Environmental Effects of Off-Grid Marine Renewable Energy

August 2025
Workshop report from the
Ocean Renewable Energy Conference, Corvallis, Oregon, United States

Background

Most environmental research and monitoring for marine renewable energy (MRE) devices have sought to understand effects that will drive permitting and licensing decisions for large, utility-scale projects. However, many near- and long-term uses of MRE will be to power remote coastal and island communities via distributed technologies, or to provide power at sea for offshore aquaculture, ocean observations, and other uses. Community-scale energy generation by MRE devices will require transmitting the power to shore via an export cable, while power-at-sea uses will generate and use the power without connection to shore in most cases. These applications are likely to operate on a much smaller scale than utility-scale MRE devices. There has been little focus on the potential environmental effects for these increasingly more common off-grid uses. The smaller MRE devices required for these applications are likely to have different, and possibly lower, environmental effects than large-scale MRE projects.

In August 2025, OES-Environmental hosted a workshop at the 2025 Ocean Renewable Energy Conference in Corvallis, Oregon, United States (U.S.), to discuss the potential environmental effects of off-grid MRE devices with interested MRE researchers, students, technology and project developers, consultants, and other industry proponents.

Throughout the workshop, Poll Everywhere, an online polling platform, was used to gather participant feedback and provide an interactive component to the workshop. The workshop began with general introductions and "icebreaker" questions to understand how participants generally view off-grid MRE. Following the introductions, a brief presentation[1] was given on the work of OES-Environmental that includes the reasons for focusing on off-grid applications, examples of current off-grid MRE projects, and the potential environmental effects (or stressor-receptor interactions) that have been given priority to date in research and regulatory contexts. The presentation was followed by an overview of two use cases for breakout group discussions:

1. Tidal energy to power the remote community of Stuart Island, Washington, U.S.
2. Wave energy to power a coastal weather observation buoy in Shelikof Strait, Alaska, U.S.

These two hypothetical use cases were created to be informative to non-experts in order to trigger discussions. Following the description of the use cases, four breakout groups were

[1] Presentation accessible on the workshop webpage https://tethys.pnnl.gov/events/environmental-effects-grid-marine-energy

formed, with each group discussing both of the use cases, one after the other, to address the following discussion points:

- What environmental effects would be of greatest concern?
- How would the environmental effects of small off-grid applications compare to those of utility-scale applications with (multiple) large devices?
- Would off-grid applications be easier to implement than utility-scale projects? Why?
- How would regulatory processes address smaller-scale applications differently?
- What challenges do you think that off-grid applications may be facing?

These questions were selected to start the conversation with the MRE community about environmental effects of off-grid applications, to gauge the interest and trigger an appetite for deeper investigation.

This document provides a high-level overview of the discussions held by the workshop participants for each of these questions, for the two use cases. At least 54 people attended the workshop. The attendees' list is provided as appendix.

Icebreaker Poll Question

Before the general presentation, the team used Poll Everywhere to ask the audience an icebreaker question ("What brought you to this workshop?") and took a few minutes to discuss the responses.

The three main recurring entries were 'whales', 'environmental impacts' / 'environmental effects', and 'energy', with some other entries directly related to the workshop topic, like 'collision', 'entanglement', and 'noise' (Figure 1). Other interesting entries indicated an appetite, from workshop participants, for more information: 'search for information', 'curiosity', and 'engage with colleagues'.

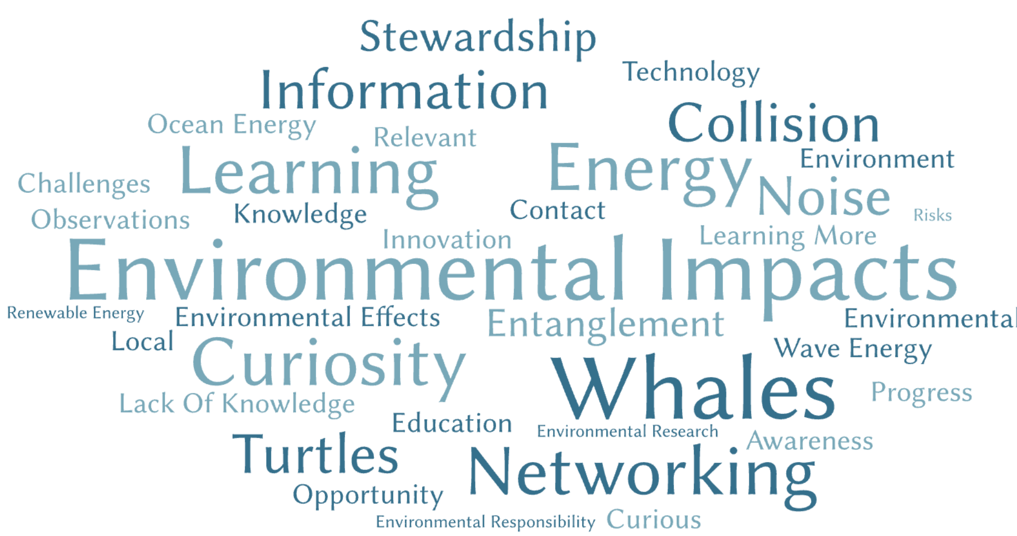

Figure 1. Word cloud of responses to the icebreaker poll question "What brought you to this workshop?". Text size increases with number of entries.

Two additional ice breaker questions were asked using Poll Everywhere, about whether MRE is relevant for powering remote coastal communities and islands as well as powering ocean observation buoys at sea, to which all participants agreed.

Discussion

The breakout discussions centered around each of the two use cases. Since the Stuart Island use case and Shelikof Strait use case were discussed by all breakout groups, all the responses to the discussion questions for each use case are reported together. The breakout groups were guided by the discussion questions, and Poll Everywhere was used to report about each use case. Through Poll Everywhere, each participant reported what stood out for them from their group's discussion. Because the technology aspect was only partially described for the two use cases, some groups spent a significant amount of time discussing technological details relevant to the scenarios presented. While notetakers transcribed those discussions, only answers relevant to the discussion questions are presented here to remain on scope. The subsections below present the report-out responses (with necessary grammatical edits where appropriate), combined when addressing similar points, and augmented by notes from the group facilitators; bullets are not ranked by any sense of greater or lesser concern.

Stuart Island remote island community tidal energy use case

- What environmental effects would be of greatest concern?
  - Risk of collision with large marine mammals and other protected species, with potential for increased attention and concern for 'charismatic megafauna'.
  - Changes or disruptions to habitat, especially nearshore and deep-water habitats.
  - Proximity to estuarine system.
  - Scour and sediment disruption due to turbine activity.
  - Biofouling of devices and its effects on marine ecosystems.
  - Long-term impacts on biodiversity of materials left underwater (e.g., anti-fouling, chemical leaching, corrosion).
  - Effects to invertebrates during installation (e.g., compaction).
  - Biodiversity loss and migratory pattern alterations.
  - Underwater noise effects from turbine.
  - Electromagnetic fields (EMF) from cable disrupting species behavior.
  - Tribal acceptance and community cultural considerations.
  - Visual effects of any above-water components (e.g. marker buoys with artificial lights, light reflection).
  - Competing uses and priorities of affected communities (e.g., fishing restrictions).

- How would the environmental effects of small off-grid applications compare to those of utility-scale applications with (multiple) large devices?
  - Smaller-scale applications would generally have fewer environmental impacts because of reduced footprints.
  - Small-scale applications are less likely to block migration paths or affect flushing rates in coastal regions.

  - Small off-grid systems impact a localized area and specific species, whereas large arrays may disrupt broader ecosystems.
  - Collision risk may be lower for fewer devices but could remain significant on a per-device basis.
  - Monitoring smaller systems can be challenging but involve less severity compared to utility-scale effects.
  - Small-scale projects may be perceived as more beneficial than larger corporate utility applications; however, it is important to engage with the community.
  - Utility-scale projects could lead to amplified effects, such as larger exclusion zones and migration disturbances.
  - Underwater noise and long-term bathymetric changes due to sediment scour would be more pronounced in large-scale setups.
  - Utility-scale deployments may introduce additive effects, such as interaction between multiple units.
  - Utility scale devices may be more visible to marine animals and contribute to higher avoidance rates.

- Would off-grid applications be easier to implement than utility-scale projects? Why?
  - Permitting might be simpler because of smaller land use and localized impacts.
  - Likely easier and faster to permit as impacts would not scale the same as utility-scale projects.
  - Off-grid applications would be easier because of reduced complexity and smaller infrastructure requirements.
  - Maintenance may be simpler because of proximity to shore, but remote locations could complicate monitoring logistics and costs.
  - Justification of monitoring costs for a single small-scale device may be difficult.
  - Economies of scale favor utility projects financially, making off-grid applications potentially more expensive for each kilowatt-hour.
  - Site-specific factors, such as community acceptance, play a major role.
  - Community acceptance may be more difficult if "not in my backyard" concerns arise.
  - Off-grid systems might require more individualized community engagement, which could present challenges.
  - Tangible benefits for small communities (e.g., lower energy costs, infrastructure electrification) should make off-grid easier to implement.
  - Implementation depends on the site and specific community dynamics.

- How would regulatory processes address smaller-scale applications differently?
  - Overall, regulatory processes for smaller-scale applications would likely be easier and more streamlined.
  - Permitting might be simplified to reflect lower risks and reduced impacts.
  - Smaller projects would allow for faster permitting processes because minimal or no impact assessment may be needed.
  - Single units are often easier to regulate compared to larger farms or utility-scale arrays.
  - Data for regulatory processes could be supplemented with in-lab testing.

  - Permitting processes and timeframes would differ.
  - Regulatory processes for smaller projects may be more difficult to understand.
  - Generally easier in the UK and Canada in comparison to the U.S.
  - Regulations may differ based on whether the project is in state versus federal waters.
  - The National Environmental Policy Act (NEPA) review process may be easier for smaller projects (e.g., environmental assessment rather than an environmental impact statement under NEPA).
  - FERC (Federal Energy Regulatory Commission) pilot licenses may be applicable for smaller-scale systems.
  - The U.S. Endangered Species Act stalls a lot of projects; it is hard to prove that a project will not affect species.
  - Monitoring could be scaled appropriately to match the system's size.
  - A lack of existing protocols for small-scale systems could introduce complexities.
  - Easier community engagement may facilitate smoother regulatory approval.

- What challenges do you think that off-grid applications may be facing?
  - Most people in relevant permitting agencies have no experience with smaller-scale applications.
  - Permitting requirements may increase costs and lead to impacts on the levelized cost of energy.
  - High costs and financial viability of small-scale projects.
  - Smaller capital availability for expensive projects.
  - Environmental impacts versus cost justification for small-scale applications.
  - The environmental footprint of monitoring may be larger than the device itself.
  - Accessibility for monitoring and maintenance.
  - Uncertainty about impacts and monitoring technology.
  - Availability of infrastructure and prior studies in off-grid areas.
  - Applicability and integration within specific off-grid communities.
  - Community buy-in and public perception challenges.
  - Social acceptance issues, including perceived risks and concerns of environmental effects.
  - Off-grid applications would provide fewer employment opportunities (e.g., maintenance) than utility-scale projects.

Shelikof Strait National Data Buoy Center buoy wave energy use case

- What environmental effects would be of greatest concern?
  - Minimal or negligible overall effects frequently noted.
  - Primary concern was entanglement of marine animals with draped cable.
  - Secondary entanglement (i.e., animals trapped in debris caught on the device, its mooring, or the draped cable).
  - Changes in habitat or displacement (e.g., artificial reef effects).
  - Disruption to wildlife pathways.
  - Noise emissions (generally low, but a potential concern).
  - EMF (from draped cable and device itself) impacts on marine life.
  - Water quality risks from device (fluid) leaks.

- Effects on fishing activity (e.g., fishing net interaction).
- Use of device as a sea lion haul out and resulting energy generation efficiency losses.
- Biofouling (e.g., attraction).
- Effects to onshore aquatic life.
- Collisions with large marine species (e.g., whales).

- How would the environmental effects of small off-grid applications compare to those of utility-scale applications with (multiple) large devices?
  - Small off-grid applications would likely have lower impact/less effect than utility-scale applications.
  - Use of a pre-existing buoy and fewer cables would lower the risks.
  - Off-grid systems would usually have smaller footprints.
  - Expected less noise, fewer stressors, and reduced EMF issues for off-grid setups.
  - Small-scale devices may have higher entanglement risk (i.e., mooring lines for larger devices can be tensioned more, small-scale devices may require more mooring lines).
  - Fewer habitat disturbances with smaller-scale devices.
  - Siting remains a critical factor for both scales.
  - Small-scale systems would create incremental changes with localized effects.
  - Smaller-scale environmental effects are manageable but not negligible.
  - Environmental effects likely less severe but still important to rely on relevant literature and invest in monitoring.
  - Utility-scale projects would likely magnify effects, especially if more cables are used.
  - The case study is feasible small scale but less likely to be feasible at larger scales (i.e., multiple weather buoys with wave energy convertors [WECs] in a small area).
  - Integrating the WEC into the weather buoy as one device may be cheaper and raise less environmental concern.
  - The assumption of decreased impact from smaller-scale devices may ease communication with communities.
  - Need to communicate to regulators and communities that there may still be uncertainty of effects (e.g., entanglement risk and/or EMF risks of the draped cable).

- Would off-grid applications be easier to implement than utility-scale projects? Why?
  - Permitting ease depends on existing policies and site-specific factors.
  - Smaller-scale impacts may lead to simpler permitting and community approval.
  - Off-grid applications would generally be co-located with existing projects, simplifying implementation.
  - Lower environmental impacts and reduced size make implementation easier.
  - Utility-scale projects face higher costs and regulatory hurdles due to economies of scale and larger impacts.
  - Small-scale devices may have lower long-term maintenance costs.
  - Reduced costs and infrastructure needs make off-grid setups more feasible for small power requirements.
  - There could be potential damage to small-scale floating WECs due to “buoy fishing” (fishers using buoys as fish aggregating devices).
  - Environmental monitoring may require more energy than the device can produce.

- Would be easier because of reduced complexity and fewer stakeholders.
- Easier communication with local communities as impacts would be more localized and direct.
- Easier to align with stakeholder understanding because of possible comparisons with offshore activities familiar to them.
- Would require early local community engagement for smoother adoption.
- Easier to align with stakeholder understanding because of possible comparisons with offshore activities familiar to them.

- How would regulatory processes address smaller-scale applications differently?
  - Permitting may be streamlined or fast-tracked for smaller-scale projects.
  - Could require less baseline data and quicker approval processes.
  - Similar regulatory questions would apply, but overall processes may be faster.
  - Co-location with existing infrastructure (e.g., buoys) can further ease permitting.
  - Regulatory processes may be easier for devices mounted to existing structures.
  - Likely simpler because of reduced risks and scale of impacts.
  - Reduced impact facilitates fewer regulatory requirements and lower costs.
  - Proving "de minimis" risk could reduce regulatory hurdles.
  - The focus would shift to local species movements and minimal impacts.
  - Liability often falls on stakeholders, potentially simplifying the process compared to public ownership.

- What challenges do you think that off-grid applications may be facing?
  - Regulators have limited familiarity and history with small off-grid technologies.
  - Regulatory burdens and permitting requirements for small-scale systems.
  - Environmental monitoring can be expensive despite smaller project scales.
  - Securing funding and interest from stakeholders.
  - Unit costs and financial benefits may be less appealing for small-scale projects.
  - Gaining social license and community buy-in.
  - Public acceptance and engagement are significant hurdles.
  - Installation and maintenance costs can be challenging.
  - Greater/stricter survivability and operations/maintenance challenges for remote installations where utility-scale projects would not go.
  - Potential conflicts with fishing communities due to exclusion zones.

Overall synthesis of the group discussions

The two use cases share many overlapping concerns, emphasizing the importance of tailored community engagement, streamlined regulatory processes, environmental monitoring, and addressing social acceptance for successful implementation of off-grid MRE applications.

- What environmental effects would be of greatest concern?
  - Risk of collision for large marine species.
  - Changes or disruptions to habitat and potential displacement of populations.
  - Underwater noise effects.

  - Electromagnetic fields (EMF) disrupting species behavior.
  - Biofouling impacts on marine ecosystems (e.g., food webs, invasive species).
  - Effects on fishing activity and potential conflicts (e.g., fishing net interaction, fishing restrictions).

- How would the environmental effects of small off-grid applications compare to those of utility-scale applications with (multiple) large devices?
  - Small off-grid applications would generally have fewer environmental impacts due to reduced footprints.
  - Utility-scale projects may amplify environmental effects due to larger footprints and more devices/cables.
  - Small-scale systems would create localized impacts, whereas utility-scale projects may disrupt broader ecosystems.
  - Environmental effects of small-scale devices would be less severe but still require monitoring.
  - Small off-grid systems are less likely to block migration paths or impact coastal processes compared to utility-scale devices.
  - Both scales necessitate attention to siting, monitoring, and mitigation strategies.

- Would off-grid applications be easier to implement than utility-scale projects? Why?
  - Off-grid applications may be easier because of the smaller infrastructure and localized impacts.
  - Permitting processes may be simpler and faster for off-grid systems compared to utility-scale projects.
  - Regulatory hurdles and economies of scale can make utility-scale projects more complex.
  - Community engagement and acceptance for off-grid projects would rely on localized benefits (e.g., tangible results like lower energy costs or better infrastructure).
  - Effective local community engagement is critical for smooth implementation of both types of projects.

- How would regulatory processes address smaller-scale applications differently?
  - Smaller-scale projects could have more streamlined or easier permitting processes because of reduced risks and impacts.
  - Permitting might require less baseline data and result in faster approval processes compared to utility-scale projects.
  - Small-scale applications may be co-located with existing infrastructure (e.g., buoys), simplifying regulatory requirements.
  - Monitoring requirements for smaller-scale systems may align with their reduced scope of impact.

- What challenges do you think that off-grid applications may be facing?
  - Regulators' limited familiarity with small off-grid systems.
  - High costs for environmental monitoring and installation, even for smaller projects.
  - Social acceptance and community engagement remain critical challenges.

- Potential conflicts with fishing communities due to device-induced exclusion zones.
- Financial viability challenges for smaller-scale projects due to economies of scale.
- Concerns over survivability and maintenance challenges for remote locations.

Summarized below are additional comments on other, less relevant, topics made by participants during the breakout group discussions and through the Poll Everywhere answers.

- Military operations in the area may cause risk of broken moorings.
- Battery storage may or may not create concerns (e.g., fire risk).
- Focus should be on alleviating the effects of diesel generators and other energy sources rather than the specific effects of MRE.

OES-Environmental Tools and Resources

Following the breakout group discussions, the tools and materials that OES-Environmental has created for a regulatory audience were presented. Then, participants were asked to provide suggestions for tools or products that may aid permitting of off-grid MRE applications. These suggestions are summarized below.

- Develop a framework to streamline permitting processes for off-grid and community-scale MRE applications.
- Compile lists or guides for offshore monitoring technologies and vendors, and best practices for measuring environmental effects.
- Summarize and share research findings through brochures and detailed case studies (e.g., siting, engagement, financing, permitting).
- Compile international examples with the associated level of environmental permitting required for each.
- Create a repository for permitting case studies, including timelines, required forms, and regulatory processes.
- Create a visual map of energy costs specific to remote communities.
- Create scaled illustrations of devices, tidal turbine rotation speeds, related infrastructure, and species of concern to enhance understanding of environmental effects.
- Develop a step-by-step process for creating regulatory change.
- Promote funding for demonstration projects and a categorical exemption for short-term deployments of small-scale devices in pre-disturbed areas.
- Develop electromagnetic transient models for various wave energy converters and distributed embedded energy converters to analyze voltage/current profiles for power converter design.
- Implement sensors to monitor mooring line dynamic loads for predictive maintenance and safety optimization.

Next Steps

The input from the breakout group discussions and Poll Everywhere responses during the workshop will be leveraged for further development of the "off-grid applications" task of OES-Environmental Phase 5, and the following steps will be taken:

- A post-workshop survey was administered; the results were tallied (see Appendix 2).
- Additional use cases for remote coastal and island communities and power-at-sea applications will be developed.
- The use cases and workshop responses will be leveraged to assess the environmental effects of various off-grid devices.
- Knowledge gained from utility-scale devices will be adapted to off-grid applications.
- Metrics that describe the potential environmental effects of off-grid devices will be developed.
- A framework, or other product, will be created to help with permitting of off-grid MRE applications.

Appendix 1 – Attendee List

Organization	Role	Number of attendees
3U Technologies	Developer	1
AltaSea	Industry	1
Applied Physics Laboratory, University of Washington	Academia	1
Biosonics	Industry	1
BMT	Consultant	1
Coastal Studies Institute	Academia	2
Cornell University	Academia	2
Department of Energy	Government	3
Energy Trust of Oregon	Non-profit	1
Florida Atlantic University	Academia	4
H.T. Harvey and Associates	Consultant	1
Lehigh University	Academia	1
Marine Situ	Industry	1
Marine Synthesis	Industry	1
National Renewable Energy Laboratory	National Lab	2
Neowave Energy	Developer	1
North Carolina State University	Academia	2
Oregon State University	Academia	2
Oregon State University, Pacific MRE Center	Academia	1
Panthalassa	Developer	1
PND Engineers	Industry	1
PRIMED	Academia	1
Quitting Carbon	Industry	1
Sandia National Laboratory	National Lab	1
Sperra	Industry	1
Stony Brook University	Academia	2
University of Hawaii	Academia	2
University of New Hampshire, Atlantic MRE Center	Academia	1
University of North Carolina, Chapel Hill	Academia	1
University of Washington	Academia	3
Pacific Northwest National Laboratory	National Lab	11
N/A		1