Learning from Early Commercial Tidal Energy Projects in the Puget Sound, Washington and the Pentland Firth, Scotland

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Abstract

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Using a textual analysis to interview data approach, this study explores two of the first multiple-device tidal energy projects to identify the key learning outcomes gained by stakeholders. The cases chosen are the Snohomish County Public Utility District's Admiralty Inlet pilot project in Puget Sound, Washington, United States, and MeyGen Ltd.'s Phase 1A project in Pentland Firth, Scotland, United Kingdom. With a focus on stakeholder learning, the research draws upon scholarly literature on innovation systems and technical innovations systems. This qualitative study uses in-depth, semi-structured, elite interviews of key informants as the primary method of data collection. The study analyzed the interview data from twenty-three stakeholder interviews and utilized MaxQDA 12 software as a platform to analyze the interviews. Learning from tidal energy projects is examined from technical, economic, environmental, policy, and social perspectives. By so doing, this research seeks to understand the interdisciplinary lessons stakeholders learned about tidal energy. The lessons learned from these case studies suggest that existing risks and uncertainties can preclude the deployment needed for the technical validation. Technical learning focused on the challenge of developing robust instrumentation for monitoring in tidal flow conditions. Economic learning focused on the need for government funding for environmental research, the potential expense of legal challenges, and the socio-economic impact of the project for local businesses. The projects served as a catalyst for examining the environmental impacts of tidal energy development. Species behavior and interaction with devices remains an area of research to address. Policy learning related to risk tolerance of regulators and the potential legal barriers faced by tidal energy. Socially, initiating the projects allowed the developers to recognize the concerns of relevant stakeholders. Spatial conflicts, exclusion, and access were major concerns of opposing stakeholders. Learning about an interdisciplinary range of issues is key to the future success of the tidal energy sector.

1. Introduction

The transition to a more low carbon energy system represents a formidable challenge. Multiple technologies are needed for renewable energy to become a significant portion of the global energy supply. To achieve the policy goal of transitioning to new energy sources, decision makers need to understand the learning that is occurring during development of emerging renewable technologies (Winskel et al., 2014). By understanding how learning is occurring, decision makers can respond to key issues hindering or facilitating the delivery of these innovations by the private sector.

System changes that are motivated by environmental problems, marked by uncertainty, and involving many stakeholders need to be addressed proactively through learning (van de Kerkhof and Wieczorek, 2005). For renewable energy technologies (RET), understanding the dynamics between research and development (R&D) investments and learning is vital for policy makers (Lindman and Söderholm, 2012). Learning is an important area of innovation research because learning influences the speed of development (MacGillivray et al., 2014).

Marine renewable energy (MRE) has potential to be a viable low carbon energy source. Marine resources poised for energy exploitation include wind, waves, and tides. The tidal stream sector is maturing (Magagna and Uihlein, 2015). Although the theoretical supply of tidal power is immense, the practically extractable resource is limited to certain places with ideal conditions. Tidal energy can be an important niche source of renewable energy for coastal areas with strong tidal flows. For tidal stream energy technologies to contribute to the energy system in the near future, the sector will need to innovate rapidly.

Currently, the tidal sector is transitioning from individual, full-scale prototype tests to multiple device projects. Designed to evaluate commercial feasibility, these first multiple-turbine projects are referred to in this paper as early commercial tidal energy projects. Early commercial tidal energy projects present an opportunity to examine the learning gained by developers, government agencies, and other stakeholders.

Projects in the sector have encountered repeated delays, suggesting that barriers exist to development beyond issues related purely to technology readiness. For the tidal sector to realize its potential, proponents need to address a range of interdisciplinary challenges (Borthwick, 2016). Responding to multiple obstacles, these projects have been forced to attempt to solve problems and reduce uncertainties in the tidal energy sector. This study provides an interdisciplinary examination of these hurdles.

2. Case Selection

This study examines two high-profile tidal energy projects in order to identify the key learning outcomes gained by stakeholders. The cases were selected by reviewing media articles from the study areas and by examining developer websites. For the Puget Sound, the Snohomish County Public Utility District's (PUD) Admiralty Inlet project was chosen as a study case because of its proximity to the University of Washington. When the Admiralty Inlet project was selected, the PUD had recently decided to discontinue the project (PUD, 2014). In the Pentland Firth, MeyGen Ltd.'s MeyGen Phase 1A project in Scotland was chosen based on the evidence of momentum for future development. At the time of case selection, the MeyGen project had secured funding, opened a project office, and received a license (MeyGen, 2016).

The selected cases have important similarities that warrant comparison. With strong tidal resources, each case location has potential for future commercial developments. Both tidal projects were intended to evaluate the commercial feasibility of tidal energy in the area. Each project proposed to have multiple turbines deployed. Similarly, each project had provisions to answer environmental questions related to tidal energy. Both project's technology developers had previously tested device prototypes at the European Marine Energy Centre (EMEC) (EMEC, 2016). See Appendix A for a list of acronyms used in this report. These similarities will help identify findings that can be applied to other tidal energy projects.

2.1. Admiralty Inlet Pilot Project, Puget Sound, Washington, USA

The PUD worked to develop the first tidal project in the Puget Sound, after starting to explore tidal energy in 2006. This study examines the entire process, from early efforts to the project's conclusion. After examining several sites in the Puget Sound, the utility submitted a Final License Application to the U.S. Federal Energy Regulatory Commission (FERC) in March 2012 for a pilot license to develop a project near Admiralty Head off Whidbey Island, WA. See Appendix B for a map featuring the project location. In May 2014, the utility received a license from the FERC to deploy two OpenHydro Group Ltd. turbines in Admiralty Inlet, Washington. The open-center (OpenHydro, 2016) turbines were to use gravity bases as foundations. The project timeline showed the utility intended to prepare the onshore component and lay cables in the spring and summer of 2015, with the turbines to be deployed in summer of 2016. Within its ten-year lease, the PUD planned to operate the pilot project for three to five years before removing the devices. The utility discontinued its project in September

2014. This decision to withdraw the application was linked to the project's escalating costs and the decision by funding sources, namely the U.S. Department of Energy (DOE), to not increase funding to meet the new projections (Spangler, 2016).

2.2. MeyGen Phase 1A, Pentland Firth, Scotland, UK

The MeyGen project seeks to become the first multi-turbine tidal development in the Pentland Firth. This research focuses on Phase 1A of the MeyGen project. The project is to be deployed in incremental stages, with Phase 1A consisting of 6 MW, which is projected to be deployed in summer of 2016. In July 2012, MeyGen Ltd. submitted an application under Section 36 of the Electricity Act and Section 20 of the Marine Scotland Act to develop a tidal energy array (Sutherland, 2012). The project received consent for the 86 MW Phase 1 in January 2014 (Marine Scotland, 2014). The project site is in the northwest corner of Caithness, Scotland. The four 1.5 MW turbines are to be located in the tidal races of the Inner Sound, a section of the Pentland Firth to the south of the island of Stroma. See Appendix C for a map featuring the project location. The turbines used for the project are 3-bladed horizontal axis turbines. In Phase 1A, one turbine design will be from Atlantis Resources Ltd. (Atlantis Resources Ltd., 2016) while the other three devices will use the Andritz Hydro Hammerfest (Andritz, 2014) design. The devices will be affixed to the seabed with a tripod, gravity base and connected to an onshore power conversion station via a 4.4kV subsea cable. The project achieved financial close of £51.3 million in September 2014. Work on the power station and cables occurred in 2015 and construction is set for 2016. After construction, the Phase 1A devices are set to run for 25 years upon which decommissioning or re-leasing will commence (MeyGen Ltd., 2016). As of August 2016, the project remains ongoing.

3. Literature Review

The following section describes two related perspectives for approaching renewable energy innovations: innovation systems theory (IS) and technical innovation systems theory (TIS). This review discusses identifying the weakness of an innovation system through IS and exploring the functions of an innovation system approach through TIS. These perspectives provided the analytical foundation for an interdisciplinary framework I conceived for examining learning, as subsequently detailed. The framework includes learning about technical, economic, environmental, policy, and social issues. The framework's categories incorporate findings from reviewing literature related to tidal energy.

3.1. Innovation Systems

IS emerged as an analytical perspective that recognizes that innovations are achieved interdependently. IS is an appropriate perspective for examining the renewable energy transition since it can identify "system weaknesses" (Jacobsson and Bergek, 2011) such as barriers to technology innovation from market forces, institutional structures, or political direction (Weber and Rohracher, 2012). IS can reveal "system strengths", areas where system functions are strong, enabling the innovation to advance (Jacobsson and Karltorp, 2013). The IS approach allows the researcher to analyze learning throughout the system supporting the technology innovation (Jacobsson and Bergek, 2011).

IS argues that any present weakness can hinder the realization of the entire system (Carlsson and Jacobsson, 1997; Edquist and Hommen, 1999; Jacobsson and Bergek, 2011; Malerba, 1996). These weaknesses have been understood as failures (Woolthuis et al., 2005) or as "systemic problems" (Negro et al., 2012). Areas where system weaknesses commonly occur include infrastructural failures, institutional failures, interaction failures, capabilities' failures (Woolthuis et al., 2005), and market structure problems (Negro et al., 2012). These weaknesses are related to technology, laws and policies, networks, the abilities of actors, and economic conditions (Jacobsson and Bergek, 2011). Infrastructure problems include knowledge infrastructure and physical infrastructure. Institutional problems can be understood as 1) formal 'hard' institutions, such as laws, standards, and rules or 2) informal 'soft' institutions, such as social viewpoints, risk perception, and trust. Interaction problems involve the relationships amongst the actors. Capability problems refer to areas where competence or resources are inadequate to meet the existing challenge. Market structure problems refer to difficulties facing the new technology from its particular economic situation. These "systemic problems" represent issues that hamper the development of RET (Negro et al., 2012).

3.2. Technical Innovation Systems

IS literature on renewable energy technologies frequently uses the TIS approach (Jacobsson and Bergek, 2011; Markard et al., 2012). A TIS is defined as the features that contribute to the advancement of a technology, including actors, networks, and institutions, and technologies (Bergek et al., 2008; Jacobsson and Karltorp, 2013; Markard and Truffer, 2008). Actors are the entities involved with the system around the technology. Networks are the links between actors, including the pathways that learning occurs. Institutions are the legal, policy, and social conditions that impact the technology. Technologies represent the technical knowledge in the system.

TIS research focuses on “distributed learning”, the learning that occurs among actors from interactions with the development of a technology and associated networks. Two stages of technology development are considered in TIS. The first formative phase includes multiple device designs, testing, niche applications, and the legitimation process. The second stage of market expansion applies the commercialization and diffusion of the technology (Winskel et al., 2014). From a TIS viewpoint, tidal energy is transitioning from the formative stage to commercialization.

Research using the TIS approach usually focuses on a specific technology category (Truffer, 2015). As such, TIS represents an appropriate perspective for evaluating case studies of the emerging tidal energy sector. Recent literature has applied a functions approach (Bergek et al., 2008; Hekkert and Negro, 2009; Hekkert et al., 2007; Kern, 2015). Bergek et al. (2008) identify the seven functions of a TIS as follows: 1) knowledge development and diffusion, i.e., creation and sharing of research related to the innovation 2) entrepreneurial experimentation, i.e., knowledge development of an applied nature 3) influence on direction of innovation, i.e., how supply-side actors contribute to a TIS 4) resource mobilization, i.e., how financial and human capital are used to contribute to a TIS 5) market formation, i.e., the development of corresponding markets for the stage of the innovation 6) legitimation, i.e., social and political process of accepting the innovation and 7) development of positive externalities, i.e., fostering benefits from a TIS. From a variety of perspectives including technical, learning pertains to the knowledge development and diffusion function. Early commercial projects are a form of entrepreneurial experimentation. Policy and economic factors impact the direction of innovation, resource mobilization, and market formation. Social and environmental concerns are related to the legitimation process. Resolving conflicts and securing benefits from the future maturation of the technology is linked to the development of positive externalities.

Critics contend TIS is too focused on technology factors and needs to consider the wider context of technology development (Kern, 2015; Truffer, 2015). Others contend that TIS underappreciates the role of political influence, policies and actors' (hereinafter termed "stakeholders") agency in advancing technologies (Kern, 2015; Markard et al., 2016). If technological innovation is examined more expansively, then the TIS analysis can better guide policy (Jacobsson and Bergek, 2011).

Bergek et al. (2015) establish four "context structures" as a model for integrating TIS into policy research. This research responds to the criticisms of TIS's narrow focus on technical advances by considering the "context structures" of economic, environmental, policy and social aspects of tidal energy, in addition to technical aspects. Informed by IS and TIS concepts, this study examines learning through an interdisciplinary framework. Learning from the tidal project is described along the "context structures" of technical, economic, environmental, policy, and social issues. Risk and uncertainty are important terms for examining this learning framework.

3.3. Interdisciplinary Learning Framework

To date, tidal energy has had few opportunities to experience learning-by-doing (Winskel et al., 2014) defined as learning from experience through action. The role of early projects as a contributor to learning deserves attention (Harborne and Hendry, 2009). It is important to examine the lessons learned from the existing demonstrations, pilot projects, or commercial tests. Even when projects struggle to pass through the commercialization 'valley of death', the learning gained is still quite valuable (Corsatea,

2014) since learning from failure is important for innovation (Weber and Rohracher, 2012).

This study posits an interdisciplinary framework for examining learning. For this paper, learning is defined comprehensively as the knowledge acquired by experience with something, i.e., the tidal energy project encountered by key informants. This acquired knowledge includes an awareness of relevant issues, an identified change in action, an informant's perception of the situation, and insight gained from research initiated in response to the project. The framework is organized into the following categories: technical learning, economic learning, environmental learning, policy learning, and social learning. A review of literature pertaining to tidal energy informs the framework.

Learning frequently related to issues of risk and uncertainty. Early projects encounter both concepts prior to deployment. For the purpose of this paper, risk will be defined as something that creates or suggests a hazard. When referring to regulatory decisions, risk is the quantified probability that the hazard will be realized. For the study, uncertainty relates to issues that are not known beyond doubt or areas where certain knowledge is absent. From a regulator point of view, risk is understood as high in areas of uncertainty. Precautionary values are chosen in light of the unknowns.

3.3.1. Technical Learning

Learning occurs throughout technology R&D. During this process, technical learning is accomplished by two ways: learning-by-research and learning-by-doing (Köhler et al., 2006; Pan and Köhler, 2007; Winskel et al., 2014). Insights from learning-by-research prior to deployment are applied to early projects, which are designed by developers to facilitate technological improvements though learning-by-doing. For the tidal industry, the next step in the technology R&D process after small-scale and full-scale prototype testing is small arrays of these full-scale devices. The projects analyzed represent two of the first attempts to develop tidal stream technology with multiple devices.

3.3.2. Economic Learning

These early projects at the small array scale seek to advance innovation while evaluating the commercial feasibility of the technology. Tidal energy's commercial prospects depend on cost reduction to be judged economically feasible (MacGillivray et al., 2014). For widespread adoption beyond niche applications, tidal energy needs to achieve a levelized cost of electricity (LCOE) that is comparable to other RET. LCOE measures the "overall competitiveness" of energy generation technologies by providing a per-kilowatt hour cost of electricity over the lifecycle of the generating device. Costs included in LCOE are capital, fuel, operations and maintenance, financing, and utilization rates (EIA, 2015). As a sector, tidal energy has high capital requirements and considerable areas of uncertainty. These factors make tidal energy projects a risky investment. Importantly, these early projects can advance the industry by encouraging investor confidence, if successful (Bucher et al., 2016). Additionally, these early projects present an opportunity to evaluate the local socio-economic impact from tidal energy. Early tidal projects can provide insight into the socio-economic impacts, such as jobs and local investment, that tidal energy can deliver (Allan et al., 2014; Dalton et al., 2015) or, potentially, displace (Alexander et al., 2013).

3.3.3. Environmental Learning

The environmental impacts of a fully commercialized tidal energy project remain unknown. These impacts will vary by location and technology. Early multi-device projects can serve as an indicator for the magnitude of a commercial array's environmental impacts. If monitored properly, these initiatives can foster environmental learning by providing new information (Brown and Hendry, 2009). Statutory requirements and environmental groups have identified issues for research (Kerr et al., 2014). Significant environmental research is often perceived as necessary before a project enters the ocean. An effective environmental monitoring strategy is required to evaluate the impacts of the devices in operation.

3.3.4. Policy Learning

Creating synergies between developers and the corresponding institutions is important for innovation (Corsatea, 2014). As a novel development, tidal energy raises broad issues about ocean governance, leading to questions about the application of the existing legal regime to the sector (Wright, 2015) and concerns about the integration of projects of national value with the interests of the host community (Kerr et al., 2015). Regulations and the planning system seek to guide this development. As such, these projects' interaction with policy issues is important to understand. For this research, policy is defined to include the planning system, regulations, laws, and incentives that apply to a tidal energy project. Yet the novel aspects of tidal energy can present a challenge to existing guidelines, which may require policy adaption or the development of new policies.

3.3.5. Social Learning

The early commercial projects give stakeholders and local communities an opportunity to gain knowledge about the potential impacts of tidal energy. These projects present the opportunity for social learning through interacting with the projects. The learning can go both ways, as the projects allow developers to understand the "societal lens" through which the public perceives changes to the marine environment (Henkel et al., 2013). By social learning, involved actors gain a "shared understanding" (Martin et al., 2014) of issues related to the technology development (van de Kerkhof and Wieczorek, 2005).

4. Research Design and Methodology

This study uses a textual analysis to interview data design to evaluate stakeholder learning from experience with early commercial tidal energy projects. Stakeholders represent the unit of analysis for this research on learning. This study identifies a preliminary list of stakeholders by examining primary documents, websites, and media articles associated with the projects. The list includes stakeholders who initiated the project, i.e., project developers and technology developers; stakeholders who were involved with the project, i.e., investors, contractors, or research institutions; stakeholders who participated in the governance of the project, i.e., government agencies from the local to national level; and stakeholders who were active in the consultation process, i.e., those that engaged with a project by supporting, opposing, or voicing concerns. See Appendix D for more information on the preliminary list of stakeholders.

4.1. Research Question and Hypotheses

This study aims to provide a better understanding about the tidal energy sector by answering the research question "What have stakeholders learned regarding the issues surrounding tidal energy development from their experience with an early commercial project?" By so doing, this research seeks to understand the lessons that various actors learned about interdisciplinary issue areas related to tidal energy.

Informed by background research and conversations about tidal energy, the study uses five research questions to explore the interdisciplinary areas of learning. These queries were tested by analyzing interviewing data. The research questions were:

- Question 1: Does learning occur regarding the technical issues related to a tidal energy project?
- Question 2: Does learning occur regarding the economic issues related to a tidal energy project?
- Question 3: Does learning occur regarding the environmental issues related to a tidal energy project?
- Question 4: Does learning occur regarding the policy issues related to a tidal energy project?
- Question 5: Does learning occur regarding the social issues related to a tidal energy project?

4.2. Data Collection and Analysis

This qualitative study uses in-depth, semi-structured, (DiCicco-Bloom and Crabtree, 2006) elite interviews (Dexter, 1970) of key informants (Tremblay, 1957) as the primary method of data collection (Yin, 2014). To gauge learning, a key informant serves as the proxy for the stakeholder group's knowledge base. Reviewing materials related to the stakeholder group identified contacts with potential to be considered as a key informant. The prospective key informant was contacted with a request for an interview via email. In the email invitation, the individual was given two options 1) to acknowledge that he or she was the appropriate person representing the stakeholder to interview or 2) to recommend a more suitable person associated with the stakeholder to interview. By so doing, the study could better identify the most knowledgeable key informant. As the interviews occurred, other key informants were identified through the snowball method, a process in which interviewed subjects recommend additional key informants (Atkinson and Flint, 2001).

Stakeholders interviewed include representatives from project developers, technology developers, government, universities and research institutions, maritime industries, conservation interests, recreational interests, and other concerned parties. Interviews were primarily conducted in person, although some phone interviews occurred as necessary. During September and October 2015, twelve interviews were recorded and transcribed for the Pentland Firth case. From November to January 2016, eleven interviews were recorded and transcribed for the Puget Sound case. No personally identifying information of the key informants is supplied in this study in line with provisions detailed by the Human Subjects Division of the University of Washington. See Table 1 for the list of stakeholder groups and organizations represented by the key informants.

Table 1: Key Informants

Key Informants		**Admiralty Inlet, Puget Sound**	**MeyGen Phase 1A, Pentland Firth**
Project Developers / Technology Developers		• Snohomish County PUD • OpenHydro Group Ltd.	• MeyGen Ltd.
Government	Local	• Island County Planning	
	State / Regional	• WA Department of Fish and Wildlife • WA Department of Ecology • WA Department of Natural Resources	• Marine Scotland • Scottish Natural Heritage • Scottish Environmental Protection Agency
	Federal / U.K.	• NOAA / NMFS	• The Crown Estate
Research Institutions		• University of Washington • Pacific Northwest National Laboratory • Sea Mammal Research Unit Ltd.	• University of Aberdeen
Conservation Organizations			• Whale and Dolphin

		Conservancy • Royal Society for the Protection of Birds
Treaty Tribes	• Tulalip Tribes	
Fishing Industry		• Orkney Fisheries Association
Marine Transportation		• Pentland Ferries
Recreation		• Pentland Canoe Club
Other		• Caithness and North Sutherland Regeneration Partnership

A limitation of the study was the inability to conduct an interview with some key informants due to time constraints, a lack of response, legal restrictions, or other factors. For Admiralty Inlet, an interview with a conservation organization occurred but was not recorded or used in this research. Interview requests with marine transportation and recreation were denied due to the key informant's view that the stakeholder group's involvement with the project was minor. No non-tribal fishing industry stakeholders were contacted since significant involvement with the project was not indicated. Responding to advice from other key informants, this study did not contact PC Landing Corp. for legal reasons. As a surrogate, a cable industry representative was contacted, but after an initial response, the key informant proved unavailable. Federal agencies including the FERC and the DOE did not agree to an interview since the case was still considered active. For MeyGen, interviews with a local government agency, EMEC, and a consultancy were not recorded or used in this research. Some key informants were unresponsive or did not appear to the scheduled meeting. For these reasons, some important perspectives and learning outcomes may not be discussed in this study.

Interview data were the primary source of information for this study. Direct observations, online resources, publically available documents, and literature about tidal energy accessed via ScienceDirect provided further insight. Each project site was visited.

Online resources include the websites of project developer, the Scottish Government, and the FERC e-library. Primary documents were pulled from websites of the Scottish Government (Marine Scotland, 2016; Marine Scotland, 2014; Sutherland, 2012) and FERC (Corp., 2016; FERC, 2008; Johnson, 2011; Morisset and Somerville, 2015). Using multiple sources of data strengthens construct validity by supplementing evidence from interviewing data (Yin, 2014).

It is important to limit interference from the researcher's pre-existing biases when analyzing qualitative data (Yin, 2014). The study uses software programs to structure the qualitative analysis in systematic way (DiCicco-Bloom and Crabtree, 2006; Tesch, 1989). MaxQDA 12 software was used as a software platform for conducting qualitative analysis (MaxQDA, 2016). Using MaxQDA 12 allows the study to systematically analyze textual data line-by-line into concepts though an iterative process. From the conceptual categories, significant quotes were pulled for examination. Insights from these significant quotes were refined through subsequent written drafts. The interviewing data and codes were analyzed again to focus upon the strongest themes. The findings reflect this iterative process.

5. Results

The following section details the key areas of learning for each case within the interdisciplinary framework. These insights are primarily based upon the data from the interviews. It is important to understand that these findings do not represent an exhaustive list of learning but rather express the major lessons learned. The affiliation of the source is noted when relevant. Consistent with the adaptation of Bergek et al. (2015) 's "context structures", learning is presented in the order established by the framework.

5.1. Technical Learning: Puget Sound

Technical learning focused on developing monitoring instrumentation robust enough to perform in the harsh tidal environment. Government informants, researchers, and developers noted advances in monitoring equipment as a key outcome. The regulatory concerns about the uncertainties regarding environmental impacts inspired this work on "next generation of environmental monitoring systems." Key informants noted how monitoring platforms incorporated many existing instruments, such as acoustic sensors, hydrophones, and acoustic Doppler current profilers (ADCPs) to address identified issues. Synchronizing the instrumentation required some work.

The tidal flow conditions are purported to challenge existing oceanographic data gathering instruments. Several key informants credited the need for more robust, resilient monitoring devices as driving the imperative to learn lessons regarding instrumentation. Using instrumentation to produce usable data from tidal races, such as Acoustic Doppler Velocimeters (Durgesh et al., 2014; Richard et al., 2013), is difficult. As a technician explained the intensity of the tidal race compounds the instrumentation problem:

> "There's a lot of instruments out there that are applicable, but aren't quite right, and haven't been put together for these kinds of conditions. I'm an oceanographer. You don't put your gear in fast tidal races or heavy waves if you can possibly avoid it."

Ideally, instruments such as hydrophones could pick up relevant marine sounds such as the whale clicks. However, the flowing water makes noise, as do the drifting cobbles and rocks, which sometime collide, producing a sound similar to whale clicks. As such, the challenge to the instrumentation is significant during the high flow conditions of concern.

From a technical perspective, learning about the device from the key informants from the Admiralty Inlet case concentrated on the turbine's ability to be remotely shut down.

Initially, the National Oceanographic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) preferred a remote braking system as a mitigation measure to allow the project to move forward. This strategy was similar to the procedure followed by Marine Current Turbines (MCT) in Northern Ireland (Royal Haskoning, 2011). For a period of time, the developer expressed confidence in its ability to shut down the turbine. Yet, the developer's engineers learned that that an automated, remote stop was not feasible for the firm's technology. A remote shut down would cause "catastrophic failure." Instead, the project addressed this problem through an alternate manual shut down procedure via a remotely operated underwater vehicle (ROV). This technical mitigation measure would take several days to facilitate, thereby increasing the level of risk to species of concern. As a result, NOAA/NMFS had to accept the risks of this technical limitation in its biological opinion (NMFS, 2013) to let the project continue.

5.2. Technical Learning: Pentland Firth

Concerns regarding the environmental impact of tidal turbines influenced researchers to focus their innovation on advancing and applying instrumentation. While challenging, monitoring for environmental changes is key to meeting the adaptive management tenets of the Survey, Deploy, and Monitor (SDM) policy (Marine Scotland, 2016). Monitoring equipment had to be developed to answer questions relevant to the consent conditions in order to allow the project to scale up after Phase 1A. Synchronizing the various instruments, e.g. multi-beam sonar, cameras, ADCP, and other sensors, in the monitoring platform is important to meeting this goal. Instrument robustness was an important technical issue where learning occurred. During the interviewing period, the project was deploying the monitoring instrumentation to gather baseline data and test the equipment's resiliency. As a government informant noted, testing the survivability of the monitoring equipment is wise because without the data the project will be stymied. Key informants emphasized the importance of having back up options in the case of failure because the project's timeline depended upon the generation of environmental data. One stakeholder had reservations about the effectiveness of the proposed monitoring instrumentation. A conservation key informant shared concerns about the absence of a shut down ability and expressed doubts regarding the ability for the instrumentation to actually reveal the extent of a collision's impact. Ensuring that monitoring equipment can produce useful data remains a key concern for many stakeholders.

Learning occurred regarding the logistical challenges of deploying, operating, and servicing the equipment. Ideal weather windows in the Pentland Firth are rare. Frequently, conditions changed and delayed deployment. Due to the economic constraints, vessel availability for monitoring was limited. These factors required the developer to integrate monitoring with other project work.

University partnerships mobilized additional resources for the project. The project involved collaboration from research institutions on recently developed environmental monitoring strategies. The university connection allowed learning from others involved in tidal energy to transfer to the project. For example, insights from FLOW and Benthic Ecology 4D (FLOWBEC), a partnership focused on the interaction of the physical behavior of water and species, expanded the environmental monitoring capabilities for the MeyGen project (NOC, 2016). From this partnership, the project could utilize a developed subsea platform for environmental monitoring (Williamson et al., 2016).

Additionally, the key informant involved with environmental monitoring was able to learn a “huge amount” about using passive acoustics for monitoring marine mammal behavior from the Sea Mammal Research Unit Ltd. (SMRU), an important contractor for the project. The subsequent interactions and knowledge exchanges increased capabilities for the project and, eventually, the sector.

5.3. Economic Learning: Puget Sound

Economically, the key informants learned about sources of increasing costs. The PUD designed the pilot project to test the commercial viability of tidal energy. The end of the Admiralty Inlet project featured a public dispute about the funding between the utility and the DOE (PUD, 2014). The PUD ultimately decided to end the pilot because it was too expensive without additional funding provided from other sources. The high cost of tidal energy was the dominant economic insight the key informants gleaned from observing the Admiralty Inlet project. Several key informants could name several areas of escalating project costs, such as contracting, environmental research, legal expenses, and insuring the turbines. Key informants opposing the project emphasized the very expensive cost of power to supplement their arguments.

Key informants learned about the expense of legal issues. Observers of the Admiralty Inlet project regularly noted the high cost of resolving possible legal challenges to the project and the challenges’ potential to drain funding. The project experienced cost increases from three sources: 1) the Jones Act 2) designing an appropriate insurance program and 3) preparing for potential litigation. The Jones Act (The Merchant Marine Act, 1920) is a protectionist law designed to ensure that American companies perform shipping and support operations in U.S. waters. The project proponents learned that obtaining an exemption is unlikely. The Irish developer, OpenHydro, was unable to use its specialized vessel, the *OpenHydro Installer*, in Puget Sound. The firm and PUD did not anticipate this outcome, resulting in the project's "single biggest ticket price increase" from one informant's perception. Future projects in the United States must take into account the Jones Act's affect on project cost estimations because using international assets for water works is not permitted. The OpenHydro and PUD informants also identified designing an insurance program for the project as an area of economic learning. Using the PUD's legal team to develop an insurance program proved to be expensive because the project involved many contractors and components and a high level of risk. Preparing for potential litigation represented a further project expense. Even without a filed suit, looming legal opposition cost the project through delay. The key informant representing the technology developer noted that addressing concerns of PC Landing Corp., a potential litigant, slowed the project's progress.

5.4. Economic Learning: Pentland Firth

The MeyGen project captured funding from sources interested in advancing the sector. For example, the Crown Estate (TCE) was motivated to invest because of the early project's potential to provide industry-wide benefits. Additionally, key informants viewed government investments in environmental research as important for moving the project forward. A regulator stated:

> "The main thing to realize is a lot of the studies going in around MeyGen would not be paid by MeyGen. They will be paid by Scottish Government, and that is because the Scottish Government recognizes that this is a way to learn, which will benefit every other project."

Studies like these relate to the "strategic research" program initiated by Marine Scotland which aims to support MRE development (ABP MER, 2012). Thus, targeted government funding for the sector reduced the burden of environmental research costs to the MeyGen project. If developing MRE project is a policy goal, strategic public funding for research targeted at addressing identified areas of uncertainty to the sector could help facilitate future tidal projects.

Many key informants expressed insight into the MeyGen's regional economic impact, showing how positive externalities are noticed. One key informant said the community was "watching with interest" to see how much local benefit comes from actual deployment. By employing local firms for contracting needs, the developer showed how tidal projects can use local businesses to deliver the project. Another key informant from a regional development partnership mentioned how a local nuclear fabrication firm was diversifying into the renewables industry by performing work for the project. Marine Scotland, an agency tasked with the broad regulation of the marine sphere, noted that the environmental research for the MeyGen project was providing local dive boats with more work, supplementing the income beyond the tourist season. However, one stakeholder noted a negative consequence of MRE in the local economy. The key informant argued that tidal energy could impact other marine industries, namely fishing. Increasing fishing pressure in areas outside of the project would likely reduce the fishing community's "collective income." This included areas fished infrequently, such as the MeyGen project site in the Inner Sound of the Pentland Firth.

5.5. Environmental Learning: Puget Sound

The Admiralty Inlet project served as a catalyst for examining the environmental impacts of tidal energy development. The project encouraged research to addressed existing areas of uncertainty. In particular, concerns regarding orca whales prompted research on the risk tidal energy posed to the endangered species. By generating environmental data, the project could provide regulators with environmental knowledge that would be useful for regulating future tidal energy developments.

For a time, the absence of scientific data on orca behavior stymied progress. Stakeholders wanted to know how endangered species interacted with the turbine, particularly orca whales. Without a prior project in the water, the risk of interaction with the turbine could only be approximated. Fortuitously, researchers with the Pacific Northwest National Laboratory (PNNL) gained access in 2013 to orca tissue samples from two carcasses (Carlson et al., 2014). PNNL researchers performed tests to see what the impact of forces similar to a rotating turbine would be on orca tissue. Key informants understood this testing as a pivotal finding that allowed the project to move forward. An informant noted that:

> "The analysis that PNNL was able to do was really instrumental in showing that, even if a collision did occur, the outcome was pretty limited. And that was really turning the whole problem on its head, thinking about it from a completely different perspective. Because no one had ever thought to ask the question about like, 'Well, can we actually simulate a collision and see how bad this is?' Everyone went, 'Collision is bad!' Full stop. And the simulation… was an impressive breaking of the chicken and egg cycle."

While the tests had limitations, the presence of new research that suggested the consequence of the worst-case scenario, a direct collision with the tidal turbine, was low, equivalent to bruising (Carlson et al., 2014). While the risk of encounter remained the same, the understanding of the consequence of the encounter was changed. From a regulator point of view, the subsequent risk of the project to the species was lowered enough to allow the project to move forward.

5.6. Environmental Learning: Pentland Firth

The need for reduced uncertainty regarding the environmental impacts of tidal energy development has encouraged targeted research on relevant environmental issues. Statutory bodies and other relevant parties engaged in collaborative discussions to identify the key areas of research. To streamline the process and reduce duplicity, the research initiated for the project aspires to apply at the sector level. A representative of Marine Scotland, the leading agency for tidal energy, explains, “Rather than getting each developer to do the same thing, at a very low level, what we’re looking for is coordination of their research, depending on the risks at their particular site.”

Species behavior is a crucial area of research for the MeyGen project. Key informants emphasized the imperative to resolve the outstanding research questions of species behavior around tidal turbines, particularly with respect to collision risk between turbines and marine mammals, fish, or diving birds. According to an environmental impacts researcher, changes in animal behavior have been observed based on the presence of a structure. The key informant speculated that this change in behavior is related to the altered hydrodynamics due to the turbine, a finding later established by Waggitt et al. (2016). Multiple government informants used a seal tagging study in Kyle Rhea, Scotland, as an example of the importance of understanding species behavior at a “far more intimate level.” The researchers had hypothesized that seals would not use the tidal race areas during strong tides, but the study suggested that some individuals used the strong tide for foraging (Thompson, 2013). Thus, the risk of collision with a turbine project in that site could be higher than expected.

Government informants and a species-focused non-governmental organization (NGO) raised concerns about the possible impact of the turbines on diving seabirds. MeyGen's location in a Natura site, the European Union's network of protected areas for rare and threatened species (European Commission, 2016), triggered the review (MeyGen, 2011; SNH, 2016). The foraging range and ability to detect the turbines while diving of these species are unknown, although this gap is being addressed (Waggitt et al., 2016). Stakeholders hope learning about seabird behavior can be used to evaluate the impacts of other projects in non-designated locations.

The regulatory community is learning to apply environmental research to guide its review of risk from the tidal proposals in light of existing uncertainty. For example, there was minimal information on salmon migration routes and on the water depths where Scottish Atlantic salmon resided (Malcolm et al., 2010). This uncertainty required the regulators to adopt a worse case scenario that assumed all fish migrated through the project site and depth. A tagging study was funded to address these knowledge gaps. From the results, regulators could use new information, that Atlantic salmon spend the majority of time in water depths under five meters (Godfrey et al., 2014), into their models. Applicable to the sector, the research suggested that the probability of salmon encounter with the turbines is lower than estimated, thus reducing the risk posed the project.

5.7. Policy Learning: Puget Sound

The FERC implemented a licensing process for marine hydrokinetic pilot projects (FERC, 2008) which the Admiralty Inlet project followed. The majority of stakeholders interviewed shared an acquired appreciation for the formal process, despite some initial skepticism. By giving stakeholders the opportunity to share concerns, the project proponents could respond. One key informant viewed this as important because "unanimous consent" for a tidal project is unlikely.

Several stakeholders' interpretations of FERC's process for licensing hydrokinetic pilot process (FERC, 2008) were colored by their experience with traditional hydropower. The Tulalip Tribes key informant said, "FERC processes have never been very good at dealing with tribal treaty rights, so we really did not expect to win anything in the FERC process." On the regulatory side, key informants from NOAA/NMFS and Washington Department of Natural Resources (WA DNR) understood the pilot project process as somewhat analogous to traditional hydropower processes. The NOAA/NMFS key informant emphasized the difficulty of responding to the application given the knowledge gaps. The key informant stated:

> "It's a little challenging to apply a freshwater, traditional hydropower relicensing framework to this marine environment, novel technology license process, where we don't have that many solid, concrete answers or science to rely on… The pilot process for marine energy is supposed to be a streamlined, quick, get something in the water type of process. But given the fact that we do not have a lot of reliable, available science to point to, to help us understand how best to monitor and mitigate for potential effects, it ends up being a little less than satisfactory feeling to try to go through that pilot process and come out with a good project."

As such, it is interesting that stakeholders who experienced FERC with hydropower had reservations regarding its applicability with the current state of tidal energy.

The challenge of responding to the entry of a new sector in an adapted policy regime caused difficulty for regulators, thus revealing that collaboration among regulators is vital to advancing projects. Key informants from state agencies and NOAA/NMFS emphasized the importance of learning from other regulators. Some key informants credited an interagency working group for fostering collaborative learning about how each agency's purview interacted with that of other regulators for the project. The interagency group was also able to identify the key scientific concerns relevant to the project. One key informant noted that by working together, the regulators and proponent were able to frame the questions and develop a research strategy that could provide usable answers. Proving no negative impact to protected species remains difficult, but adaptive management strategies were viewed as important for addressing uncertainty as a project advances.

Government informants defined risk "classically" as probability multiplied by consequence. Regulators worked to quantify the risk by using historical data on orca whales gathered by the Friday Harbor Whale Museum researchers, supplemented with further studies. NOAA/NMFS was responsible for dealing with endangered species and marine mammals. The agency appeared to be the most hesitant government agency to offer permission to the project, given the uncertainty of collision risk to the orca population. Anecdotally, the agency's risk tolerance was lowered, allowing the project to move forward, by the new information from the PNNL research (Carlson et al., 2014) and from a pivotal meeting attended by "fairly senior people" in the agency. These officials had the authority to absorb some risk for the project that others lacked. From new research and seniority, NOAA/NMFS's risk tolerance threshold was raised enough to allow the project to advance.

5.8. Policy Learning: Pentland Firth

Scottish regulators start from a precautionary standpoint in response to the uncertain environmental impacts from tidal turbines. This precaution applies the parameters within the existing models related to risk. For example, a government informant stated:

> "As with all these things, you've got no idea of avoidance rate. So you work out a very precautionary avoidance rate to start with, and then over time you will build up a picture of the likely avoidance rates of them based on actual collisions and information."

To advance the MRE industry with precautionary principles, the Scottish Government's uses an adaptive management approach with the SDM policy (Marine Scotland, 2016) applies. SDM is a risk-based policy allows for scientific data to be generated as the project develops to reduce uncertainty (Wright, 2014) and has been identified as helpful to the emerging sector (Wright, 2016a). This allows projects like MeyGen Phase 1A that are identified as low risk projects proceed until the environmental monitoring suggests impacts of a larger deployment are acceptable.

Staged consent allows environmental data to be generated while the risk remains acceptable. This approach helps the developer securing financing, since having a full consent lowers the investment risk. Upon proving a low impact result, the firm can scale up in a streamlined fashion. For MeyGen, staged consent allowed the project to move forward in the context of Marine Scotland's potential biological removal (PBR) management method for seals (Scottish Government, 2016). For MRE, the PBR policy requires quantifying the level of acceptable negative impact from a project. The PBR of six harbor seals influenced the project's scale. This limit impacted the project greatly by necessitating that the consented 86 MW Phase 1 be divided into Phase 1A for 6 MW, with Phase 1B developing the remainder. After proving the collision risk to harbor seals is less than estimated, the project can proceed.

The E.U. Habitat Regulations influence development in the marine sphere by requiring a burden of proof for projects in designated areas. The designations have been noted as a concern for MRE in the U.K. (Wright, 2016a). The project is located in site with an E.U. designation as the North Caithness Cliffs special protection area (SPA). This legal requirement poses difficulty in consenting marine projects with uncertain impacts. As one key informant stated, the law is quite stringent, requiring the developer to "prove beyond scientific doubt" that the action will have no adverse effect. By allowing some development to occur despite existing scientific uncertainty, Scotland's SDM policy conflicts with the stringent E.U. requirements. A key informant explains:

> "So it's the regulator taking a fair chunk of risk onto their own back, but allowing the sector to actually progress. Because under E.U. Habitat Regulations, all scientific doubt has to be removed before the project can go ahead, essentially. You can't remove all scientific doubt from tidal projects. It's literally impossible at the moment. And so this is essentially the Scottish Government going against the grain somewhat with regards to the E.U. regulations. And in doing so, taking on some of that risk. But if you didn't take on that risk, the sector just wouldn't develop."

Thus, the SDM is a critical asset for a developer seeking to move forward in E.U. designated locations.

Flexible policies were recognized as valuable to the developer. The Rochdale Envelope policy helps projects like MeyGen advance by addressing uncertainties in design (MER, 2012). Described as design neutral, the Rochdale Envelope gives developers flexibility. Developers can define the project within certain parameters. To account for the environmental effects, the policy requires project assessments to account for the 'worst-case' impacts from the envelope (Wright, 2016b). According to a government informant, MeyGen used the envelope for its design of turbines and foundations. With its range of options, the application is more complex for the regulator, but the policy appears useful for projects initiated before turbine design convergence because the developer can continue to improve its device.

5.9. Social Learning: Puget Sound

From the pilot, the project developer recognized the relevant stakeholders. The PUD key informant emphasized that involving stakeholders early was a priority. Several key informants concurred, saying the PUD did a “good job” with outreach. Local to the project site, the utility used its existing relationships to engage with stakeholders. As such, the technology developer remained in the background, allowing the utility to spearhead engagement. However, some stakeholder concerns were difficult to resolve. Stakeholders that perceived a spatial conflict opposed the project. Submarine communication cables and treaty right-based fisheries were threatened interests. The project’s major opponents, PC Landing Corp. and the Tulalip Tribes, had concerns regarding the interaction of the turbines with their claims to ocean space.

PC Landing Corp., a company that operated a trans-Pacific fiber optic cable, vigorously opposed the project. The company viewed the deployment and operation of the tidal turbine as an unacceptable risk to its cable’s integrity (Johnson, 2011). The intensity of the opposition appeared to catch the project proponents off guard. One key informant concluded, “The cable industry is terrified of marine energy development and its implications for cable integrity.” The PUD looked to WA DNR, the state agency responsible for leasing the seabed, to solve the conflict between the two leases. While WA DNR did not issue a lease prior to project cessation, the agency key informant expressed with high confidence that it was prepared to do so. Still, the cable industry has the capacity to greatly impact a project. Although the project stopped before a court case was filed, the cable company showed a strong intent to engage in legal opposition. A key lesson from this, observed another informant, was the cable industry is “a deep, deep pocket” and represents a formidable opponent to tidal energy.

The Tulalip Tribes were another active potential litigant against the project (Corp., 2016; Morisset and Somerville, 2015). Since fishing gear could tangle with the turbine, the project would effectively exclude the area from fishing. The Tulalip Tribes key informant viewed this project as a gateway to commercial scale development, which would exclude fishing in a large portion of usual and accustomed fishing area. The key informant stated,

> “When we thought about going to a utility scale project, it would have required us closing a huge section of water for fishing in Catch Area 9, and that’s just not something that the tribe’s willing to do.”

The tribe believed it could eventually win its appeal based upon the treaty-based right to its usual and accustomed fishing area. One key informant surmised that a tidal project in Puget Sound could not be realized without approval from the tribes. Unless the tribes consent to a project, the potential exists for the courts to rule in favor of the tribes claim of exclusion from their usual and accustomed fishing area. No suit was filed.

5.10. Social Learning: Pentland Firth

Social learning occurred through communication. Several key informants described the developer’s pro-active communication with the community. By placing an emphasis on outreach, this developer distinguished itself from firms operating in the area with a reputation for poor engagement. By using the connections of a local development organization, MeyGen could share its project with an established network of stakeholders. However, a few stakeholders noticed reduced communication as the project achieved its benchmarks. Arguably, the nature of a project, with its stops and starts and interim periods, reduces the need for consistent engagement since there is frequently no update to share. Still, stakeholders appear to prefer to have a steady stream of project relevant information.

Prior MRE development in the area influenced stakeholder perceptions. Poor communication resulted in conflict. As an example, TCE's 2010 MRE leasing round surprised the local fishing community. A fishing representative described the experience saying:

> "A map was published which showed all the areas that were auctioned for lease for tidal and wave energy. And there had been no consultation whatsoever with any local fishermen about the ramifications for fishing. So it was a huge howler, really, coming from The Crown Estate. And unfortunately for the energy companies, they were kind of implicated in it, too."

The involved parties have learned from the experience. Fishing interests worked to collect data about the economic importance of fishing to the area, to increase the industry's capacity to protect its interests in the Pentland Firth. TCE provided funding for research applicable to the local crab fishery. In response to this stakeholder concern, the developer and a regional fishing association have communicated about the project, primarily about the impact to the small boat, pot fishery in the Inner Sound.

Communication helped to solve the manageable concerns from navigation interests regarding the project. The project is sited in a relatively low use area of the Pentland Firth. The vessel traffic is mostly composed of small boats with shallow drafts. By having the turbines deep enough for eight meters of clearance, the project largely satisfied local users of the site. Recreation interests became involved in the project to ensure that recreation was recognized as a user of the site. The local kayaking club identified the project site area as frequently accessed on summer days during the periods of calm tides. Clearance for the kayaks was not the issue. Instead, issues were raised regarding access and safety concerns during marine operations, which likely occur during the same weather window ideal for kayaking. To resolve the issue, the developer agreed to communicate with the recreational stakeholder so the kayaking organization can be aware of planned project operations and adjust accordingly. Thus, communication about site conditions and the project design contributed to resolving navigational concerns.

6. Discussion of Learning

Tidal energy development needs to accelerate learning to quickly become a viable renewable energy source. This study examines stakeholder learning from projects prior to deployment. The findings provide insight about an interdisciplinary range of issues as represented in the hypotheses posed.

6.1. Technical Learning

- Question 1: Does learning occur regarding the technical issues related to a tidal energy project?
- Admiralty Inlet Finding: Motivated by concerns for an endangered, iconic species, technical learning occurred regarding the technical ability to monitor in the difficult tidal environment and the technical capacity for turbines to offer mitigation options.

Adapting instrumentation to the tidal environment is important to generating usable data for evaluating project impacts. By collecting baseline data and refining instrumentation, key informants involved in environmental monitoring learned about the abilities of technical sensing equipment in the difficult tidal environment. Less extensively, some government informants and opponents learned about the capabilities and limitations of existing monitoring equipment. The environmental monitoring key informants noted technical learning about dealing with the challenge of tidal conditions. The finding is less important if low-tech alternative methodologies, such as trawl surveys for fish or observer coverage for cetaceans, are accepted or preferred for producing environmental information.

The OpenHydro technology cannot execute a remote shut down without device failure. For projects utilizing technology sharing this feature, a remote shut down procedure may not be an available mitigation strategy for responding to species concerns. The environmental monitoring key informants learned how challenging it is to designing an automated marine mammal alert system that would trigger the turbine to shut down. However, the technology developer learned that shutting down its device would result in "catastrophic failure." The key informant from the lead regulator, NOAA/NMFS, the proponent, and the environmental monitoring key informants learned that a remote shut down procedure was not technically feasible. Even if feasible, the alert system was superfluous without the turbine's shut down capability. This finding may be reversed if the developer's tidal energy technology has the ability to engage in a remote shut down.

- MeyGen Phase 1A Finding: Technical learning occurred as technicians developed monitoring capabilities to meet consent conditions.

Advances in monitoring equipment are needed to meet regulatory concerns. Learning-by-doing from testing the equipment prior to deployment is important for proving capabilities and covering the regulatory risk posed by technical failure. The MeyGen project provided the opportunity and imperative for technicians to test and fine-tune monitoring equipment when gathering baseline data in preparation for turbine deployment. The equipment must be robust enough to survive the tidal conditions and accurate enough to detect impacts. This finding applies in situations where regulatory requirements demand high quality monitoring data. This finding will become less relevant as monitoring equipment matures and risks from environmental impacts are retired.

Encouraging collaboration among technicians of differing expertise on leading projects can result in technical learning that can contribute to the sector level. Establishing a monitoring group allows the regulatory bodies to be better informed about technical progress, setbacks, and capabilities. From those involved in the monitoring advisory group, learning occurred regarding the technical feasibility of durable monitoring equipment and integrating deployment and maintenance of monitoring equipment within the project's logistics. Linkages among those involved in monitoring enables learning from the project to help the MeyGen project better achieve consent and be translated to the tidal sector. This finding applies in locations subject to regulatory requirements requiring high tech monitoring.

6.2. Economic Learning

- Question 2: Does learning occur regarding the economic issues related to a tidal energy project?
- Admiralty Inlet Finding: Since the project was cancelled for financial reasons, economic learning occurred about various sources of cost increases for the project.

Those invested in the tidal sector's performance pay close attention to sources of project cost increases and the availability of government funding. While researchers involved in the industry credited the big picture market conditions for cancellation, the project proponent identified many specific sources of rising costs. Government informants are less concerned with the project cost. Government informants were aware that the proponent's decision to end the project was financial and linked to limited government funding. Opposing key informants use tidal's current expense to justify their position. A limitation of this finding is that many key informants were not privy to financial information.

Legal expenses can significantly impact a project's economic viability. The proponent and technology developer recognized the high cost of designing an insurance program to cover the project. The key informant who issued an appealed permit learned about the potential for opponents to add cost and delay to the project through litigation, regardless of the verdict. The developer and a key informant involved in collaboration learned about the consequence of the Jones Act on a project intending to utilize overseas technology. The finding exemplified by the Jones Act barrier applies to projects in jurisdictions where protectionist laws prevent developers from using international assets. The finding related to legal expense and delay may be less relevant in jurisdictions where the legal recourse for project opposition is less impactful.

- MeyGen Phase 1A Finding: Economic learning occurred regarding the commercial viability of tidal energy and local socio-economic impacts from the project.

By initiating Phase 1A, MeyGen seeks to learn about the commercial viability of the tidal energy sector. Achieving financial close for an early commercial project is difficult. Raising the necessary capital requires creativity to secure investment from public and private sources. Many key informants were aware of the significant government funding for the project and tidal sector. Key informants with a "vested interest" in the finances of the project learned about the challenge of securing investment from multiple funding sources. Skeptical from prior promises unrealized by the tidal industry, key informants view a successful MeyGen project as an opportunity to increase investor confidence in tidal energy. This finding aligns with the Scottish Government's favorable policies for tidal energy. If public support is limited or unavailable, securing private finance may prove even more critical to a project's success.

Tidal projects will have a level of socio-economic impact in the project area. Local key informants and agencies responsible for marine economic development are learning about the local socio-economic impacts, both positive and negative, as the project develops. Community members learn about the extent, direction, or absence of these economic impacts. To provide local economic benefits that are recognized by the community, a developer may wish to explore ways to utilize local businesses to assist in the project's supply chain. This finding applies to developers seeking to provide local benefits from the project. Some developers may not have this goal. For example, some developers may have established supply chains outside of the project area and may prefer to transfer these capabilities from outside the project area to the development.

6.3. Environmental Learning

- Question 3: Does learning occur regarding the environmental issues related to a tidal energy project?
- Admiralty Inlet Finding: Environmental learning occurred about the degree and consequence of potential environmental impacts to orca whales.

Determining the extent of the consequence from an identified risk can change the degree of concern regarding that risk. For example, government informants and researchers learned that orca whales had a low, but existing, potential to interact with the turbines. To move forward with the project in the presence of this risk, government informants, researchers, and the proponents learned about the consequence from a national lab study on the impact of a collision to orca tissue. If the absence of relevant science is problematic, producing research that can be identified as ‘best available science’ can meet a regulatory need. A limitation of this learning is that identified risks may not be able to be fully resolved from limited research.

Acoustic impacts to marine mammals represent an important concern to regulators and species advocates. The response of these species to noise impacts from turbines remains uncertain. Given the importance of sound to marine mammals, research on turbine noise is important to evaluating the development’s impact upon these species. Government informants and researchers learned about the existing noise in Admiralty Inlet from research at the University of Washington, which helped contextualize the noise emitted from the turbines. Understanding how species interact with the turbines remains a key area of uncertainty to address in the future for regulators, researchers, and conservation interests. Each marine site has a different noise budget, which could influence the degree of impact to a species.

- MeyGen Phase 1A Finding: Environmental learning occurred as research examined priority species to evaluate the risk posed by the tidal project.

Environmental research focused on species behavior in tidal flow environments can change the risk estimate for a tidal project. The proponent and government informants were aware of environmental issues, but the project provides an opportunity to learn about the actual level of risk posed by the impact. By researching the behavior of protected species in tidal flow environments, the government informants and project proponents hope to reduce the risk estimates based off species density models. Sitedependent factors are a limitation of this finding as research at one location may be less relevant at other locations. Project sites may have different species of concern present.

The level of risk that tidal projects pose to seabirds, seals, or salmon from disturbance or direct collision is considered uncertain. Encouraged by environmental groups and legal obligations, government informants are learning about species behavior at sea from tagging studies, which may impact future assessments for MeyGen. Targeting priority species can focus research capabilities. Tagging studies appear to be an example of targeted research that provides useful information. Species of concern may be identified through environmental groups, regulators, or other stakeholders. This finding applies to projects while uncertainty regarding the environmental impacts of tidal energy remains. This finding can be extended to sites where other species are a concern. Alternate research strategies may be necessary. For example, cetaceans may represent an important consideration for projects, but research such as tagging may not be feasible.

6.4. Policy Learning

- Question 4: Does learning occur regarding the policy related to a tidal energy project?
- Admiralty Inlet Finding: Policy learning occurred regarding the advantages and drawbacks of the FERC process for hydrokinetic pilot projects.

For tidal pilot projects in the United States, the FERC process presents opportunities and challenges. Government informants and researchers learned that the FERC process provides beneficial opportunities. Stakeholders can raise concerns. Also, stakeholders can pursue collaborative solutions to those issues as a part of this process. However, adapting a policy framework from an existing generation source may bring some complications, or "baggage", to the evaluation. As examples, government informants may struggle to learn the differences in turbine technology, or stakeholders may expect similar responses to their concerns from other projects. Illustrated by the experience with the FERC, this finding applies to countries that are regulating tidal energy by adapting processes from other energy policies, instead of crafting a specific framework for projects like tidal energy.

Collaboration can guide scientific studies to better satisfy the various concerns facing a project. Government informants cited the opportunity to work together with other regulators and the proponent as a learning experience that prepared them to ask the right scientific questions for monitoring the pilot project. In this case, the key informants working on the monitoring learned that NOAA/NMFS represented the key agency to satisfy regarding the level of risk posed to the Endangered Species Act (ESA) listed Southern Resident orca whale population. NOAA/NMFS appeared hesitant to accept risk resulting from a lack of scientific information. This finding's application may be limited in situations where constricted time and resources makes fostering collaboration difficult.

- MeyGen Phase 1A Finding: As the project develops incrementally to allow risk to be assessed, policy learning is occurring, revealing the merits of the applied policy strategies.

Given existing uncertainties, government informants and environmental groups exhibit concerns about large-scale tidal energy development. Projects may benefit by starting small and scaling up as concerns are addressed. Government informants and conservation interests were concerned about the scale of the initial MeyGen proposal. Constraining deployment by a staged consent placated these interests, since the policy gives them an opportunity to learn about environmental impacts from a low risk deployment. The staged consent policy places responsibility on the project's environmental monitoring strategy to justify the project's future expansion. This finding applies to the transition stage of tidal energy from R&D to commercialization. As the tidal sector matures and uncertainties are addressed, developing in stages may not be necessary. Also, certain locations may not be considered sensitive environments, and thus would not require a graduated process to evaluate impacts.

At this stage, uncertainties regarding environmental impacts are inherent to tidal projects. This reality may conflict with rigid environmental policies that have a 'no impact' criterion. To address uncertainty, regulators may wish to allow projects to proceed, provided information about the identified uncertainties can be produced. As appreciated by conservation interests and government informants, the MeyGen project site's E.U. designation presents a challenge to develop a project with uncertainties regarding environmental impacts. In response, regulators have adopted the SDM approach for the staged MeyGen project. To advance the industry, regulators can allow projects to proceed with some low level of risk, instead of stringently adhering to the 'no impact' policy. This allows uncertainties to be addressed. This finding can apply to projects in facing ESA concerns in the United States, Habitat Regulators in the European Union, and other jurisdictions with 'no impact' legal requirements for certain environmental concerns. This finding may be less relevant for projects located in sites without legally protected species or habitats present.

Though it increases project complexity for regulators, developers benefit from policy that allows flexibility in technology design. Government informants cite the Rochdale envelope, or 'design neutral', policy as an option for developers like MeyGen to continue learning with their technology as the project takes time to develop. This requires the regulators to consider a broader range of options during assessment, but this expanded review may be worthwhile for allowing the project to adapt. This finding may not apply to a policy regime that prefers certainty or prioritizes certainty regarding environmental concerns to the exclusion of developer concerns. This finding may not be relevant to a developer committed to a specific technical approach.

6.5. Social Learning

- Question 5: Does learning occur regarding the social issues related to a tidal energy project?
- Admiralty Inlet Finding: Social learning occurred concerning the major sources of opposition to the project.

Failing to address the concerns of a stakeholder with significant motivation and resources to oppose the project can thwart an outreach strategy. The subsea cable industry appears to have significant concerns regarding tidal projects. In this case, key informants learned that PC Landing Corp. virulently opposed the project. The key informants were surprised to learn the "tenacity" of the opposition. This finding applies to developments that encounter stakeholder's with a property right claim in the project site that they perceive is at risk from a tidal development.

Treaty tribes are highly concerned about impacts to fisheries and access restrictions to traditional areas. The majority of key informants were aware of the opposition of the project by the Tulalip Tribes. The key informant from the tribe and many key informants noted the opposition was based on the risk posed to the salmon fishery and the potential for commercial development of tidal energy to infringe upon the tribes' usual and accustomed fishing territory. Given the tribes' ability to litigate projects, a tidal developer in the Puget Sound ought to be aware of usual and accustomed rights. Effort to gain support for the project from tribal stakeholders may be worthwhile, if successful. This finding primarily applies to the Puget Sound and other areas where treaty rights from indigenous peoples to ocean space exist. However, this finding may apply to locations where access to ocean space for fishing purposes represents an important concern.

- MeyGen Phase 1A Finding: Social learning occurred as communication pathways were established, allowing stakeholder concerns to be addressed by the relevant entity.

Communication among relevant actors can address potential conflicts, particularly navigational concerns. By learning from a local development agency, the developer's communication with the local community was strong. The developer communicated with navigation interests for the project site, and the key informants learned that clearance should be adequate. While the deployed turbine may not significantly impede the usual transiting vessels, key informants learned there may be some impact during site operations. The absence of communication can damage trust and relationships. After upsetting the area's fishing community with a surprising lease round in 2010 (from which MeyGen received a lease), TCE is learning to repair relationships with the fishing industry. The fishing sector is learning how to quantify its economic impact. Depending on the existing concerns applicable to the project site, the ability to resolve conflict through communication may vary. Communication has merit, but this finding may be less applicable for concerns against the existence of the development. For example, a concern of an environmental group regarding the threat of a turbine to a whale might not be resolved through communication alone. Research or 'safer' turbine designs might be a necessary addendum to communication to address such concerns.

7. Conclusions

Accelerating the development of new RETs represents an urgent challenge for meeting the policy goal of reducing pollution the energy system. Creative technologies that can cleanly generate electricity from untapped resources, such as tides, are vital to emission reduction aspirations. MRE represents an exciting new source of renewable energy. Yet, taking new RETs from concept to commercialization is a significant challenge, especially in the marine environment. Novel technologies can encounter barriers from technical limitations, economic difficulties, environmental factors, policy regimes, and social concerns. These barriers can result in delay, thus slowing the pace of innovation for MRE. For tidal energy, the delays appear to be impacting some of the sector's leading projects during the 'valley of death' transition from prototype to commercialization. Striving to achieve commercialization, developing an RET is a learning experience for those involved. This study examined the Admiralty Inlet pilot project and the MeyGen Phase 1A project to explore an interdisciplinary range of lessons learned regarding the obstacles to commercialization.

The goal of this study was to synthesize learning from early tidal energy projects. Existing risks and uncertainties motivate stakeholder concerns about tidal energy. Stakeholders learn about interdisciplinary issues from these projects. As learning occurs about key risks and uncertainties facing the tidal sector, developers will have the ability to move projects forward into the commercial phase. Monitoring environmental impacts, securing funding, navigating regulatory pathways, and engaging stakeholders are vital elements for advancing the sector to the commercial phase. Whether canceled or continuing, early projects provide the opportunity for the fledgling tidal energy sector to learn, potentially streamlining the development of future projects.

Currently, a wide range of tidal stream technologies is under development. As these technologies and the sector mature, interest in tidal energy in the Puget Sound and Pentland Firth will continue to grow. Future projects can learn from these findings and contextualize their experience from this learning framework. By so doing, the projects can better approach the key stakeholders relevant to the project's community and jurisdiction. If the interdisciplinary concerns can be addressed to the satisfaction of key stakeholders, then future project will have the opportunity to generate predictable, clean power from the strong tidal flows of the Puget Sound and the Pentland Firth.

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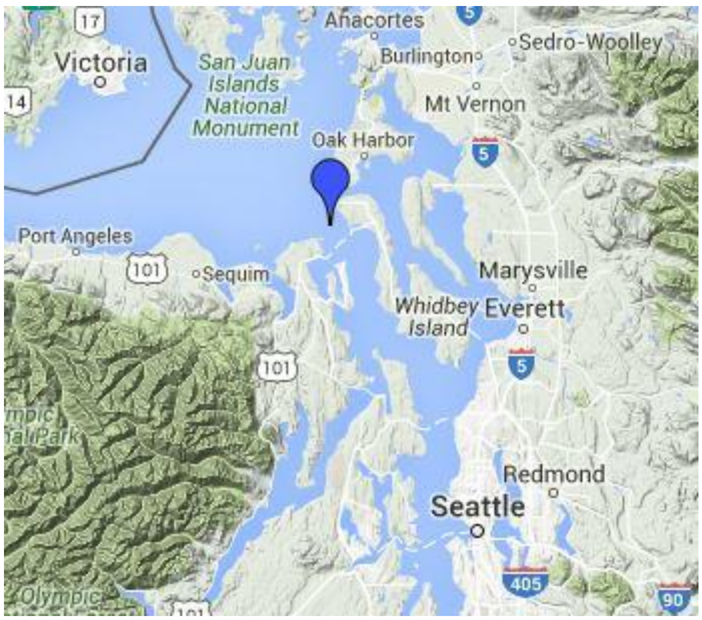
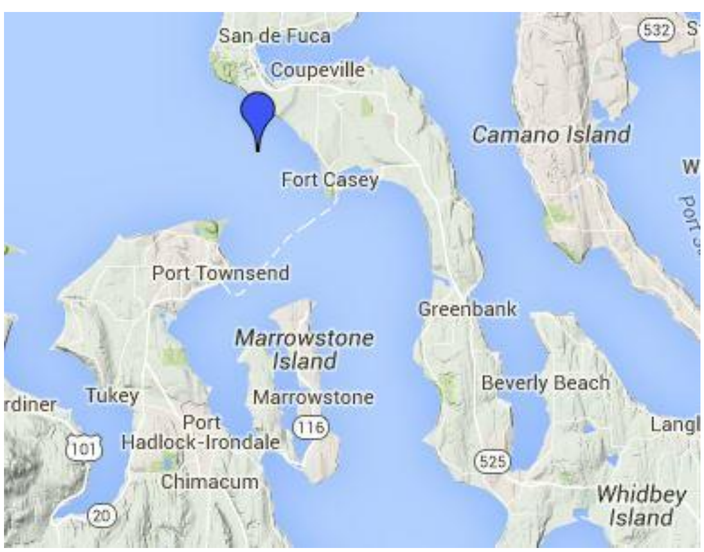
Appendix A: List of Acronyms

RET	Renewable energy technologies
R&D	Research and development
MRE	Marine renewable energy
PUD	Snohomish County Public Utility District No. 1
EMEC	European Marine Energy Centre
FERC	Federal Energy Regulatory Commission
DOE	U.S. Department of Energy
IS	Innovation systems theory
TIS	Technical innovation systems theory
LCOE	Levelized cost of electricity
ADCP	Acoustic Doppler current profilers
NOAA	National Oceanographic and Atmospheric Administration
NMFS	National Marine Fisheries Service
MCT	Marine Current Turbines
ROV	Remotely operated underwater vehicle
FLOWBEC	FLOW and Benthic Ecology 4D
SMRU	Sea Mammal Research Unit, Ltd.
TCE	The Crown Estate
PNNL	Pacific Northwest National Laboratory
NGO	Non-governmental Organization
WA DNR	Washington Department of Natural Resources
SDM	Survey, Deploy, and Monitor
PBR	Potential biological removal
SPA	Special Protection Area
ESA	Endangered Species Act

Appendix B: Map Showing Location of Admiralty Inlet Tidal Energy Pilot Project





Appendix C: Map Showing Location of MeyGen Limited Tidal Energy Project

Appendix D: Preliminary List of Involved Stakeholders

Involved Stakeholders		Admiralty Inlet, Puget Sound	MeyGen Phase 1A, Pentland Firth
Project Developers / Technology Developers		• Snohomish County PUD • OpenHydro Group Ltd.	• MeyGen Ltd. • Atlantis Resources Ltd.
Energy Industry			• European Marine Energy Centre • SSE Ltd. • National Grid • Dounrey Site Restoration Ltd.
Government	Local	• Island County Planning • City of Port Townsend	• Caithness and North Sutherland Regeneration Partnership • Highlands and Islands Enterprise • Orkney Islands Council • Highlands Council • Dunnett and Consiby Community Council • Caithness Chamber of Commerce • Caithness Horizons
	State / Regional	• WA Department of Fish and Wildlife • WA Department of Ecology • WA Department of Natural Resources • Puget Sound Partnership • WA Department of Transportation	• Marine Scotland • Scottish Natural Heritage • Scottish Environmental Protection Agency • Historic Scotland • Visit Scotland • Scottish Government Energy Consents Unit • Scottish Government Planning • Scottish Government Ports and Harbors
	Federal / National	• Federal Energy Regulatory Commission • Department of Energy • NOAA / NMFS • U.S. Navy, Naval Facilities Engineering Command • Coast Guard • U.S. Army Corps of Engineers • U.S. Department of Interior • Public Safety and Homeland Security Bureau of the Federal Communications Commission • National Park Service	• Department of Energy & Climate Change • The Crown Estate • Health and Safety Executive • Marine and Coast Guard Agency • Ministry of Defense Estate

		• U.S. Environmental Protection Agency	
Research Institutions		• University of Washington • Pacific Northwest National Laboratory • Sandia National Laboratories • Sea Mammal Research Unit, Ltd.	• University of Aberdeen • Heriot Watt University, Orkney Campus • Scottish Association for Marine Science • University of St. Andrews • European Marine Energy Centre • Sea Mammal Research Unit Ltd. • Environmental Research Institution
Conservation Organizations		• Orca Conservancy • Orca Network • Friday Harbor Whale Museum • Pacific Whale Watch Association • Whidbey Environmental Action Network	• Whale and Dolphin Conservancy • Royal Society for the Protection of Birds • The National Trust for Scotland • Joint Nature Conservation Committee • Scottish Wildlife Trust • Marine Conservation Society • Caithness Sea Watching
Fishing Industry			• Orkney Fisheries Association • Association of Salmon Fisheries Board • Scottish Fishermen’s Federation • Caithness District Salmon Fishery Board • Association of Scottish Shellfish Growers • Scottish Fisheries Protection Agency • Scottish Federation of Sea Anglers • Scottish Creelers and Divers • Scottish Fisheries Committee • Orkney Fishermen's Society • Caithness Sea Angling Association • Caithness Static Gear Fishermen’s Association • The Salmon Net Fishing Association of Scotland • Scottish White Fish Producers’ Association

		• Scottish Salmon Producers Association • Scottish Pelagic Fishermen's Association • Seafish Industry Authority • Scottish Fishermen's Organization • Caithness Sea Angling Association
Treaty Tribes	• Tulalip Tribes • Sauk-Suiattle Indian Tribe • Swinomish Indian Tribe • Point No Point Treaty Council • Suquamish Tribe	
Marine Transportation	• American Waterways Operator • Washington State Ferries	• Pentland Ferries • John O'Groats Ferries • Northlink Ferries • Northern Lighthouse Board • Chamber of Shipping • Royal Yachting Association • Royal National Lifeboats Institution
Maritime Industry	• PC Landing Corp. • GCI Communications Corporation • North American Submarine Cable Association	• United Kingdom Cable Protection Committee • British Marine Aggregate Producers Association • British Ports Association • Wick Harbour Authority • Scrabster Harbour Trust • Gills Harbour Ltd.
Notable Contractors		• Xodus Group Ltd. • JGC Engineering • Fisher Marine Services • John Gunn & Sons • ABB
Recreation		• Pentland Canoe Club • Caithness Diving Club • Scottish Canoe Association • Scottish Coastal Forum • Scotways • Scottish Surfing Federation • Surfers against Sewage
Archaeological Interests		• The Prince's Foundation • Caithness Archaeology Trust • Castle of May