monitoring strategies and technologies
- Research, development, and deployment of noise abatement and mitigation technologies (including alternative installation techniques)
- Research to assess disturbance on marine species and habitats
- Supply chain and infrastructure improvements

5. Which of the following noise abatement and mitigation technologies are most promising for reducing the noise associated with the installation of fixed-bottom foundations? Please select your top three choices. **Select top three choices.**
    - Bubble Curtains (e.g., single, double, enhanced)
    - Hydro Sound Damper (HSD)
    - Modified pile driving (e.g., smaller pile diameter, reducing tip resistance and friction)
    - New hammer technologies (e.g., PULSE®, MENCK Noise Reduction Unit)
    - Noise Mitigation Screen (e.g., IHC Offshore Systems)
    - Prolongation of the impulse duration (e.g., BLUE piling)
    - Resonator system (e.g., AdBm Noise Mitigation System)
    - Other (please specify)

6. For the noise abatement and mitigation technologies you selected above, what is the highest priority R&D need? **Open response.**

7. Which of the following alternative foundation types is most promising for reducing the noise associated with installation of offshore wind turbines? **Select one.**
    - Gravity-based foundations
    - Jackets foundations
    - Shallow water floating foundations
    - Suction buckets
    - Other (please specify)

8. For the alternative foundation type you selected above, what is the highest priority R&D need? **Open response.**

9. What is the highest priority environmental research focus to better understand and assess underwater noise and associated mitigation effects on species and habitats? **Select one.**
    - Better understanding the potential effects of particle motion
    - Determining hearing thresholds and potential impacts for key marine species
    - Disturbance to benthic habitats through use of alternative foundations
    - Other (please specify)

10. With regard to underwater noise requirements for permitting and authorization, what is the highest priority need related to data access, standardization, and model consistency? **Select one.**
    - Advances in efficiency for processing and analysis of large data sets (archival and real-time)
    - Data access, sharing, and transparency
    - Model development and validation

- Standardization of data collection and modeling
- Other (please specify)

11. What is the highest priority need related to supply chain and infrastructure improvements to facilitate access to technologies and alternative foundations in the U.S.? **Select one.**
    - Access to and availability of noise abatement and monitoring technologies
    - Increased production capacity for alternative foundation material types
    - Increased specialized vessel availability
    - Port improvements
    - Other (please specify)

12. If you would like provide any additional feedback related to underwater noise reduction, please do so below. **Open response.**