Tidal Energy Scenario Analysis: Holistic Stakeholder Considerations for Sustainable Development

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Abstract

Tidal Energy Scenario Analysis:
Holistic Considerations for Sustainable Development

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Interest in renewable energy development to mitigate climate change and provide a secure energy source includes investigation into the feasibility of marine renewable energy sources, including the harnessing of tides. Tidal renewable energy is a growing area of research and development with key benefits including its location near coastal communities, minimal viewshed impacts, a powerful ocean resource, and a uniquely high level of predictability. I conducted a research study to understand perceptions of risk and benefit around tidal energy development, focusing on lessons learned from a proposed project in Puget Sound, WA. I used grounded theory methodology to conduct interviews and a focus group, and to analyze these data. I used scenarios to show conceptual tidal energy technology alternatives, with a focus on considering not only technical differences, but also economic, environmental, and social dimensions. Results of my study show that there is much uncertainty in this new technology, and aspects of its development were perceived as being risks or benefits. Spatial position and scale were both common frameworks for considering trade-offs, and marine life interactions were a particularly sensitive area of risk. Market applications of tidal energy aligned seemingly conflicting goals, as slow, sustainable development of this technology enhanced the benefits from many perspectives. My study shows that slowly building from small to commercial scale, working collaboratively with many disciplines, and focusing on holistic learning may be crucial for tidal energy development, especially in advance of a clear drive for a fully renewable energy market.

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Chapter 1. INTRODUCTION

Tidal energy may contribute to a diverse renewable energy portfolio to reduce carbon emissions and mitigate the effects of climate change. There are specific benefits of tidal energy, including high predictability, minimal viewshed impacts, and resource collocation with coastal communities and other marine energy needs including measurement buoys and ports. However, there are many existing uses of the ocean space and introducing this new technology requires including stakeholders in the decision-making process [1-3]. There is overall societal support for renewable energy [4], but there may be an imbalance between the global benefits and the local impacts of marine renewable energy (MRE) projects. Historically, energy industries have operated without much consideration for environmental and social outcomes, and energy projects have disproportionally affected low income and minority communities. Tidal energy is at an early development stage, and those researching and developing the technology are in a position to determine the best ways to holistically move forward. Despite challenges associated with some early deployments of MRE projects, there are opportunities to create a sustainable tidal energy industry. Sustainable tidal energy has the potential to be technically and economically sound as well as socially and ecologically responsible [5].

Tidal turbine devices may eventually converge to a standard design, but at this nascent stage of the industry, no such convergence exists, creating uncertainties about the final design, economic viability, and socio-ecological impacts. These uncertainties may be viewed as potential benefits or areas of concern [1]. Additionally, there are many existing users of the marine space, for whom decisions about tidal energy projects may have significant outcomes. Major contemporary environmental issues have high uncertainty, disputed values, and high-stakes decisions, which characterizes research in the tidal energy field as a ‘post-normal science’ [6-7]. Post-normal science reframes the relationship between research and decision making, especially when facts and values cannot be clearly separated [6-13]. Decisions with far reaching societal impacts often must be made while there is still uncertainty, and it is argued that the most effective approach under these circumstances is a dialogue among all stakeholders [6-7]. Stakeholders are defined as those who can affect or may be affected by a project, and includes many users of the marine space where tidal energy development will be implemented [14, 15]. Scenario analysis is one common method used in post-normal scientific contexts to explore future options with a diverse stakeholder group [13]. The aim is not to reduce uncertainty, but to identify and manage it while understanding differing values and incorporating them in deliberations. One example of a post normal scientific process that includes scenario analysis is the Intergovernmental Panel on Climate Change Assessment [16, 7]. In this research, I used scenarios to consider tidal energy design options, specifically indicating a range of technologies and considerations for scaling from single devices to larger projects. Scenarios were used to facilitate discussions with stakeholders on holistic considerations of tidal energy development so that many perspectives and holistic considerations could be incorporated. In this way, various stakeholders with differing perspectives could envision practical, as well as technical, potential to contribute to renewable energy needs.

There is often not a clear path linking social values and technology development. Figure 1 demonstrates various stages of ‘upstream’, ‘midstream,’ and ‘downstream’ engagement as three opportunities to govern technology at different development stages [17].

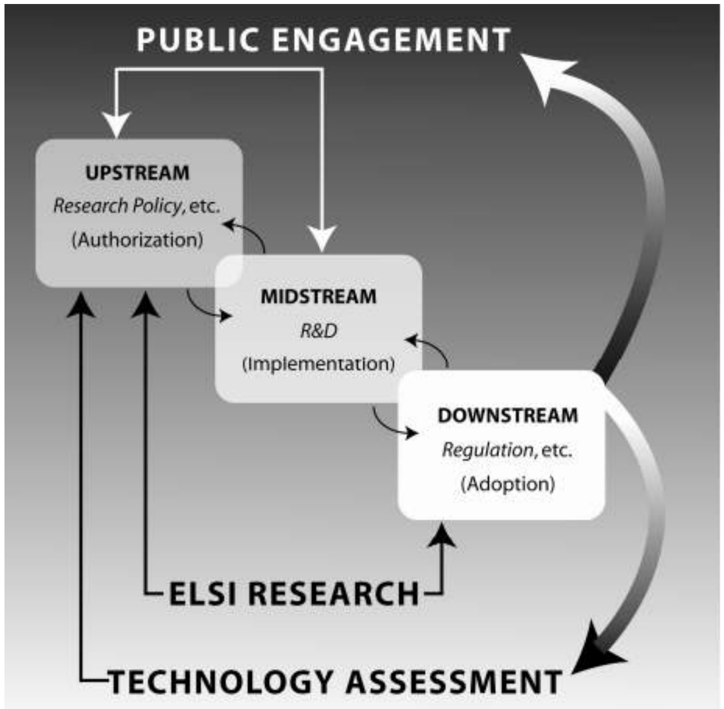

Figure 1 – Technology Governance Stages can occur upstream in early research stages, midstream in research and development, and downstream when technology is being implemented, (ELSI – Ethical, Legal, and Societal Implications) [17]

There may be policy and social influences brought to bear when decisions are being made whether to implement a technology ‘downstream’ once it has already been developed and the technology is ready for adoption. Alternatively, there are mechanisms to authorize technology through policies directed at early research ‘upstream’ to mandate specific societal goals. ‘Midstream’ engagement during research and development may be a crucial area of technology development and implementation that could later influence society, but there are few policy mechanisms to employ at that stage [17]. Thus, my research seeks to understand stakeholder perspectives of tidal energy while the technology is still in research and development stages. This may contribute to research in midstream technology governance stages. Thus, providing an opportunity for technology development to incorporate social and environmental learning as the MRE industry develops towards design convergence and larger scale projects.

1.1 Snohomish PUD Proposed Tidal Energy Pilot Project

Puget Sound has the necessary tidal current resources for energy extraction, and has been considered for tidal energy pilot projects. My research was motivated by a proposed tidal energy project in Admiralty Inlet, which serves as the major connection between Puget Sound and the Strait of Juan de Fuca, leading to the Pacific Ocean. The Snohomish County Public Utility District #1 (SnoPUD) tidal energy pilot project did not move forward for financial reasons, but many lessons can be learned from the planning and environmental permitting processes that were associated with the early stages of the project. The project was planned for deployment in Admiralty Inlet, Washington, USA, consisting of two 6-meter diameter OpenHydro turbines installed at a depth of 55 meters [18, 19]. A Federal Energy Regulatory Commission (FERC) license was granted in early 2014 after an eight-year licensing process. The process highlighted several potential stakeholder concerns including interference with tug and tow vessel traffic, siting near telecommunication cables, effects on tribal usual and accustomed fishing rights, and impacts to iconic species such as orcas and salmon [18]. Stakeholder groups and individuals involved in the SnoPUD project subsequently participated in my research study, but my research questions were framed more generally to apply to tidal energy development in Puget Sound or other locations globally.

Chapter 2. METHODS

I identified participants from a range of stakeholder groups including marine renewable energy developers, researchers, regulatory and resource management agency representatives, tribal members, mariners, fishermen, and nongovernmental organization leaders. My research seeks to understand stakeholder perspectives of tidal energy in Puget Sound, especially with respect to the Admiralty Inlet case example. Because each MRE deployment project will be subject to specific local considerations, results from a specific project will not be universally transferrable, but can contribute more generally to knowledge in the tidal energy research domain.

My research questions were: Can tidal energy scenarios uncover scenario trade-offs, risks, and benefits across a variety of stakeholder perspectives? In exploring various stakeholder perspectives, are there significant areas of agreement and/or conflicting views? Can this understanding highlight sustainable ways to develop tidal energy, inclusive of all stakeholders?

2.1 Grounded Theory Methods

I used grounded theory methodology to address my research questions. Grounded theory is a structured yet flexible method that allows theory to emerge from the data [20-23]. My methods consisted of stakeholder interviews and a participatory focus group. Data were recorded, transcribed, and analysed in Atlas.ti coding software to uncover themes and develop theory.

2.1.1 *Data Collection Methods*

I collected data through interviews and a participatory focus group. I conducted interviews with thirty tidal energy stakeholder participants, identified through the snowball method [23]. I made initial contacts based on those with knowledge and interest in tidal energy, especially those who had been involved with the proposed tidal energy project in Admiralty Inlet including the previously mentioned stakeholder groups. The interviews lasted from 30 minutes to one hour and were audio recorded and later transcribed. Following the interview, interviewees were invited to attend a focus group, resulting in twelve focus group participants.

The focus group participants represented environmental and social sciences, engineering research, industry, and government agencies. The focus group exercise was 5 hours in duration. After an introduction of the goals of the focus group, the participants were divided into two groups. Each group was assisted by a facilitator and a note-taker. Activities were varied from individual, to pair, to group table discussions. Towards the end of the day, the two groups were mixed to discuss key findings. Finally, there was an open discussion with the entire room and an exit survey concluded the focus group.

The focus group offered an opportunity to discuss many of the topics brought up in interviews, but in an interdisciplinary group setting. In this way, the focus group highlighted several trade-offs and potential paths forward. The interviews provided a breadth of perspectives, which were compared to the key findings from the focus group.

2.1.2 *Data Analysis Methods*

I used grounded theory methods and Atlas.ti software to analyse the data, using the following inputs and methodological steps. Data included transcribed interviews, field notes, notes from the workshop discussions, and other materials generated during the study. Codes were developed based on the data to find concepts that were mentioned often; interview and focus group data were considered as separate but complementary sets. Memos were written consisting of notes that described the emerging codes, and were used to develop higher level concepts for coding the data. I used pile sorting to sort the exemplary quotes into key themes. The key themes contributed to higher levels of coding in Atlas.ti and integrated the theory to give structure to the study findings [20-23].

2.2 Scenario Analysis

Many tidal energy design options are technically feasible and may become economically viable, but may have latent environmental and societal considerations. Scenario analysis is a method that enables interdisciplinary research, is inclusive of diverse participants, embraces uncertainty, and expands future options [6-13]. I used tidal energy scenarios throughout the study to demonstrate technology variations that could prompt discussion of various dimensions of tidal energy development. Scenario analysis is not meant to predict the future, but to identify future alternatives and opportunities and use them to shape research and policy decisions [6-13]. My goal in using scenario analysis was to enable interdisciplinary thinking on tidal energy through a participatory approach with a diverse stakeholder group. Considering scenarios in this way reframes risks and benefits of tidal energy, and may present a path forward for research and policy. Figure 2 gives visual context to the scenario analysis framework, in which complex drivers and various perspectives are brought together to identify future paths of change.

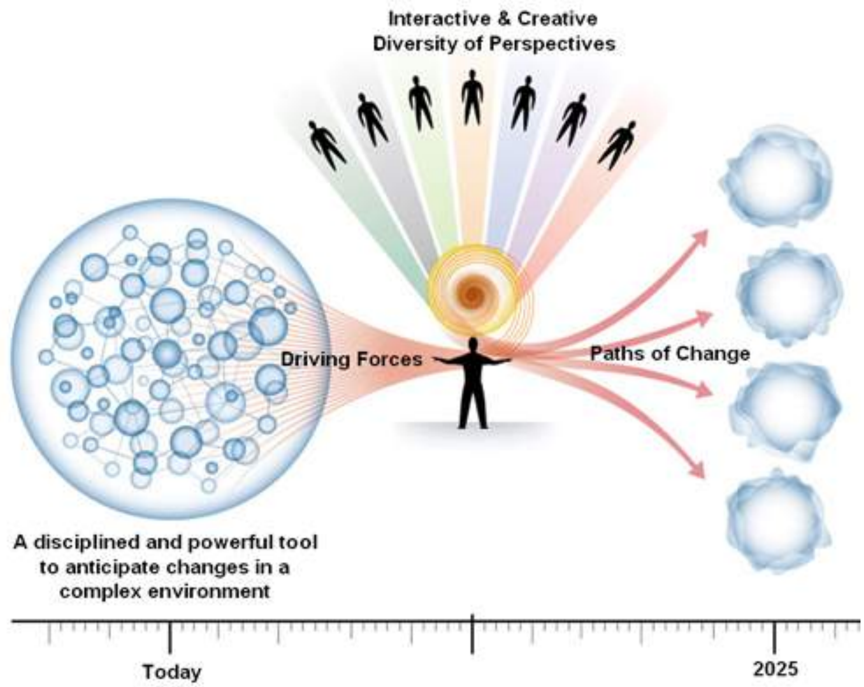

Figure 2 – Scenario Analysis Conceptual Model: many complex driving forces are considered by many diverse perspectives to identify paths of change [24]

I used tidal energy scenarios in this study to demonstrate the range of tidal energy options that could be implemented. These options focused on technology types, position in the water column, and considerations for scaling up to larger tidal energy arrays. Three scenarios were developed (Figure 3) depicting the three most developed tidal energy device types, where 60% of global tidal energy development to date has been axial flow, 8% has been cross flow, and 4% has been oscillating hydrofoil, deployed at one of three positions in the water column [25, 26]. These scenarios were not meant to be exhaustive, but to demonstrate the scope of possible tidal energy projects.

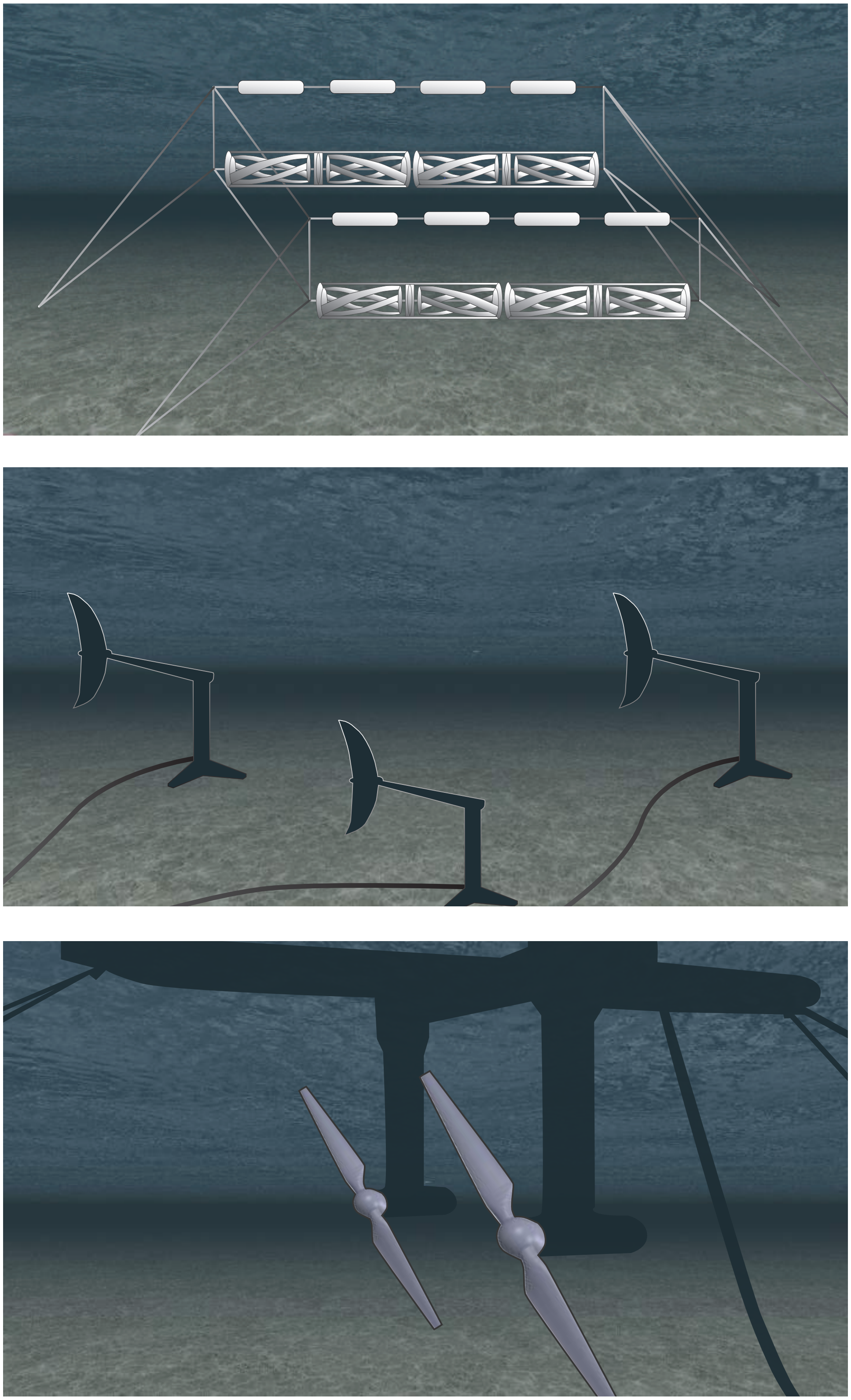

Figure 3 – Tidal Energy Scenarios: 1) cross flow compliant mooring network (top); 2) oscillating hydrofoils bottom-mounted (middle); and 3) axial flow surface mounted (bottom).

The first scenario demonstrated cross flow turbines on a compliant mooring network. This consisted of two rows of cross flow turbines mounted on a common compliant mooring, with shared connection points with the seafloor, a single power export cable, and the flexibility to spatially adjust the array position. The second scenario included oscillating hydrofoil devices on a bottom-mounted foundation with power export cables on each individual device. The third scenario included axial turbines, the most common tidal device [25], mounted on a surface platform with a common power export cable. The variations in tidal energy scenarios were used with the stakeholders as a lens to consider aspects of tidal energy projects including the technology, economic viability, environmental considerations, and social values.

2.2.1 *Holistic Considerations Framework*

My research study used a holistic consideration framework to expand considerations beyond a single discipline, and to include a variety of perspectives [6-13, 24]. The holistic wheel gave a visual representation to this framework and included technical, economic, environmental, and societal dimensions (Figure 4). Examples shown on the wheel fit within each category and overlapping adjacent categories. For example, efficiency and durability fall into the technical area, while environmental monitoring reaches across technical and environmental areas, and the levelized cost of energy reaches across the technical and economic areas [27, 28].

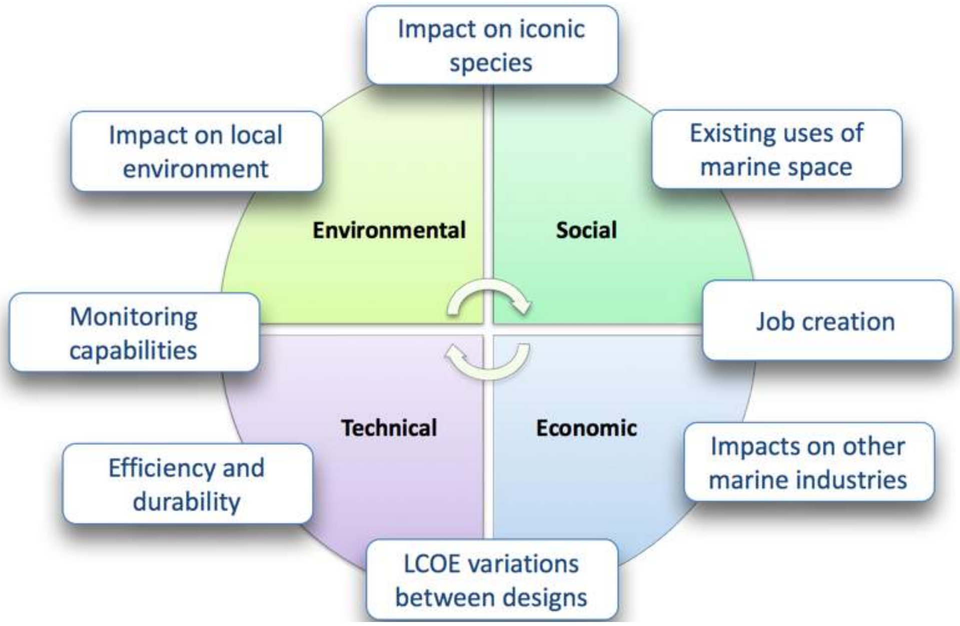

Figure 4 – Visual depiction of the Holistic Consideration Framework, showing the Environmental, Social, Economic, and Technical Dimensions. Some of the topics that fall into each category as shown, as are some that reach across more than one category.

Consideration of risks and benefits of tidal energy development formed the framework for this study, similar to the public opinions of risks and rewards of MRE examined by Bailey et al. [29, 30]. Interview and focus group participants discussed risks, benefits, and trade-offs among scenarios. It was valuable to understand the greatest risks and benefits from all participant perspectives. Interviewees were encouraged to examine the scenarios from their own perspectives and across the groupings of categories depicted by the holistic wheel. Participants may have focused on: technical or economic trade-offs between the scenarios; the potential for high to low levels of environmental risk; and potential interactions between tidal energy development and other users of the marine space.

Chapter 3. RESULTS

Analysis of interview and focus group data revealed six key themes including: tidal energy scenario trade-offs, spatial position, scale, marine life interactions, uncertainty, and market applications. The themes interact with each other in such a way that tidal energy scenarios are filtered through individual core values, expertise, and risk tolerance. The participants considered spatial position, scale, environmental risk, and tidal energy market applications relative to the scenarios. The combination of these stakeholder perspectives with external drivers created future visions of tidal energy (Figure 5).

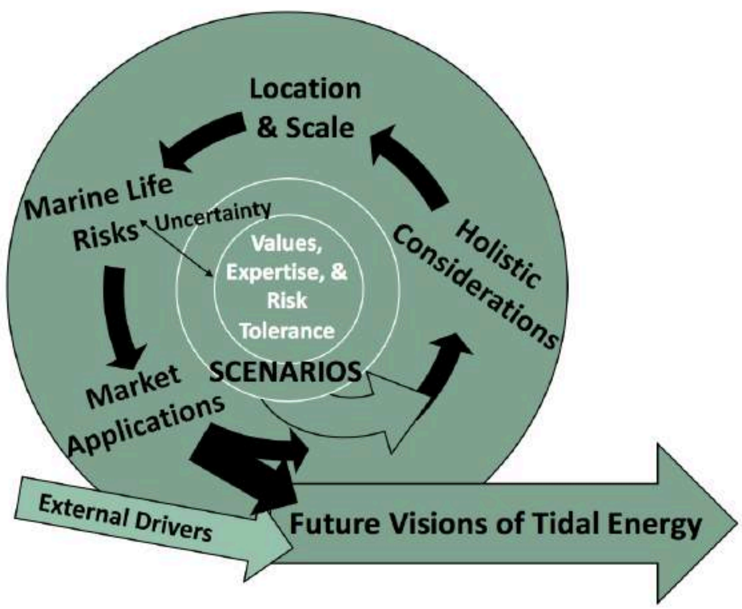

Figure 5 – The stakeholders started their considerations from their values, expertise, and risk tolerance (in the center of the figure), combining them with other holistic considerations and especially the spatial position, scale, marine life risks, and market applications (next concentric circle). Combined with external drivers, this leads to future visions of tidal energy.

The participants' mental models and personal values drive their perceptions of risks and benefits when they are faced with the uncertainty [31] that is part of the early stage of tidal development.

Participants tended to consider the spatial position of the tidal energy scenarios, especially the position in the water column and volume of water taken up by devices. Similarly, the scale of scenarios was often considered, where assessments of small to large-scale projects may vary with the size of individual devices and with the number of devices included in a project. Marine life interactions, including collision and entanglement, were perceived to have the largest associated risks and uncertainties. The participants' exploration of alternative tidal energy scenarios sheds light on trade-offs, and consideration of market applications revealed alternative ways of viewing the new technology in the marine space.

3.1 Tidal Energy Scenarios

The participants discussed tidal energy scenario trade-offs, indicating viewpoints that may align or diverge. Interviewees sometimes had a preferred tidal energy design scenario, but often stated their preferences in terms of design criteria that all scenarios may aim towards. Participants in the focus group did not reach consensus on one preferred tidal energy scenario, but discussed several themes that are pertinent, including the need for sustainability across all four holistic categories (Figure 3). The breadth of these discussions can be illuminated by quotes from the interviews and focus group (Table 1).

Table 1 – Theme of Tidal Energy Scenarios

Selected Quotes on Tidal Energy Scenarios
"Axial flow turbines are known for much higher efficiency, but they do have more moving parts."
"Turbines are much more mature [than the oscillating hydrofoil], we have been spinning things for centuries."
"I would think [oscillating hydrofoils] wouldn't affect fish migration much, so if anything was going to be developed in Puget Sound, that would be it"

> "You have a bunch of mooring lines in scenarios one and three and those tend to be expensive."
>
> "You don't want whales swimming through mid-water installations, potentially harming the installation and the whale."
>
> "Personally I don't think tidal energy is the way to go, at least not in Puget Sound."
>
> "My preference would be for those designs that minimize collateral damage to the environment"
>
> "We should consider maximum energy output per environmental footprint"

Several participants stated views that applied to all the tidal energy scenarios; these were most commonly related to environmental risk. Species of significant importance in Puget Sound were mentioned most often, including salmon and orca. Some participants felt that tidal energy would not be economically viable for any of the scenarios, and they believed that there are methods of producing energy that would pose less risk to the environment. Some participants felt that the tidal technology is already converging towards axial flow turbines mounted on the seafloor as development of these designs has progressed the furthest. In addition to their stated preferences, participants considered possible trade-offs among all the design scenarios. The pros and cons of each device and foundation type are summarized (Table 2).

Table 2 – Scenario pros and cons between devices and mooring types based on data

Scenarios	**device trade-offs**		**mooring trade-offs**	
	pros	**cons**	**pros**	**cons**
Scenario one: cross flow and compliant mooring network	• design simplicity • harness reversing flow direction • lower rotation speed • no exposed blade tips	• less efficient than axial flow designs at this stage • sometimes perceived as a 'lawnmower blade'	• flexible • scalable • few seafloor connection points • aggregate power cable to shore	• may be expensive and complicated to model • several lines in the water
Scenario two: oscillating hydrofoils and bottom mounted	• perceived as 'working with nature' • may have lowest collision risk	• earliest research stage with lowest efficiency at this stage	• lots of space in the water column above the array • simple deployment • many bottom mounted projects thus far	• benthic environment impacts • individual cables to each device • lower current speed near seafloor
Scenario three: axial flow and surface mounted	• highest efficiency of the three designs • borrow knowledge from the wind industry	• high perceived collision risks with exposed tips • highest rotation rate	• highest flow rate near surface • easy access • position known exactly • collocate with other uses • few seafloor connection points	• viewshed impacts • taking up space on the surface with many other users • design complexity • exposed to high wave loads

3.1.1 *Tidal Energy Device Trade-offs*

The interview and focus group participants identified advantages and disadvantages of each scenario and corresponding device type (Table 2), with the axial flow turbine scenario considered the most efficient, and the oscillating hydrofoil scenario considered the most environmentally benign. The cross flow turbine scenario was seen as a middle option: more environmentally benign than the axial flow turbine, and more efficient than the oscillating hydrofoil.

Several participants made a clear distinction between the axial flow and cross flow technologies as more developed and more efficient than the oscillating hydrofoil devices, as we have 'been spinning things for centuries.' However, there was also a common view that the oscillating hydrofoil, bottom-mounted scenario would be the most environmentally benign. Most participants who stated that environmental risk was their primary concern felt that the oscillating hydrofoil was preferable, as long as they could be made to be technically effective. The focus group participants also felt that the oscillating hydrofoil scenario may be best accepted by the public as the motion looks like it is 'working with nature, not against it.' However, they also noted the importance of being economically viable and other factors that affect the acceptability of a project.

Differences between axial flow and cross flow devices were also discussed. Axial flow turbines have the advantage of being the most efficient device type at this stage and having the benefit of learning from the wind energy industry. Cross flow devices were also seen as advantageous; participants noted that these devices may be more environmentally benign than axial flow designs because there is no exposed turbine blade tip and a lower rotation speed. These factors may lower the risk of animals colliding with the turbine blades, and may decrease the noise of the devices, posing less potential harm for marine life. However, both axial and cross flow devices were perceived as having the potential to chop up sea life and block water flow. Additional benefits remarked upon for cross flow devices included the simplicity of the device with few moving parts, the ability to capture flow from reversing tides without the need to pitch or yaw, and the potential to improve efficiency of arrays with tight spacing.

3.1.2 *Moorings, Foundation, and Position in the Water Column Considerations*

Spatial position in the water column, moorings, and foundation trade-offs were also considered by the participants, as they relate to the three scenarios (Table 2). Participants noted the higher flow speed that would be available for mid-water and surface mounted scenarios. However, there may be more marine users higher in the water column, and surface platforms could impact viewshed. For surface mounted designs, there were technical advantages of easy deployment and maintenance strategies, but a trade-off of being exposed to wave loads. Navigation was brought up as a concern, but also a benefit because it may be better to know the exact position rather than have a hidden danger of a mid-water or submerged scenario, depending on the depth. Additionally, the opportunity for beneficial combined uses of the surface platform were also considered.

The mid-water compliant mooring and surface platform scenarios were viewed as beneficial for minimizing connection points with the sea floor, and their ability to be flexible and scalable. However, bottom-mounted designs were also seen as beneficial for their simplicity and perhaps taking up less space overall in the water column, although with lower flow rates near the bottom, designs would need to be larger to produce the same amount of power as designs making use of higher flow rates closer to the surface. There were various ecological considerations at all depths, and so it was not clear which position in the water column would minimize risk.

The number of mooring lines in the water and simplicity of the devices were discussed frequently. It was often stated that fewer mooring lines in the water may be beneficial, and this was reflected throughout all four holistic categories. Multiple mooring lines may be expensive and difficult to model in order to predict the system behavior. In addition to technical and economic challenges, many mooring lines were often considered relative to social and environmental risks, especially entanglement risk to marine life as well as entanglement risk to fishing gear and tow lines.

3.1.3 *Focus Group Scenario Preferences*

The participants in the focus group coalesced around two different ‘preferred scenarios’. One faction preferred mid-water or surface mounted options with few connection points to the seafloor and an aggregate power export cable. The second group preferred a bottom-mounted scenario with fewer mooring lines, reflecting a smaller environmental footprint per unit energy produced. The participants debated the cost effectiveness of a surface platform versus a bottom-mounted solution, as well as the implications for viewshed and navigation safety. It was considered that surface platforms may be used in early stages as technology is being developed, and future larger scale projects may be submerged once the technology and environmental impacts are known. The participants discussed the advantages of designing tidal energy projects around the values of a local community, versus an overall strategy that considers the larger industry and economies of scale. Overall, there was consensus that tidal energy designs should be simple, cost effective, and consider local environmental impacts, local marine users, and direct community benefits.

3.2 Spatial Position

Position in the marine space also emerged as a key theme among the study participants. The locations in Puget Sound where tidal energy might be best suited are narrow areas with many existing uses, including commercial shipping, passage of orcas in and out of the Sound, and tribal fishing areas. There is concern that tidal energy projects will be exclusionary and remove large areas from other uses. Participant views can be exemplified by several quotations (Table 3).

Table 3 – Theme of Spatial Position in the Marine Space

Selected Quotes on Position in the Marine Space
"There are a lot of other people, animals, and use of this environment…in an ocean environment it's the volume that's occupied. There are organisms at every depth."
"This has been one of the biggest issues in Puget Sound…there are only two main entry and exit points…they are narrow areas with limited space for orcas and shipping."
"Being at the surface is a blessing and a curse. It's easier to access…It's now a navigation hazard…although if it was a navigation hazard that wasn't piercing the surface that would be really bad."

Participants considered the position of tidal energy devices and especially their spatial characteristics throughout the water column. Participants mentioned that the marine environment needs to be considered in three dimensions rather than on a map because there are ‘organisms living at every depth.’ Several participants discussed that the ideal tidal energy sites in Puget Sound are constricted areas with higher flow, which are areas with many other uses. ‘They are narrow areas with limited space for orcas and shipping’ and crucial for water circulation in Puget Sound. Thus, perceptions of blocking these areas was perceived as a risk. The use of space and position in the water column was discussed relative to the scenarios, such as trade-offs between surface and submerged scenarios and scaling up the array size.

3.3 Tidal Energy Project Scale

The scale of the devices was another theme that emerged, especially considering future large-scale arrays. Several participants saw the proposed Admiralty Inlet pilot project as a stepping stone to larger projects to produce meaningful energy, which often enhanced social and environmental concerns. Table 4 shows some of the ways the participants regarded the scale of tidal projects.

Table 4 – Theme of Scale

Selected Quotes on Scale of Projects
“Small projects are meaningless to a big utility, they don’t generate enough power. You would have to take up a really large area and we really don’t know the impacts to fish.”
“Will tidal energy become large farms or more distributed?”
“You’re not going to have funding to develop a variety of technologies when they’re at larger scale, you need a clear subset of technologies that are better to narrow it down.”
“A lot of work is being done on a small scale. There’s a lot that can be done to learn and maximize performance at a small scale and the smaller ones are easier to deal with in terms of operation and maintenance.”

Several participants noted concerns about scaling up projects while there is still uncertainty, especially for social and environmental reasons. None of the participants advocated for moving to large-scale and several mentioned the importance of technical learning while at a small scale. 'There's a lot that can be done to learn and maximize performance at a small scale' while keeping the costs down and minimizing risks of failure.

3.4 MARINE LIFE INTERACTIONS

Marine life interactions can be a particularly sensitive risk, and this is especially true in Puget Sound. Many participants discussed the importance of the natural resources, the many stakeholders that care about preservation, and the precautionary regulatory approach used in Puget Sound. In addition to the regulatory environment, Native American tribes are very involved in managing the local resources and the proposed project was located in a Usual and Accustomed fishing area. Some participants stated that technologies on the outer coast of Washington would be more feasible than those in Puget Sound because of the limited space, many users, and importance to the region. Marine life interactions were mentioned frequently, and some of the quotes from interviews are listed below in Table 5.

Table 5 – Theme of Marine Life Interaction

Selected Quotes on Risks of Marine Life Interactions
"You are always going to have fish and marine mammal issues…there's the perception the turbines could spin quickly and fish or orcas could get hit or chopped up."
"The fact that [tidal energy] has so many moving parts makes it hard to project how that might influence the organisms."
"If you attract fish and invertebrates then you could increase mortality because it's like drawing birds to a birdfeeder and then putting a cat there. Or a big fan and chopping them up."

"Depending on the whale species you have different considerations. Killer whales will detect this and either swim towards it or away from it… Gray whales are unlikely to be able to detect it... you could imagine a case where a gray whale would dive on it and become entangled and hurt itself."

Participants discussed collision risk, entanglement risk, the potential for artificial reefs, behavioral changes, and the difficulty to predict cumulative changes. Endangered and iconic species including orca and salmon were the most frequently discussed in relation to environmental risk.

3.5 Uncertainty

Uncertainty was often mentioned during interviews and the focus group. The scenarios show a range of possible tidal energy technology types, but many more variations are possible and ultimate design convergence is uncertain at this stage. Participants brought up uncertainty in tidal energy durability in the marine environment and in the economic viability of future projects. Environmental uncertainty was discussed often, related to marine life interactions and environmental processes. Additionally, there was uncertainty in how tidal energy may coexist with other marine users. Table 6 shows thoughts that came up while discussing uncertainty.

Table 6 – Theme of Uncertainty

Selected Quotes on Uncertainty
"They're not necessarily obstacles, but they're certainly concerns."
"One might ask though, how does taking that energy affect the Sound?"
"We still don't really know enough about the impacts the technology has on migrating salmon."
"I think about environmental impacts more than I think about efficiency."
"There are always unknowns."
"We place an undue burden on marine renewables to have a no net impact. We overstate the uncertainty and impacts that we don't in other contexts."

"We should move forward without certainty and use our laws which have provisions to make changes if we're wrong. And the process should be proportionate to the impacts."

3.6 Market Applications

Tidal power market applications are another major theme to emerge from the data. Participants discussed that beyond large-scale energy generation, tidal energy may be able to provide power for remote coastal communities and fill niche markets. Some potential uses of tidal energy included power needs at sea, such as for data collection buoys, aquaculture, data centers, and future offshore energy needs such as shipping processing centers which could be used to increase security in the shipping sector by inspecting vessels offshore. Specific benefits of tidal energy were discussed, and the high level of predictability was the most frequently stated benefit. Table 7 below shows some of the ways that participants considered tidal energy applications.

Table 7 – Theme of Market Applications

Selected Quotes on Tidal Power Applications
"The main benefit [of tidal energy] is generating power on a known cycle."
"People tend to live in port areas with inland waterways…so you could have energy collocated with demand which is really good."
"Aquaculture is a good application for tidal energy."
"Tidal energy makes sense in a small village where electricity cost is high, they're using diesel, and they don't use much power. So it wouldn't take many turbines to meet their needs."
"Renewable energy deserves a lot of attention…we need a portfolio of strategies to meet our energy needs."
"There's a lot of issues with powering things in the ocean. So one transformative application for marine renewables is to power things in the water."

Chapter 4. DISCUSSION

My research study explored stakeholder perceptions of tidal energy based upon the proposed pilot project in Admiralty Inlet, Puget Sound, WA, while also contributing to knowledge of tidal energy development in other locations. A group of participants contributed input from interviews and in a focus group. The themes that emerged from their contributions were interrelated, and highlight some of the main aspects of tidal energy considered by the participants. The three themes of tidal energy scenarios, spatial position, and scale demonstrated various ways of envisioning tidal energy in the marine space. Uncertainty around tidal energy development is a theme that often arose, especially associated with a heightened perception of risk. Additionally, marine life interactions were among the most sensitive and frequently discussed perceived risks. Finally, market applications for tidal energy development projects can be used to consider different futures with scenario alternatives, spatial position, and scale in mind.

4.1 Lessons Learned

The proposed tidal energy project in Admiralty Inlet, WA was subject to an eight-year environmental permitting process. The literature finds that many early MRE pilot projects have had burdensome, precautionary regulatory processes [32]. The extended period required for permitting influenced the project cost, and ultimately, financial concerns overwhelmed the project. Several participants in this study discussed stakeholder concerns that were identified during the National Environmental Policy Act (NEPA) environmental permitting process. Some participants had concerns that the initial pilot project would lead to much larger scale future projects with greater risk and uncertainty in order to meet significant energy needs in the region. Several participants noted that the high cost of energy from the Admiralty Inlet project (which was far from competitive with conventional energy sources) made the project unappealing. Some participants stated that the combination of high energy cost with opposition from several stakeholders influenced the final decision not to increase the funding required to move forward.

Sustainable elements of tidal energy project development were identified by the participants (Figure 6). Small projects with a supportive local community or specific purpose may develop project details after getting input from local stakeholders, as noted by several participants and in the literature related to MRE outreach and engagement [1, 2]. A clear economic need and focus on local socio-economic benefits can help a project move forward by gaining local support [14]. While tidal energy may contribute to a diverse renewable energy portfolio, at the small scale considered here, local benefits and social acceptance are crucial to sustainably developing projects.

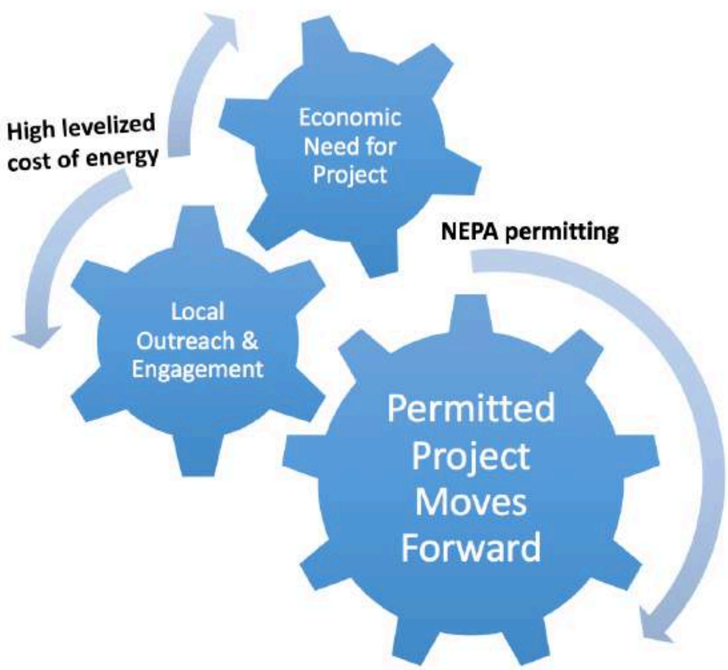

Figure 6 – Early Stage Sustainable Tidal Energy Development: one gear demonstrates local outreach & engagement and another signifies socio-economic benefits and a clear economic need for a project. These are essential to increase perception of project feasibility, especially at early stages with a high levelized cost of energy. Working with local stakeholders early may contribute towards project support, facilitate the permitting process, and move a project forward.

4.1.1 *Tidal Energy Scenarios*

Participants did not identify one preferred design scenario, but indicated aspects of each scenario that they preferred or that were of concern to them. Considering the scenarios from each category in the holistic wheel shows technical, economic, environmental, and societal preferences. Participants preferred a simple, robust technical design for a turbine, including fewer mooring lines and a single export power cable. The participants noted that placement higher in the water column would be better for flow and that a surface platform may be advantageous, but placement lower in the water column may be more out of the way of other uses. These outcomes created a disagreement over the best foundation type and position in the water column. Economically, a cost-effective design was preferred, particularly in the context of considering the energy footprint to environmental impact proportion. Axial turbines that are informed by wind technology were seen as technically beneficial, but were not always determined to be the best option. Redundancies within an array to keep projects running if small parts needed repairs, and cost effective deployment, operations, and maintenance strategies were seen as beneficial.

From the environmental perspective, tidal energy scenarios that are most environmentally benign were preferred. Determining which scenarios will produce the lowest environmental impacts is difficult to predict and requires ongoing environmental monitoring, research efforts, and interdisciplinary collaborations to resolve. Overall, open space between devices, fewer lines in the water, and less overall volume taken up in the water column were listed as preferable.

In the social dimension, it may take considerable time to gain social acceptance, alongside learning from projects and public outreach. The appearance of a technology or project may influence public acceptance, but the focus group participants stated that ensuring the technology is environmentally benign is the higher priority. In general, participants were concerned that projects would become large in scale and would exclude areas from other uses. Marine spatial planning may be one way to identify ideal locations for projects early, through a participatory approach including all stakeholders [33]. Working with all stakeholders from the early stages of projects and being transparent about project details throughout were listed as very important for successful projects.

4.1.2 *Spatial Position*

Participants reflected on whether tidal energy would exclude other uses of the marine space. There may be trade-offs as to whether tidal energy projects are spread out over larger areas with space between devices, or more concentrated but taking up less space overall. The focus group participants considered energy per footprint as a metric to assess tidal energy by directly comparing the energy output with the potential environmental impact. In discussing market applications, combining tidal energy projects with existing uses of the marine space often made projects appear more feasible, even among participants who were highly opposed to tidal energy. Potential combined use of space included other renewable energy projects, aquaculture, and associated with port activities.

4.1.3 *Tidal Energy Project Scale*

Participants discussed the scale of tidal energy projects and future large-scale tidal energy arrays that would be required to contribute to significant energy production. Although early-stage tidal energy pilot projects are small-scale, they may be seen as a first step towards a larger scale projects. This perspective created heightened uncertainties around environmental impacts and shared use of space and often created opposition to small scale-tidal energy projects. While perceived risks of large-scale projects may seem like a conflict, there is literature that also supports slow, sustained growth of the MRE industry, based on lessons learned from the wind industry [34]. There is often a drive to scale up to large projects coming from investor incentives and a desire for the industry to prove the technology, but moving to large-scale too quickly may increase the potential for failures. Thus, slow, sustained growth may be an opportunity for the industry to become established while also providing an opportunity for the public and other stakeholders to be part of the conversation as the technology develops and adapts based on learning. Public funding is required during these early and middle development stages to sustain the industry until it is ready to competitively enter the market.

4.1.4 *Marine Life Interactions*

Participants expressed concern about risks to marine life including collision, entanglement, and behavioral effects. These impacts are difficult to predict, especially behavioral effects and cumulative changes. Artificial reefs are sometimes listed as a potential benefit of MRE projects, but participants noted the risk of increased collision as a result of attracting more species to projects. Several participants mentioned that the lack of information from early projects in other regions was slowing forward momentum, and having videos and studies to share among projects would be helpful in the future. Environmental monitoring of projects and research on environmental impacts will be crucial elements of tidal energy development. It is important to learn, share knowledge, and streamline processes, but also to be acutely aware of the local priorities and site specific considerations. Collectively, the participants' views on marine life interactions were conflicting, and so there is no apparent solution at this stage except to continue to include environmental impacts as a priority through monitoring and research, alongside MRE technology development.

4.1.5 *Uncertainty*

New technologies and future scenarios have many associated uncertainties and unknowns. There may be uncertainty in the magnitude of impacts, and unknowns including impacts that may end up being significant, but have not yet been considered. Risks and uncertainties may be heightened based on the sensitive marine environment as well as existing, potentially conflicting uses of space. Some participants, especially those working in the area of MRE, focused on benefits, and others, who work on environmental conservation, were more aware of risks in the face of uncertainty. It was suggested that this apparent dichotomy is a natural part of an emerging technology, and that working together with all stakeholders and being transparent throughout the process is critical.

4.1.6 *Market Applications*

The market application of tidal energy was another major theme discussed. Large-scale energy generation is often the ultimate goal of tidal energy development, but there are many other specific benefits of tidal energy and potential niche markets that might be realized along the way. Many participants were supportive of small-scale projects for remote communities, niche applications for power needs at sea, and combined uses of tidal energy with other marine uses. Participants stated the importance of developing a diverse renewable energy portfolio for utility scale power production, but that was often seen as a future aim as the cost of energy from marine renewables is presently very high. Applications beyond large-scale energy generation may provide markets where tidal energy can be more competitive at this early stage, and where a smaller scale project may be suitable. Additionally, stakeholders may see more direct economic and local benefits of these small niche projects, and less risk of potentially scaling up quickly, if smaller projects were filling a direct economic need. Test centers, which are run independently and allow space and resources for many devices to be tested in the marine environment, were also listed as beneficial for developing different technology types and facilitating learning between members of the tidal energy community such as developers, environmental researchers, local stakeholders, and the public.

4.2 Policy Recommendations

Development of MRE could be aided by market driven and industry permitting policy changes. Fossil fuels impose environmental externalities locally, such as air pollution affecting human health, in addition to carbon emissions that contribute to climate change. Subsidies are one tool to internalize benefits of renewable energy in a market where the carbon externalities are not included. In the U.S., the wind energy sector has benefited from the production tax credit and the investment tax credit [35], and tidal energy would also benefit from subsidies. A cap-and-trade scheme may be the best way to internalize carbon externalities, but this may not be politically feasible in the U.S. for some time. Offshore renewable energy markets can also be facilitated by obtaining project leases in suitable locations [35, 36]. In combination with marine spatial planning efforts, optimal siting locations may be identified.

In addition to market barriers, tidal energy development is also slowed by a burdensome regulatory processes [32]. Most U.S. tidal energy projects are governed under the National Environmental Policy Act, and prepare an environmental assessment and/or an environmental impact statement to obtain a permit. This is crucial for understanding environmental impacts of projects, considering alternatives, and gaining feedback from the public and stakeholders [37]. However, given the early stage of the tidal energy industry, there is much uncertainty, increasing the burden on developers, and the precautionary permitting process often takes considerable time. I suggest that, at this early stage of technology, determining realistic, short permitting timelines and allowing for flexible, learning-focused, adaptive management could be helpful. Adaptive management plans allow environmental monitoring to be adjusted with project learning to resolve uncertainties over time. The proposed project in Admiralty Inlet, Puget Sound, WA included adaptive management as part of its environmental monitoring plan, which outlined ways to maximize knowledge gain and transfer between the public utility district, regulators, and stakeholders [38]. In addition to streamlining the process and using adaptive management, other safeguards could be put in place such as ensuring that all stakeholders are included early in the process, environmental monitoring plans are carefully designed, and the scale of projects are gradually phased in pace with learning. Test centers may be beneficial in expediting the permitting process for individual device testing once the test center has been permitting. Additionally, an established test center can foster collaborations throughout continued testing of several early- and mid-stage development devices. The economic benefits of MRE, as well as positive environmental externalities, can become a viable alternative to benefit society through correcting for existing government and market barriers.

Chapter 5. CONCLUSION

Tidal energy can be a sustainable contributor to national energy security and local marine industry by incorporating social and environmental learning into technology development. My research showed various perspectives around potential tidal energy developments in Puget Sound, and especially informed by the case example in Admiralty Inlet, WA. The importance of working with many stakeholders in the marine environment is highlighted. This may be especially important in tidal constrictions with limited space, many existing users, important ecological services, and abundant marine life.

Uncertainty shaped perspectives, especially with respect to personal values, areas of expertise, and risk tolerance. Scenarios were a way to envision different tidal energy futures and consider trade-offs across holistic categories. Space and scale were key to considering trade-offs and alternatives. Marine life was an especially sensitive area of risk, particularly in Puget Sound. Market applications showed a variety of options and highlighted the benefits of generating power at sea, especially for offshore and remote community power needs. Such tidal energy applications may provide ways for smaller scale projects to succeed through early and middle research and development stages before aiming for large-scale electricity generation.

Renewable energy from tides will likely have a strong market demand in the future, as the need for renewable energy becomes more urgent and the costs decrease. The industry could at that time be technically ready, as well as holistically viable through collaborative, learning focused, slow and sustained growth. This may lead to responsible development of the technology and project viability in all four holistic categories. Small-scale, niche markets for tidal power will fill a clear economic need and be more widely viewed as a viable ocean industry. This may be especially true to gain local support beyond climate change mitigation, to emphasize and ensure economic and socio-economic benefits.

Evidence suggests that for tidal energy projects in Puget Sound, the local community and stakeholders should be involved throughout the processes, as well as representatives from industry, academia, government, and other groups. Interactions between these groups can lead to success in identifying projects that could fill a specific need and gain local support. In these early development stages, many MRE projects and companies can share knowledge with a focus on learning together and collaborating with different stakeholders and across disciplines. This nascent technology may then move forward and be ready to fill future demands for reliable tidal power.

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