Choosing wave energy devices for community-led marine energy development

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Abstract—**As we pursue more just and community-driven renewable energy projects, more decision making is put in the hands of community leaders. Appropriate tools and resources are necessary for communities to determine what wave energy device or developer might fit their community needs and wave resource. While there are methods and tools for communities, researchers and wave energy developers to determine the wave resource or potential locations for wave energy development, we are lacking a tool to help communities take the next steps in pursuing wave energy.**

A community driven design process was undertaken in Sitka, Alaska, USA, in conjunction with evaluating the local area for wave energy resource. The community had interest in wave energy development, a decent wave resource area accessible, and existing maritime expertise that could aid in operations and maintenance. Further, as a remote island, the community viewed alternative energy development positively as a way to achieve more energy independence. Still, in this community driven process, we identified a gap: while the community may be interested in a wave energy project, there is little data on which wave energy devices would be appropriate for the community and few tools to help them choose.

This paper will highlight questions that the participants from Sitka still have after engaging in a community centered design process. We compare the requirements that the community prioritizes with the tools that researchers and developers have to evaluate those requirements, allowing assessment of whether these tools are adequate for community use. We also show an analysis of a selection of current wave energy developers with some of the community focused factors and proposals for tools that may be useful in future community energy development. This research ultimately highlights what tools and information must become available to communities to enable them to make informed choices when considering wave energy technology.

Keywords—**wave energy converters, community-driven design, decision support tools**

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I. INTRODUCTION

IN the United States, we are observing an increasing trend toward community led renewable energy projects. This development may change the energy transition landscape by putting resources and decision-making authority in the hands of the communities where energy projects are being developed. Previous approaches tended to fund the developers of technologies, who would then seek communities that fit their technology.

One program created in this vein is the Energy Transitions Initiative Partnership Project (ETIPP), which is a U.S. Department of Energy program that provides technical assistance to remote and islanded communities interested in energy transitions. While the program is technology agnostic, many communities have expressed interest in understanding if marine energy is right for their community now or in the future. In this case, technical assistance providers typically provide resource assessment, an evaluation of the seasonal or daily variations of their resource for combination with other renewables, and an assessment of feasibility based on distance to existing transmission lines or shore. With this information, communities may begin to understand that they have a potential marine resource, but lack the information to take the next step in pursuing a project.

The community of Sitka, Alaska, USA applied to the ETIPP program in 2021. Alongside the typical analysis for this project, an additional project focused on a community-driven design process was designed and tested with community members. This project allowed us to understand an existing community interested in wave energy, but also analyse the existing academic and research resources for answering the community's questions. From this research, we can divide the types of unknowns or uncertainties into two categories: 1) epistemic knowledge, knowledge that we could define for many communities and share with community members for decision support and 2) community specific knowledge, defined as knowing that will need to produced for each specific community for them to make decisions. This paper aims to find gaps in the epistemic knowledge to create additional resources for communities that have interest in moving forward with pursuing marine energy device installation.

This paper highlights the types of questions that communities have, as well as the current level of existing knowledge to give communities appropriate tools to decide if a wave energy converter (WEC) is right for their community

II. METHODS

A. *Gaps identified through community driven design process in Sitka, Alaska*

Sitka, Alaska is a remote and island community of approximately 9000 people, located in southeast Alaska on the outer coast (Figure 1). The community is currently powered with two hydropower dams, with backup diesel generation that is used infrequently. The community is eager to electrify cars, homes, and boats, as all diesel is barged in; the community values self reliance and is also interested in climate resilience. The main economic drivers are fishing and tourism. The wave climate is potentially suitable for wave energy development (Figure 2) and also has some opportunity to pursue tidal energy development.

Before beginning our community driven design process, we performed detailed wave energy characterization at two sites: one closer to town near the airport, called the Japonski site, and one further to the outer coast, called the Biorka Island Site. While the Japonski site is unlikely to be able to be developed commercially, it was used to show the difference that site selection can make for communities. This site near the airport was also a site of a new hospital development in Sitka, so potentially a good location for new infrastructure and easier interconnection. The average energy matrix for each of these sites is shown in Figures 3 and 4.

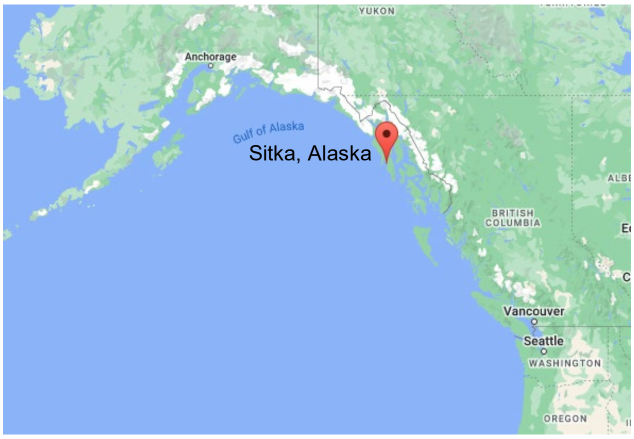

Figure 1. Red pointer shows the location of Sitka, Alaska on Baranof Island on the outer coast of southeast Alaska.

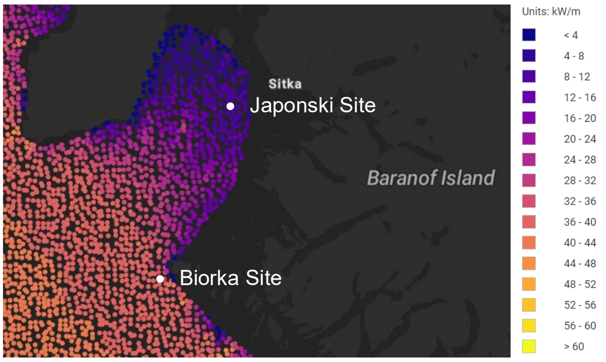

Figure 2 Screen Capture from the Marine Energy Atlas Tool (https://maps.nrel.gov/marine-energy-atlas/) showing data of Omnidirectional Wave Power from 2021 Alaska Wave Model.

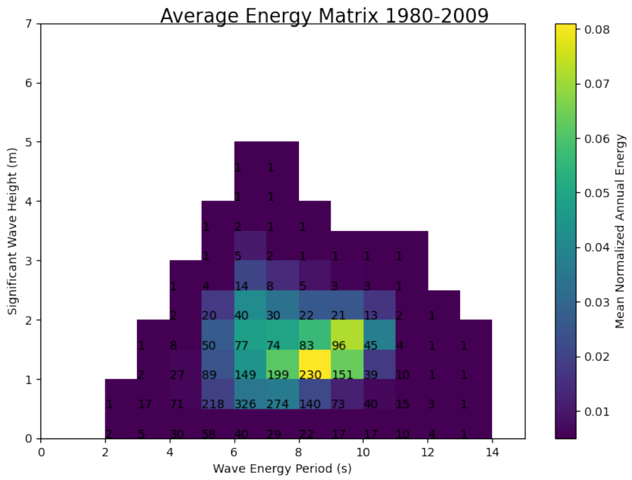

Figure 3 Average annual energy matrix for Japonski site

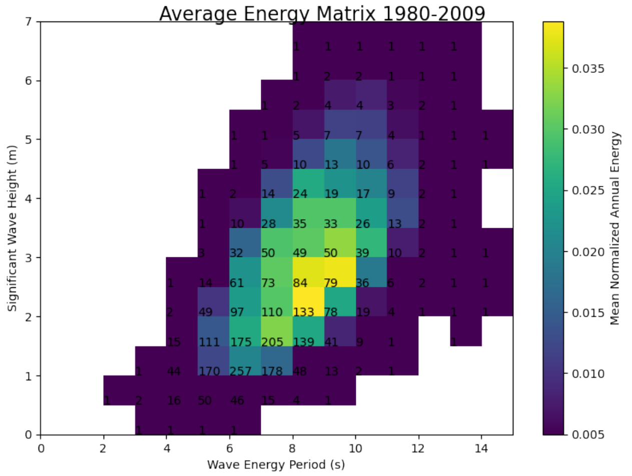

Figure 4 Average annual energy matrix for Biorka Island site

A community driven design method was tested in Sitka in 2022, including three workshops with community members who we will henceforth refer to as Designers. The goal of these workshops was twofold: 1) to test if existing community driven design methods could be applied to wave energy and 2) to understand how wave energy designs might differ with community driven input in the early stages of design.

During each workshop, the facilitator prepared datasets to help the Designers make decisions about wave energy designs that they might prefer for their community. From each of those workshops, the facilitator flushed out details from the Designers questions and brought research to support decision making in the next workshop.

After each workshop, designers were prompted with a question that we used to shape the following workshop and provide decision support data, “What questions are most important (to you) to answer about today's set of concepts in order for you to continue the design process?”

The responses to the questions were grouped into the following categories:

- Questions about Sitka, typically including questions about the end use for the energy and questions about current energy production or usage
- Questions about wave energy, typically including questions about types of technology, size and shape of technology, energy production, and maintenance
- Questions about site specific wave energy questions, typically including where to site devices, how to minimize environmental and social effects, and maintenance of device
- Question about state of technology, typically wondering if technology has been proven, is cost effective and is robust enough for remote Alaska

B. *Gaps in literature for community decision making*

As we develop a better understanding of what communities need to make decisions about whether or not to pursue marine energy and subsequently what kind of device to pursue, developers and researchers must rely on the literature or models to respond to these inquiries. Communities often have questions asking how to match up their needs with the existing technology. These questions might be, “How does the power demand I have impact what WEC I should choose?,” or “How do environmental concerns impact what WEC I should choose?” We propose thinking about responses to these types of questions as a matrix of inputs from the community (hereby called Inputs) with outputs from the literature that could be used to make those decisions (Outputs). The input categories are defined as Market, Community, and Ocean Space Inputs. The Output categories we chose are type of WEC, Power Take Off (PTO), Station Keeping, Energy Storage, and Array Research. We used these categories to perform a literature review mapping Inputs and Outputs and analyze the gaps for community decision making.

III. Results

A. *Workshop in Sitka, AK*

Designers in the Sitka workshops responded to a series of questions after each workshop. After Workshop 1, prompted by the question “What questions are most important (to you) to answer about today's set of concepts in order for you to continue the design process?”, Designers’ questions fell into the following categories:

- 7 questions specific to Sitka, the end use for the power, and their current energy production
- 14 questions about wave energy generally
- 2 questions about site specific data
- 5 questions about technology readiness

After Workshop 2, prompted with the question, “What questions are most important (to you) to answer about today's set of Concepts in order for you to continue the design process?", Designers came up with a variety of questions. These questions included a focus on many questions about the potential end use of a wave energy device's power, such as if the wave energy device was used to power greenhouses. The questions were sorted into questions related directly to wave energy and those focusing more on the end use (two examples of such questions are, "How much food is consumed in Sitka", and "How much energy would need to be generated to power a greenhouse?"). While these questions may be relevant to future community driven design, this analysis focused just on those questions related directly to wave energy. Generic end use questions such as, "What output do we want? Electric or kinetic?", were kept. Designers' questions fell into the following categories:

- 7 questions specific to Sitka, the end use for the power, and their current energy production
- 9 questions about wave energy generally
- 1 questions about site specific data
- 2 questions about technology readiness

After Workshop 3, prompted with the question, "What questions would you need answered in order for you to choose between today's concepts?". During the third and final workshop, not every Designer finished this question before the end of the workshop. Designers' questions fell into the following categories. 4 questions specific to Sitka and their current energy production

- 1 question specific to Sitka, the end use for the power, and their current energy production
- 2 questions about wave energy generally
- 2 questions about site specific data
- 2 questions about technology readiness

From this study, the majority of questions tend to fall into a category focusing on general wave energy questions. We hypothesize that most questions in this category could be answered with a more generic community support tool that would not need extensive tailoring per community to provide resources to evaluate wave energy device options.

Questions focused on technology readiness typically wondered if the logistics for installing wave energy was feasible in remote Alaska and may not be as common in other communities. Many questions focused on the end use for the power and were categorized in the community specific category. It is possible that end use questions may be able to be generalized for multiple communities in a future decision support tool.

B. *Gaps in academic literature*

An initial literature review showed many gaps in the Outputs that communities might need for decision making, as seen in Table 1. Some squares in the matrix may not produce useful questions or meaningful research, such as the overlap of bottom type and energy storage. A few examples of the kind of research products that exist are highlighted in this section.

1) *End Use and Wave Energy Converters*

Depending on the end use that a community has in mind, whether that is a small scale offshore power need or grid connected, there is a need for research support questions about how different wave energy converters might be more appropriate for specific end uses. There is a significant amount of literature focusing on a specific end use, particularly those focused on ocean observing and aquaculture. Green at al describe the power needs for specific end use for ocean observing applications, highlighting how different WECs may be appropriate to integrate into existing ocean observing platforms [1]. Aquaculture studies focus on feasibility of integration, as well potential auxiliary benefits, such as breakwater protection [2][3]. Cascajo et al. surveys experts to determine the highest valued criteria to assess the feasibility of wave energy generation projects, which may provide useful in determining which WEC to match to a specific end use. The authors summarize previous criterion considered in other studies but note that none include specific the end use of the energy produced [5].

This category has some overlap with the Power Demand and Wave Energy Converter research, such as matching the right WEC to the need for a consistent or specific amount of power.

2) *Depth and Tidal Range and WEC*

Depth and Tidal Range combined with the WEC architecture is a well studied area, with developers needing to define typical operating conditions for their devices. Some comparison studies have been published to compare how different WECs perform at different depths, including an evaluation of different point absorbers at different depths [8], the trade offs and power efficiencies with developing in more coastal or deeper environments based on WEC type [10], and a description of which WECs can be used in certain depth applications, encouraging development at less energetic sites [6].

3) *Depth and Tidal Range and Station Keeping*

Some reviews have been performed, highlighting how the depth and tidal range of a potential wave energy site impacts decision making for station keeping. Station keeping may be an area that communities do not initially have questions about, but do eventually have questions as they pursue a project – some station keeping methods will have a lower footprint of effected areas. Harris et al. describe what station keeping methods and moorings may be appropriate and certain depths and tidal ranges [7]. Nobre and al. highlight some constraints for development based on depth, including "... for most systems, sea bottom must be deeper than 30 m but less deep than 200 m (due to economical reasons)" [11].

4) Environmental Concerns and Array

Environmental issues have been studied extensively and documented regularly through the Ocean Energy Systems - Environmental's (OES-E) regular publication on the State of the Science Report, highlighting the current state of knowledge around the environmental effects of marine renewable energy [4]. With few devices in the water and even fewer arrays, much of this knowledge is still based on modeling, other industries, or single device pilot projects. Further, communities may have environmental concerns, such as a specific commercial fishery, that do produce community specific questions. More research is needed to understand if community environmental concerns can be generalized for decision support.

5) Energy Storage

Both energy storage and array effects are areas that need significantly more research as the industry matures. While these overlaps with our other factors are not currently well studied, we propose that better understanding how wave energy development might pair with energy storage for different end uses or resource size or end use is a decision point that communities may be interested in making.

TABLE I

OVERVIEW OF AVAILABILITY OF DATA TO SUPPORT COMMUNITY QUESTIONS (INPUTS) WITH CURRENT RESEARCH (OUTPUTS). AREAS WITH MORE RESEARCH ARE HIGHLIGHTED IN GREEN, SOME RESEARCH IN YELLOW, LITTLE RESEARCH IN RED. AREAS WHERE OVERLAP IS NOT APPLICABLE ARE HIGHLIGHTED IN GRAY.

FOR OUTPUT TYPE, THE FOLLOWING ACRONYMS ARE USED: WAVE ENERGY CONVERTER (WEC), POWER TAKE OFF (PTO), STATION KEEPING (SK), ENERGY STORAGE (ES), ARRAY (A)

EXAMPLE REFERENCES DIRECTED AT ANSWERING THESE TYPES OF QUESTIONS FOR AVAILABLE INPUT-OUTPUT CONNECTIONS ARE CITED IN EACH BOX. ADDITIONAL CONNECTIONS ARE POTENTIALLY AVAILABLE THROUGH FURTHER SYNTHESIS OF EXISTING DATA AND MORE THOROUGH LITERATURE REVIEW

EXAMPLE REFERENCES ARE DISCUSSED MORE THOROUGHLY IN TEXT.

Input Type		Output Type				
		WEC	PTO	SK	ES	A
Market	End use	[1] [5]				
	Power Demand	[1]				
Site	Spatial Concerns			[11]		
	Environmental Concerns	[4]		[4]		[4]
	TRL/ risk appetite		[9]			
Ocean Space	Bottom type	[12]		[7] [12]		
	Depth and Tidal Range	[8] [10][6]		[7][11]		
	Direction of Resource	[6]		[7]		
	Resource Size					[6] [11]

IV. DISCUSSION

Research in Sitka showed that the majority of questions needed to support community decision making are basic research about wave energy, as opposed to truly site specific or community specific questions. Still, there is almost no category of existing research that has a satisfactory level of research to support community questions. In the interim, more device comparisons, as well as standardized graphs and methods for presenting data that is created for community decision support, will allow for broader use of existing knowledge. We hypothesize that some of this knowledge exists and could be better collected through a synthesized literature review combined with wave energy expert surveys. Ultimately, wave energy research needs to be structured to answer questions that communities have.

V. FUTURE WORK

Future work in this area will focus on examining additional community questions through work with communities that have asked for technical assistance under ETIPP. By analysing additional community questions as they decide to pursue marine energy, a better decision support tool can be created. These types of questions could include making community decisions for a specific end use of the power, such as desalination or breakwater, or could be focused on mitigating certain impacts that marine energy development can have. For example, in working with both the Makah Tribe in Washington State and Sitka, Alaska through ETIPP, it is clear that we must better understand how specific WEC archetypes impacts specific fishing methods. While this would typically fall into spatial analysis or environmental concerns, additional research may be necessary to sufficiently answer these community questions.

Building on this analysis of gaps as well as community interest, future work in this area aims to create tools for community use.

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