Clean Energy from the Ocean

Measuring the Environmental Footprint of Devices

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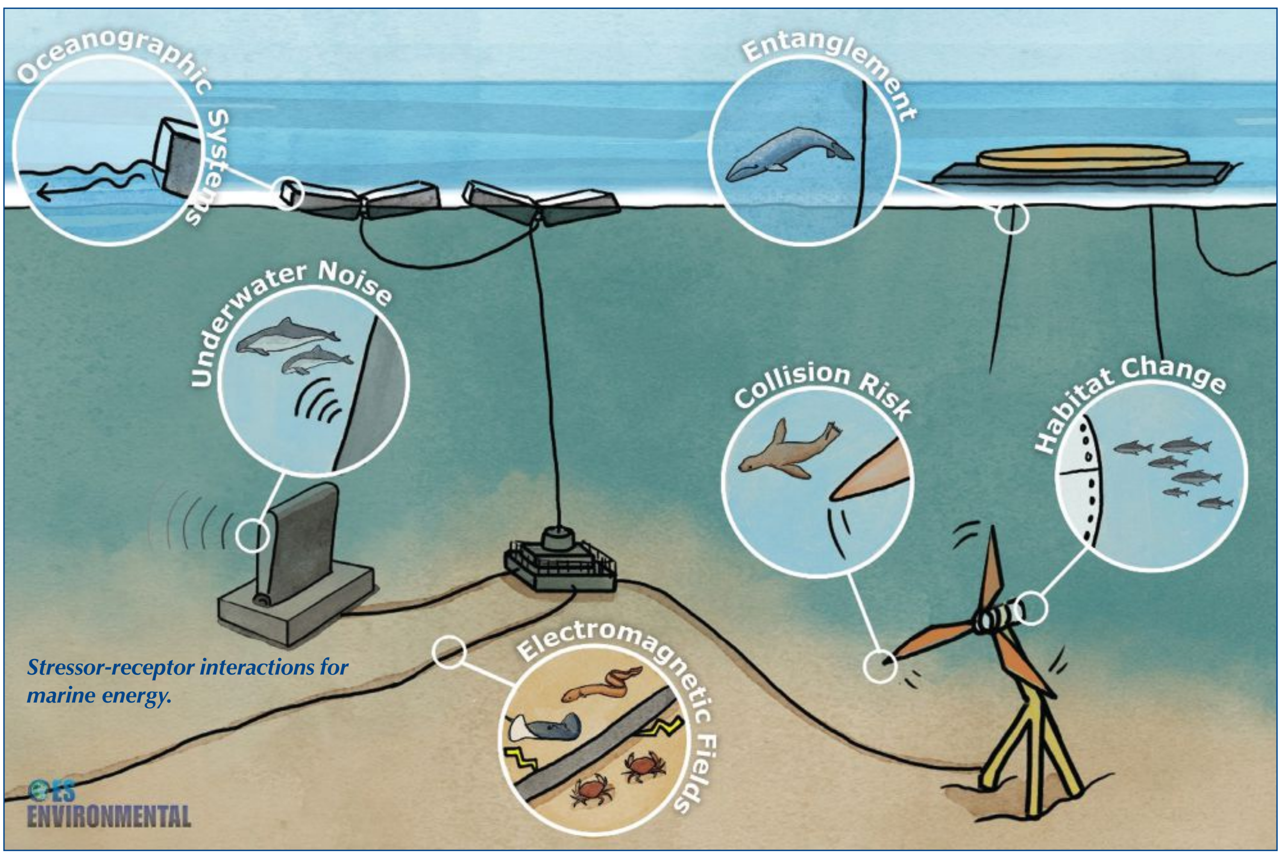
Marine energy, also referred to as marine renewable energy or marine and hydrokinetic energy, is energy harvested from the movement of water in the oceans or large rivers, and ocean gradients. This includes tides, currents, waves, river flows, temperature gradients and salinity gradients. Offshore wind is excluded, as the source of power is not ocean water. Most marine energy devices use rotating or moving parts to harness energy. The energy may then be used at sea, exported to land via electric power cables, or used to generate stable fuels or products such as ammonia or hydrogen that can be transported for use.

According to research from the National Renewable Energy Laboratory, there is an estimated 2,300 terawatt-hours per year of marine energy available in the U.S., which is enough energy to power 220 million homes and provide up to 57 percent of all U.S. electricity generation. The majority of this is from potential wave



Stressor-receptor interactions for marine energy.

Triton fieldwork in Sequim Bay. (Credit: Andrea Starr, PNNL)

and tidal energy in Alaska, though each coastal state has access to marine energy resources. Ocean thermal energy conversion in the Gulf of Mexico and around tropical U.S. island territories also provides significant contribution to the total energy potential.

Numerous potential benefits exist from marine energy development. Projects can stimulate local economies and create high-paying jobs in installation and maintenance. Once installed and operational, marine energy provides a secure energy source to reduce vulnerabilities from natural disasters and oil dependence (including eliminating possible oil spills and poor air quality from burning petroleum), as well as the potential for mitigation of climate change with reduced fossil fuel consumption. Marine energy can also provide power for unique areas and applications where other renewables such as solar are not feasible, such as in the Arctic or far offshore. Furthermore, marine energy is more consistently available and predictable than many other renewable energy resources, taking advantage of cyclical and perpetual natural phenomena such as waves and tides. Additional benefits to ecosystem functions with the creation of habitat and marine reserves are also possible.

US Marine Energy Capacity

Despite the magnitude of the resource and the potential benefits, the marine energy industry in the U.S. and internationally is still in the early stage of development. According to data from the International Renewable Energy Agency, there was approximately 530 MW of installed marine energy capacity in 2021.

In the U.S., there are currently only a few operational devices and test centers for marine energy. The Iguigig Hydrokinetic Project has been harnessing the power of the Kvichak River in Alaska off and on since initial demonstrations in 2014 and provides electricity to the village grid, reducing the reliance on burning diesel to power the community. The Roosevelt Island Tidal Energy Project was the first commercially licensed tidal power project in the U.S. and tested several iterations of turbines in the East River of New York from 2002 to 2022. The Cobscook Bay Tidal Energy Project in Maine was the first revenue-generating, grid-connected tidal project in North America, testing devices intermittently from 2012 until decommissioning in 2022. There are also two test sites for wave energy converters in the U.S.—PacWave in Oregon and the U.S. Navy's Wave Energy Test Site in Hawaii. There are several other marine energy projects in various stages of development across the U.S., as well as planned projects that were never deployed for a variety of reasons.

Environmental Effects

One of the reasons for these deployment issues is environmental concerns that have stalled the industry both in the U.S. and internationally. The oceans are an important resource for both humans and other species, and many of these species and traditional uses are protected by regulations. These laws are critical to protecting the ocean environment from harmful activities, but they also create barriers to innovative and research-oriented marine energy projects that may, in reality, present very low risks. To advance the marine energy industry in an environmentally conscious manner and to mitigate risks from possible deployments, data are needed to quantify potential risks and interactions between energy devices, marine animals and the ocean environment during project development.

Interactions between marine energy devices and the marine environment can be described in terms of stressors and receptors. Stressors are the parts of a device or system that may cause harm or stress to a marine animal or the environment. Receptors include the marine animals living in and traversing the vicinity of a marine energy development area, the habitats into which devices are deployed, and the oceanographic and ecosystem processes affected by a device or an array of devices.

There are six key stressor-receptor interactions that have been investigated for marine energy. None of these interactions are expected to pose significant risk to marine animals and habitats, particularly with only small numbers of devices in the water.

Collision Risk. This is the possibility of direct contact between an animal and a device component or turbine blade. Collision of an animal with moving device parts (e.g., turbine blades) or a moving device (e.g., tidal kite) could cause permanent injury or death.

Underwater Noise. This is the sound generated during the operation of a device. Sound is an integral sensory modality for most marine animals. Humans and terrestrial animals often rely primarily on sight to communicate, navigate, interact, forage and avoid predation. In contrast, underwater sound is essential for marine species, particularly marine mammals. Depending on the intensity and characteristics, additional noise from human sources may cause stress, behavioral changes (e.g., avoidance), physical injuries and temporary or permanent reductions in hearing ability, as well as masking other important sound cues in the marine environment.

Electromagnetic Fields. EMFs are physical fields generated by electrically charged objects. Marine species with specialized sensory capabilities, such as some species of sharks, skates, rays, fish, turtles and crustaceans, may detect and react to EMFs. Artificial EMFs from underwater marine energy or other electricity transmission cables could cause changes in the behavior and movement of susceptible animals and may potentially cause long-term changes in their growth or reproductive success.

Changes in Habitat. These are caused by introducing any new structure to the marine environment, which has the potential to alter where animals live, how common they are at a particular location, and their foraging or reproductive success. Changes in habitat can be caused by the installation, operation and/or decommissioning of marine energy systems, and can have both positive and negative effects.

Changes in Oceanographic Systems. The operation of large numbers of marine energy devices could cause changes in oceanographic systems, such as alteration of water circulation, wave heights or current speeds, as well as removal of energy from the system. These changes, in turn, could affect sediment transport, water quality and/or marine food webs. Wave and tidal devices have the potential to affect oceanographic systems in unique ways, based on how devices are designed to harvest energy.

Entanglement. Entanglement or mooring-line encounter is unlikely to be dangerous to marine animals because mooring lines or underwater cables used for marine energy devices have no loose ends or slack to create loops that cause entanglement. However, entrapment may occur with large arrays of devices if an animal were to enter an array and become unable to navigate out due to the presence of multiple cables and devices.

Not all of these environmental interactions are well understood for marine energy. Ocean monitoring in the high-energy conditions ideal for marine energy harvesting is a difficult task, considering the technical challenges presented by corrosive seawater, biofouling, low light, turbid conditions, debris, access for maintenance and

TFiT changes-in-habitat research. (Credit: Cailene Gunn, PNNL)

potential for interference with device operations. Additionally, the lack of standard practices and tools for environmental monitoring around existing devices makes data-sharing difficult, intensifying requirements for expensive, site-specific monitoring. However, in addition to ongoing research projects, information can be gained from other comparable industries, such as offshore wind or oil and gas platforms, to make predictions for marine energy. The complex relationships between stressors and receptors can be examined through observations, laboratory and field experiments, modeling studies or a combination of these.

Understanding Stressor-Receptor Interactions

The U.S. Department of Energy Water Power Technologies Office and National Laboratories are working on closing some of the gaps in understanding of these stressor-receptor interactions through experiments, data collection and observations during marine energy testing, data syntheses, application of data from other industries, and collaboration with regulators. The two core projects in this effort are the Ocean Energy Systems (OES)-Environmental Initiative and the Triton Initiative, both led by teams of researchers at Pacific Northwest National Laboratory (PNNL).

OES-Environmental. OES-Environmental is an international collaboration of 16 countries, led by the U.S. through PNNL, that aims to mobilize information and practitioners to coordinate research and progress the marine energy industry in an environmentally responsible manner. OES-Environmental synthesizes scientific research about marine energy and the environment into reports for various audiences, including a comprehensive State of the Science Report produced every four years. The State of the Science, most recently released in 2020 and scheduled again for 2024, summarizes and synthesizes current research knowledge around the environmental effects of marine energy. Each of the six stressor-receptor interactions is assessed in the report, with additional chapters on socioeconomic data collection, environmental monitoring, marine spatial planning and adaptive management.

In addition to this synthesis work, OES-Environmental curates a database on marine energy publications through the Tethys website (https://tethys.pnnl.gov) and has also been developing outreach tools for regulators to translate the science into permitting and management decisions. These tools include an informational brochure for new regulators, ongoing webinars and guidance documents for each of the stressor-receptor interactions and specific country contexts. Learning and collaborating internationally allows each participating country to gain knowledge from projects in various stages around the world, as well as how other countries address permitting challenges within their particular context.

Triton. The Triton team is based out of PNNL-Sequim in Sequim, Washington, and leverages the capabilities of the Marine and Coastal Research Laboratory. This team researches and develops technologies and methods for environmental monitoring around marine energy devices to understand and quantify the stressor-receptor interactions identified through OES-Environmental's research. Triton projects range from monitoring animal behavior, assessing underwater noise, characterizing EMF, modeling collision risk, and leveraging open-water facilities to validate emerging research technologies. Part of Triton's efforts include communication, outreach and engagement with the environmental monitoring research community and marine energy end-users to best address industry needs and bolster impact.

The Triton Field Trials project (TFiT) was a four-year effort to evaluate and test existing monitoring technologies for applications with marine energy, emphasizing changes in habitat, collision risk, EMF and underwater noise. Two of the significant challenges TFiT aimed to address were environmental monitoring costs and lack of standardization of methodology and analyses. The custom nature of new marine energy technologies makes it difficult for marine energy developers to both create a functionally viable device and conduct the necessary environmental monitoring to satisfy permitting requirements for their deployment. Ultimately, the TFiT project developed recommendations for instrumentation and monitoring methods from tests at open-ocean, riverine and tidal project sites in California, Alaska, New Hampshire and Washington, and published these recommendations in a special issue of a journal.

Synergy. For an example of the synergy between the two PNNL projects, habitat change was one of the six stressor-receptor interactions identified in the OES-Environmental 2020 State of the Science and was addressed by the Triton team with targeted research. Marine energy devices must be attached to the seafloor (e.g., using gravity foundations, pilings or anchors), with mooring lines and devices themselves in the water column and transmission cables running along the bottom.

The physical presence of these elements has the potential to disrupt or create new benthic and pelagic habitats, or alter the behavior of organisms in the area of a project. Through its work with the international marine energy community, OES-Environmental has summarized the current scientific knowledge on these potential effects, as well as identified remaining knowledge gaps and uncertainties around these effects.

In addition, the project team has listed guidance and recommendations to help increase the understanding of the various possible changes to marine habitats at short- and long-term scales. A major caveat highlighted in the process was the inconsistency in the data collection methods used at different project sites, and sometimes between project phases within a site, which could make challenging the identification of changes in habitats or the transfer of data between project sites.

The role of TFiT in advancing knowledge of this stressor was to identify the technologies that would bring the most consistent results for monitoring changes in habitats through in-depth reviews and field testing. The recommendations from these studies are intended to be used by all in the marine energy community to help figure out what technologies to use, when and why.

Conclusion

Collaboration between the OES-Environmental and Triton Initiatives as described for research on changes in habitat, as well as multiple other stressors of concern, has allowed for synergistic outcomes for the marine energy industry, and is expected to make research and outreach engagements even more efficient as the industry progresses in the U.S. as well as internationally. These iterative processes and feedbacks between the two research teams allow for refinement of the research process to become more efficient and support broad learning and sharing of information around the world.

As the industry grows with the support of the U.S. Department of Energy and the National Laboratories as a research backbone, the U.S. can expect to see an increase in community-scale marine energy projects, new devices demonstrated at existing test centers and evolution of markets for marine energy, in particular, low-power applications such as providing energy for aquaculture, ocean observations, remote communities and more.

Funding marine energy projects takes myriad forms. Private investments, community-backed cooperatives, research competitions with prizes and government support are all pieces of developing marine energy devices that meet real-world needs at reasonable costs and with minimal environmental impact.

Energy from the ocean will play a key role in the coming decades in efforts to combat climate change while supplying cities and small communities with clean, reliable power that people can feel good about using.

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References

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