



Original research article

Staying current: A community readiness framework for marine energy applied to river current energy in Alaska

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ABSTRACT

Marine energy—including wave, tidal, and river current energy—can provide a local energy source for rural and remote communities. Marine energy has the potential to bolster self-sufficiency and create economic opportunities while preserving ecological integrity. Communities may be interested in deploying, testing, and advancing these early-stage technologies to meet their needs. However, limited capacity, workforce constraints, and other barriers can challenge development. To better understand a community's interest in and preparedness for marine energy, we developed a suite of 150 'metrics of readiness.' Organized across seven categories—technical, social, environmental, strategic, governance, economic, financial—and 29 subcategories, the metrics provide a holistic perspective beyond the technical aspects of an energy device. We conducted a desktop application of the metrics of readiness for Igiugig, Alaska. The metrics were applied retrospectively for two points in time: before (2009) and after (2018) in-stream testing of a river current energy device. By documenting changes among categories and subcategories of the metrics, our results show the evolving nature of community readiness for river current energy. They also illustrate how our interdisciplinary framework captures the investment in environmental effects research and commitment to strategic planning that occurred in Igiugig. In future applications, we envision the framework could be used to foster public engagement in marine energy, collaborate with communities in project development, shape capacity building activities, prioritize investments, and inform research needs. While our study focuses on enabling river current energy in Alaska, the metrics of readiness have the potential to inform implementation of other renewable technologies with communities in new geographies.

1. Introduction

The culture, livelihoods, and well-being of rural and remote communities are often intertwined with the natural environment that surrounds them [1–4]. Yet, geographic isolation and exposure to extreme weather can lead to energy and infrastructure challenges that threaten the social, economic, and environmental fabric of these populations [5,6]. Rural and remote communities may face challenges related to energy security, opportunities for economic development, and disruption of critical services [7–9]. Limited or non-existent grid connections can lead to high electricity costs and reliance on imported fossil fuels [10–14]. External energy sources are often subject to price volatility, transportation barriers, and environmental risk, all of which can increase social vulnerability [15–18]. Less geographically isolated

communities may also contend with intermittent connections or unreliable transmission, especially with more frequent extreme weather events [19–21]. To address these challenges, many rural and remote communities are exploring energy solutions that can help them realize multiple economic, social, and environmental goals [22,23].

Renewable energy provides an option for rural and remote communities interested in sustainable development for energy resilience and independence [24,25]. If implemented through policies and financing mechanisms that give communities control over their own energy production [26], renewables can support energy security [27], generate economic development opportunities [28], and promote community well-being [29]. These technologies can also reduce emissions, enhance resilience from natural hazards, and provide opportunities for ecological restoration [30–32]. Moreover, several studies have shown that

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communities are more interested in renewable energy projects that bolster local goals for employment, revenue streams, human well-being, energy accessibility, and environmental conservation [18,33–37].

Options for community development of renewable energy technologies depend on geographic location, resource availability, financing mechanisms and costs, cultural preferences and perceptions, and environmental and infrastructural constraints. In rural and remote areas, a suite of energy options may be important for sufficient electricity generation with varying resource availability, both seasonally and over the longer-term [12]. Although solar and wind energy are the most deployed renewable technologies globally [38], these technologies alone may not fulfill a particular community's needs and interests. For that reason, researchers and community-based organizations have been engaging rural and remote communities interested in technologies that harness ocean-based and river current energy resources. Referred to together as “marine energy” by the United States Department of Energy (DOE), these technologies convert energy from moving water to electricity or other forms of usable energy [18,39]. Marine energy resources include waves, tides, currents, temperature gradients, and salinity gradients, as well as river current energy¹ harvested from the flow of water downstream. Marine energy is highly predictable, and the daily and seasonal cycles of marine energy resources are often complementary to other sources of renewable energy, like solar and wind [39–42].

Since marine energy is at an early stage of research and development [39,40], continued testing and demonstrations are necessary to refine the technologies before commercial deployment [43–45]. Rural and remote communities may be particularly interested in—and successful at—testing and deploying marine energy for several reasons. First, geographically isolated communities may possess a strong sense of self-reliance that aligns with a desire to generate energy locally [46–49]. Second, small communities may have the flexibility, independence, and creativity to innovate and collaborate with technology experts, and community leaders can play an outsized role in changing the course of local decision-making [50–52]. Third, as we highlight above, rural and remote communities may already be facing high energy costs and energy security challenges, driving them toward the exploration of alternatives for generating energy locally [10]. Purchasing marine energy devices once the technology is commercially ready would be cost prohibitive for most communities; whereas testing typically does not require the upfront investment from communities [53].

Despite the potential drivers of interest, rural and remote communities may face limited human capacity and resources to manage and maintain new energy technologies [54,55] or to navigate permitting processes, ownership models, and public perceptions of early stage technologies [34,56]. For example, workforce acquisition or training challenges could prevent a community that is otherwise well suited to exploring marine energy from taking part in early deployments and testing. This situation could, in turn, affect both the community's ability to progress their energy systems and the industry's opportunities for testing and improving the technology. There is a need, therefore, to better understand communities' preparedness for, willingness to engage with, and ease of action related to marine energy. In other words, understanding a community's ‘readiness’ for marine energy, and the factors that impact readiness, could help enable testing to progress from the research to operation phase. Understanding readiness early in a planning process could also advance self-governed production of energy by communities and shape infrastructure and personnel investments to support community goals for local energy development.

An interdisciplinary, transparent, and repeatable approach that combines technical dimensions with metrics related to a community's environment, socioeconomic context, and governance is needed to more

accurately capture and track community readiness for marine energy. Technical dimensions, such as the availability of sufficient marine energy resources, the suitability of a site for particular devices, or operations and maintenance requirements are commonly prioritized when evaluating locations for marine energy [39,57,58]. More recently, researchers, industry, and coastal planners are considering social and environmental factors in site selection for marine energy [59]. However, evaluating readiness differs from evaluating potential marine energy sites in that readiness includes factors that are not simply characteristic of the geographic context, but are characteristic of the human community living in proximity to, and regularly interacting with, the site [4,60]. Various organizations, institutions, and researchers have proposed readiness criteria for different energy technologies [61–63] and renewable energy development more generally [64,65]. These criteria include enabling conditions, local context, drivers, and challenges, and have been applied at different scales [61,66–68]. Many readiness assessments are conducted on a national scale and tend to focus on favorable policies, governance, and economic factors [61,65,69], all of which are important, but insufficient for understanding readiness on a community scale.

Given the early stage of this technology, the dearth of operational projects in the U.S., and the desire for multiple social, economic, and environmental outcomes, marine energy for rural and remote communities warrants a tailored approach. Here we report on a series of questions or ‘metrics’ that can be used to understand readiness for marine energy and shift project design to center communities more explicitly in planning and implementation. The metrics were developed as part of a larger effort by DOE's Hydropower and Hydrokinetic Office (H2O) (formerly known as the Water Power Technology Office (WPTO)) to support the resilience and energy independence of rural and remote communities through marine energy projects. The metrics are intended to help communities, community-based organizations, technical assistance providers (e.g., universities, DOE national laboratories, other researchers), and funders explore opportunities for marine energy. The metrics and organizing framework can be used to foster public engagement in marine energy, support community-based project development, shape capacity building, prioritize investments, and inform research needs.

In this paper, we first describe the approach used to develop the metrics of readiness. Next, we delineate the hierarchical organization of the metrics, including the categories, subcategories, and scoring rubric. Finally, we report on the results of a desktop application of the metrics for Igiugig, Alaska, a remote community that operated a river current energy device. We applied the metrics retroactively at two points in time—prior to and following in-stream testing—to explore how the metrics can be used to understand the evolving nature of readiness. Although this study focuses on one community in Alaska, the metrics of readiness are designed to be broadly applicable to rural and remote communities across the U.S. interested in marine energy. Furthermore, while the metrics of readiness were developed to fill an immediate need in the area of marine energy development with rural and remote communities, many of the metrics are applicable to other coastal, riverine, and watershed communities. Looking beyond marine energy, the framework is also relevant to community readiness for other energy technologies; the metrics could be adapted accordingly and applied with communities situated in different geographies and environments. In the wider context of research on community energy systems, the metrics of readiness contribute to the growing body of literature aimed at understanding the drivers of deployment and opportunities for improvement of renewable energy projects in local contexts.

2. Methodology

To develop the metrics of readiness, we used an iterative approach that combined literature review, outreach, expert review, and application of the metrics over the course of three years from 2022 to 2025 (see

¹ River current energy technology differs from hydropower as it does not necessitate water storage behind a dam or a diversion structure, instead allowing the river to flow freely. As such, it is considered marine energy.

Fig. A1 in Appendix A). We began by reviewing literature to identify metrics used within different disciplines and across renewable energy technologies to understand community readiness. Next, we conducted a series of interviews and surveys with community leaders and experts involved in community-driven energy projects to better understand practical barriers to—and opportunities for—strengthening readiness. We then synthesized and built on this information to develop a set of questions tailored to marine energy in the U.S. We refer to these questions, organized hierarchically in topical categories and subcategories, as the “metrics of readiness.” The metrics were reviewed in multiple rounds with subject matter experts from the Pacific Northwest National Laboratory (PNNL), the National Laboratory of the Rockies (NLR, formerly known as the National Renewable Energy Laboratory (NREL)), and DOE. We embedded the questions and scoring rubric in a spreadsheet-based tool. We applied the metrics through a desktop analysis to a river current energy project in Igiugig, Alaska at two points in time and used the results to help further refine the questions. In addition, we tested the metrics in close collaboration with Sustainable Energy Galena (SEGA) and University of Alaska, Fairbanks (UAF) in Galena, Alaska, a community interested in the potential of river current energy from the Yukon River to serve as a local power source. The results for Galena are reported in a complementary manuscript in preparation.

2.1. Definitions

In this work, we adopt U.S. DOE's definition of **rural and remote communities** as geographic populations (i.e., towns, cities, or unincorporated areas) with 10,000 residents or fewer that encounter challenges related to outdated energy generation or high energy costs, or that are more easily disconnected from the grid due to extreme events [70].

We adopt U.S. DOE's definition of **marine energy**, also known as marine and hydrokinetic energy or marine renewable energy, as a renewable power source harnessed from the natural movement of water, including waves, tides, and river and ocean currents. Marine energy can also be harnessed from temperature differences in water through a process known as ocean thermal energy conversion, as well as differences in salinity.

Lastly, we define **readiness** after the Merriam-Webster Dictionary as the state of being prepared, the willingness to engage, and the ease of action. We further elaborate on different dimensions of readiness through the development of the “metrics of readiness”.

2.2. Literature review

Our approach to the literature review consisted of three phases: gather, review, and synthesize – each of which is described further in [71] and summarized here. The gathering and review phases were conducted through an incremental process that allowed us to amass new information through a snowball approach. We gathered peer-reviewed literature, programs, tools, and case studies using existing programmatic knowledge and experience from within PNNL and NLR as well as more formal searches. Preliminary reference lists were compiled by research librarians at the two national laboratories and expanded upon through topic-specific web searches using Google Scholar. While not exhaustive (nor limited to these search terms), our approach included a broad sampling of the literature on community readiness for renewable energy technologies, community-engaged research in marine energy, and participatory science-policy processes across a variety of sectors. Through this process, we reviewed 126 papers, 34 tools, and various resources related to six case studies in the U.S. and United Kingdom.

We categorized each document or resource by type (e.g., literature, tools, case studies) and relevant sector (e.g., renewable energy, marine energy, sustainable development, fisheries management, conservation planning, etc.). For each document, we also extracted a short version of the abstract and recorded attributes of readiness and the geography and

context (e.g., remote, island, rural, urban) of the study. We noted if the document or resource included case studies, quantitative analysis, and/or relationships with other sectors beyond energy. We then compiled the attributes of readiness in a separate spreadsheet. These were then grouped into seven categories (technical, financial, governance, economic, social, environmental, and strategic) and a suite of subcategories. Finally, we used the attributes collected from the literature review as a basis for drafting questions that could be answered to better understand and strengthen different dimensions of community readiness for marine energy in the U.S. Because the overall goal of the literature review was to broadly understand factors that may influence readiness, the only attributes we rejected at this phase were those irrelevant to a U.S. context (i.e., some governance literature was EU centric).

2.3. Outreach

In addition to the literature review, we explored key components of readiness with myriad participants across several community-based technical assistance programs supported by DOE. The community-based programs, which are often technology agnostic, connect community organizations with the national laboratories to receive technical assistance that is designed to advance their specific energy goals. To better understand factors that may influence a community's readiness for renewable energy technologies, we conducted surveys and interviews with technical assistance providers at four national laboratories and project leaders from four community-based organizations, 12 DOE offices/programs, and nine communities. This effort resulted in 43 semi-structured interviews and 16 survey responses.

Following the survey and interviews, we conducted both inductive and deductive thematic analyses by extracting themes post hoc based on the interview responses. We then grouped similar themes and quantified their frequency among responses. The results from this analysis allowed us to understand perspectives from members of our target audience related to characteristics of communities that may influence readiness for renewable energy technologies and barriers and opportunities for strengthening readiness. The results were also used to further refine the metrics of readiness. The methods and results from the surveys and interviews are described in detail in [72].

2.4. Expert review and iteration based on community applications

To hone the metrics of readiness and tailor them to the marine energy and technical assistance context, we leveraged the expertise of marine energy researchers and professionals at PNNL, NLR, and DOE that regularly collaborate with communities. We worked with experts in marine energy technology, environmental science, social science, policy, finance, economics, governance, and strategic planning. Over two years, we refined the metrics of readiness questions based on the literature review and outreach with feedback we elicited from numerous discussions and both independent and collaborative review sessions. We considered the detailed wording and potential nuances of each question as well as the organization of the metrics. The researchers and professionals contributed their practical expertise working with communities and marine energy as well as their familiarity with the emerging literature. Finally, we integrated insights from applying the metrics in Igiugig (see Section 4 Retrospective application) and working with Galena (manuscript in preparation) into our revision of the questions. As a result of the review and application process, we eliminated and combined some questions to remove redundancy, re-organized subcategories to better communicate the intent of particular topics, clarified questions that were confusing to experts and community members, and re-ordered the questions to help with ease of application. For example, we expanded the number of subcategories in the social dimension to include “public confidence” and “community perceptions” to more fully address and communicate the intent and importance of these topics. The final organization of metrics as applied in Igiugig is described in more

detail in the following section.

3. Metrics of readiness

The metrics of readiness are organized in an interdisciplinary and hierarchical framework (Fig. 1). They consist of seven categories, 29 subcategories, and 150 questions (see Appendix B for full list of questions, answer options, and scoring). The seven categories encompass a range of topics that influence community readiness for marine energy: technical, strategic, environmental, social, economic, governance, financial (described in Table 1). Each category includes 3–5 subcategories that focus on different components of the broader topic areas. For example, the technical category includes both questions related to understanding “existing resource availability” as well as questions related to “future load.” As another example, the environmental category includes questions related to “siting and design” and others related to “permitting.” This structure allows users to understand relative strengths and opportunities to improve readiness across broad topics, as well as to home in on more specific areas where technical assistance or focused engagement could help to bolster a community's interest and preparedness for marine energy.

Each of the questions within the metrics of readiness can be answered with responses in one of several formats depending on the topic. The formats include ‘yes/no/not sure/NA’; ‘select all that apply’; ‘high/medium/low/not sure’; multiple choice; or Likert scale [1 to 5]. Each question receives a score of 0, 1, or 2 based on what the answer implies about readiness, with a score of 0 indicating not ready, 1 indicating some readiness, and 2 indicating readiness. All ‘not sure’ answers are 0 points, though other answers vary. Sometimes both a ‘yes’ and a ‘no’ receive full points, as knowing the information implies greater readiness (e.g., Does timing of marine energy power generation (daily or seasonal) match consumption? Does the community currently receive subsidies for electricity?). Sometimes only a ‘yes’ answer receives full

Table 1

Description and number of questions for metrics of readiness categories.

Category	Description	Number of Questions
Technical	Factors that influence the practical readiness or feasibility of a site for developing, installing, maintaining, and harvesting marine energy.	27
Financial	Factors that influence the ownership, funding landscape, and risk of a marine energy project.	20
Governance	Factors that influence the legal, political, or regulatory aspects of a marine energy project.	20
Economic	Factors that influence the market and impacts of a marine energy project within a broader economic landscape.	13
Social	Factors related to culture, core values, or composition of a community that may influence its readiness for marine energy.	23
Environmental	Factors that influence the permitting requirements and potential effects of a marine energy project on protected or otherwise valuable species and habitats.	23
Strategic	Factors that influence the broader process, planning, engagement and implementation for a marine energy project.	24

points (e.g., Have policy or regulatory barriers within the community been assessed? Have the project's impacts on household energy burden been assessed? Are the motivations of the community in relation to renewable energy understood?). In the latter case, having completed the activity or having a particular characteristic implies greater readiness. It is important to note that a ‘not sure’ response to a question is as instructive for understanding readiness as a ‘yes/no’ response. ‘Not sure’ responses indicate an opportunity for increasing readiness that could be addressed, for example, through future research, strategic planning, capacity building, or collaboration with community members and/or

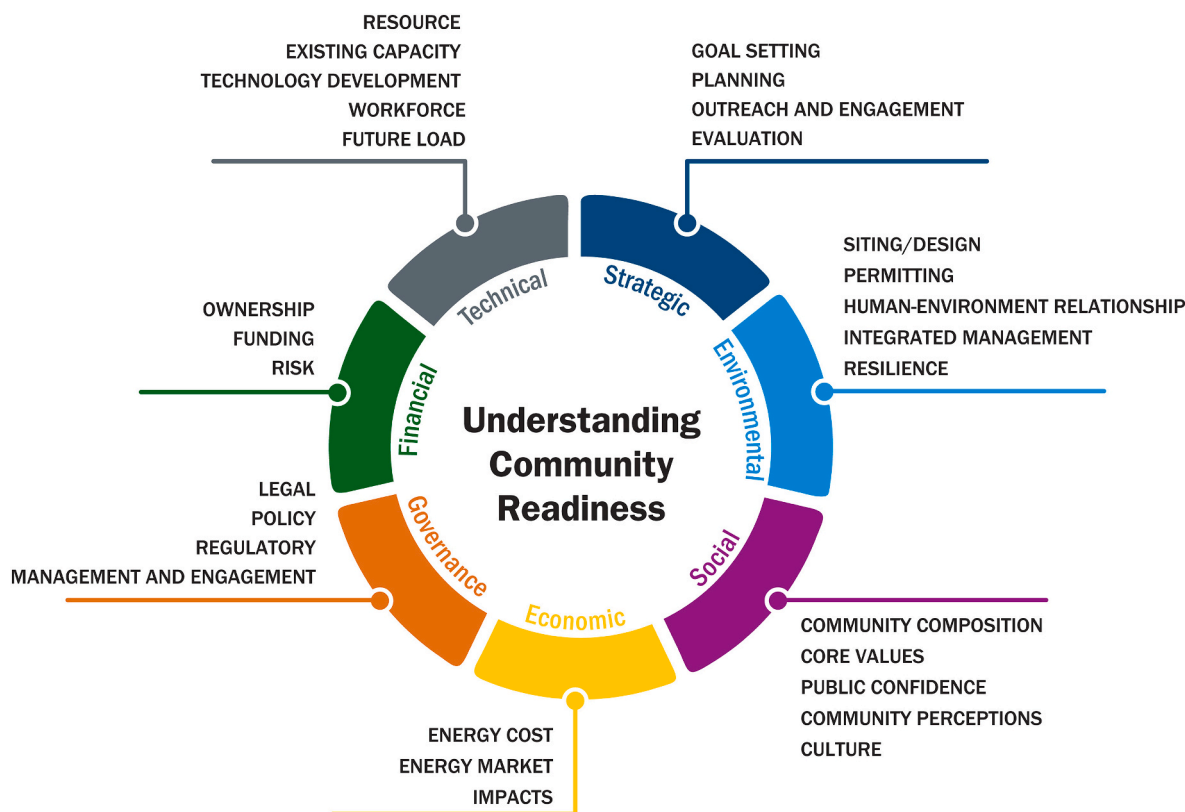


Fig. 1. The metrics of readiness for marine energy are organized in an interdisciplinary and hierarchical framework with 3–5 specific subcategories subsumed within each of the seven broad categories.

experts with knowledge about a particular topic. In this way, the responses to the metrics reflect not only the readiness of a community to consider marine energy, but also the readiness of the community-based project team to pursue deployment of marine energy with the broader community.

The scores are then summed for each category and standardized to a base 100. Standardization across categories is used to ensure that no one category has an outsized effect on readiness, and that readiness within each category is the primary consideration. All questions are weighted equally within each category, but the variability in the number of questions per category (Table 1) influences the relative weight of each question. For example, each question within the economic category ($N = 13$ questions) has a greater impact on the score for that category than each question in the strategic category ($N = 24$), which has more questions.

The questions in the metrics of readiness can be answered using several different approaches. One option is to collaboratively answer the questions. This approach could draw on expertise from community leaders and community-based organizations to complete the questions related to local culture, social dynamics, or strategic planning, for example, and expertise from local government officials on questions related to governance. Scientists and engineers providing technical assistance for the marine energy project may have the best available information for several of the technical and environmental sub-categories, while leaders of the potential marine energy project might know more about the permitting process or potential development options. Consultants, natural resource managers, and others involved in project development could also play a role. If applied collaboratively in this way, the metrics can serve as a common framework for describing community readiness. Project teams can apply this framework through a participatory process to help facilitate discussions about various dimensions of readiness and foster collaboration through early identification of project needs and options for mitigating obstacles. Alternatively, the questions can be answered independently by individuals and used to explore differences in perceptions of readiness among community members, project team members, and/or technical assistance providers. Finally, the metrics can be answered by a single person with broad knowledge of a project and community, recognizing the subjectivity inherent to any single person's response based on their personal and professional experience. The approach to applying the metrics depends on the users' goals for understanding readiness.

4. Retrospective application of metrics to river current energy in Igiugig, Alaska

We tested a draft of the metrics of readiness in August 2024 using a then operational river current energy project in Igiugig, Alaska as a case study (Fig. 2). The goals of this application were to 1) test whether the questions were relevant to a real-world, community-based, marine energy project, 2) determine whether the questions sufficiently capture a diversity of topics related to readiness and identify gaps in our framework, and 3) to explore how the responses to the questions changed over time for a community that had progressed from being curious about river current energy to spearheading an in-river demonstration. The metrics were completed retrospectively by one of the co-authors of this paper based on their experience working on the river current energy project in various capacities. They answered the questions to the best of their knowledge, as an individual from outside Igiugig, based on their prior experience during two key phases in the river current energy project: 2009 and 2018. Given the goals of this study, we explicitly did not engage local leaders from Igiugig so as not to burden them with a retrospective, desktop test of the framework [73–75]. For the same reason, we did not generate recommendations based on the metrics, as answers based on information for 2009 and 2018 would not have been meaningful for the community at present. We acknowledge that the goals and approach for this retrospective application differ from our intended application of the metrics to inform future marine energy demonstrations, as motivated in the Introduction. We elaborate on the implications of the retrospective application in the Discussion and aim to be clear about what we can and cannot infer from the desktop analysis about the potential for the metrics to inform future deployments and demonstrations of marine energy.

4.1. Background on Igiugig, Alaska

Igiugig Village (Igyararmiut), which means “like a throat that swallows water” in the Yup'ik language, is a small village with a population of 68 people. Located in southwestern Alaska, the village resides where Lake Iliamna drains into the Kvichak River [76,77]. This area lies at the convergence of three major Alaska Native groups—the Alutiiq, Dena'ina, and Yup'ik—and has been inhabited for over 8000 years [78].

Subsistence practices are critical to the identity of the Igyararmiut (or people of Igiugig) [76,78]. The community depends on the Kvichak River as its primary source of drinking water and salmon, which have served as a critical food source and culturally significant species for



Fig. 2. Location of a) Igiugig, Alaska and b) the ORPC RivGen devices, one submerged and the other on station in the Kvichak River in 2023. Photo credit: Igiugig Village Council.

generations [76,79]. The Kvichak River drains from Lake Iliamna and flows 106 km to Bristol Bay, which supports the largest sockeye salmon fishery in the world and as well as other significant commercial, recreational, and subsistence fisheries [78,79].

Igiugig has historically encountered high energy costs due to the absence of a centralized electrical power grid and dependence on generators powered by imported diesel [80,81]. Due to the high costs of diesel and the potential for hazardous spills during fuel delivery by plane or barge [82], Igiugig has long been interested in local sources of energy generation [80].

4.2. Timeline of river current energy development

Development activities leading up to the deployment of river current

energy date back to 2000 (Fig. 3). In 2000, Igiugig completed its first comprehensive community vision and plan, identifying “alternative energy” as a priority [77]. To develop the plan, the community gathered to discuss various challenges and identify innovative solutions while making decisions based on full consensus [83]. According to Gram-Hanssen [51], Igiugig worked to enact transformational social change through their efforts to reduce dependence on fossil fuels by exploring options for renewable energy generation. While river current energy is an earlier stage technology, Igiugig faces some challenges with more established technologies like wind and solar which may have influenced the village's interest in the river as an energy source. Solar in Alaska is particularly seasonal and wind speeds in Igiugig can be extremely strong, making it difficult to find a reliable turbine with adequate maintenance support for the remote location. In an early efficiency and

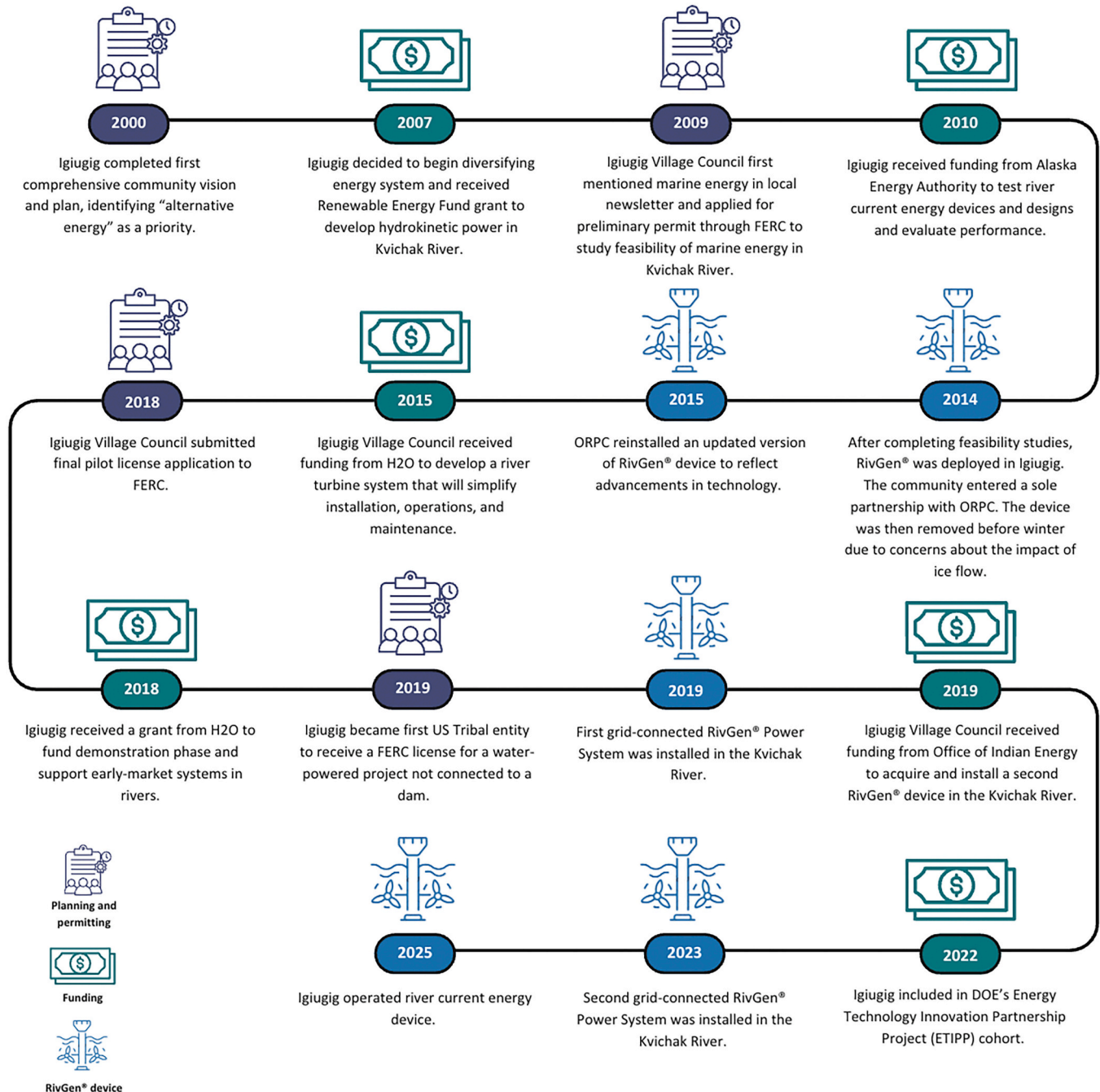


Fig. 3. Timeline of key energy development activities in Igiugig, AK.

renewable energy assessment initiated by the Igiugig Village Council and conducted by NLR, river current energy emerged as a potential generation source [77,84].

Although Igiugig was interested in marine energy for years, the village formally decided to begin diversifying their energy system in 2007 (Fig. 3) [83,85]. That year, Igiugig received a grant from Alaska's Renewable Energy Fund to develop hydrokinetic power in the Upper Kvichak River [83]. In the spring of 2009, the Igiugig Village Council first mentioned river current energy in their newsletter, aligning the technology with their goal to build the healthiest model community in the U.S. [86]. On August 10, 2009, the Igiugig Village Council applied for a preliminary permit through the Federal Energy Regulatory Commission (FERC) to study the feasibility of river current energy in the Kvichak River [87]. The following year, Igiugig received funding from the Alaska Energy Authority (AEA) to test several designs for river current energy devices and evaluate performance. One of the devices included the RivGen® Power System from the Ocean Renewable Power Company (ORPC) [80].

In 2014, after completing renewable energy feasibility studies with the support of the AEA and NLR, Igiugig became a permitting test bed for river current energy. The community decided on the RivGen device and entered a sole partnership with ORPC to develop a river current energy project that would not harm salmon in the Kvichak River [77]. Igiugig proceeded with ORPC as a developer, since the company had honored the community's Indigenous knowledge and maintained a strong relationship grounded in trust [83]. The RivGen® Power System is a horizontal cross-flow hydrokinetic turbine that consists of a proprietary Turbine Generator Unit mounted on a chassis, and includes the device, mooring system, transmission and data cables, and an onshore station [88]. The RivGen was deployed in Igiugig in 2014 as ORPC's first river current energy project, however the device was removed before the winter due to concerns about the impact of ice flow [41]. In 2015, the Igiugig Village Council received funding from DOE to develop a river turbine that demonstrated installation, operations, and maintenance improvements [89]. Also in 2015, ORPC re-installed an updated version of the device to reflect technology advancements [90].

In 2018, the Igiugig Village Council submitted the final pilot license application, and in the following year, Igiugig became the first U.S. Tribal entity to receive FERC license for a water-powered project not connected to a dam [53]. The demonstration phase of this project was funded by a \$2.3 million grant from DOE to Igiugig in 2018, which supported early-market systems in rivers that do not impede the flow of the river or negatively impact the environment [53]. This funding allowed for the permanent installation of the RivGen turbine system in Igiugig, with the goal of moving the community closer to using diesel fuel exclusively for emergency backup [91].

In 2019, the first grid-connected RivGen Power System was installed in the Kvichak River, with the second system installed in 2023 [88,92]. This was achieved with funding from the DOE Office of Indian Energy, which awarded the Igiugig Village Council with funding from 2020 to 2023 to acquire and install a second RivGen system, along with smart microgrid electronics and energy storage [93]. In 2022, Igiugig was included in Cohort 2 of the U.S. DOE Energy Technology Innovation Partnership Project (ETIPP). ETIPP focuses on connecting selected communities with the national laboratories to provide energy system analysis and decision support to identify energy reliability and affordability solutions best suited to each community's needs [84].

The need for local energy sources has come into particularly stark relief as the community has faced significant challenges associated with fuel delivery. Igiugig previously received fuel via barge; however, as water levels became more erratic, the community transitioned to air delivery in smaller batches. In 2024, a cargo plane carrying the community's fuel crashed, leading to challenges finding a new provider. In addition, the fuel storage facility, containing 114,000 gallons of diesel, nearly collapsed into the Kvichak River as a result of erosion [83]. As of November 2025, Igiugig operated its river current energy device;

however, the ownership structures and performance of the RivGen devices are currently under evaluation. While grid-connected, the RivGen has contributed less than expected annually to the Igiugig electric grid due to persistent reliability issues and integration challenges [84,94]. As we highlight above, and in the Introduction, marine energy is a newer technology with a lower technology readiness level (TRL) distinct from community readiness. The technical category in our framework includes questions related to community understanding and preparedness for low-TRL devices (see Appendix B. Technical questions 10, 18, 21), not questions designed to evaluate a particular technology or device. Thus, early application of the metrics of readiness would not have surfaced these issues nor the lessons related to reliability, integration, and annual generation learned through on-going deployment.

4.3. Results

The results from the retrospective analysis of the metrics of readiness suggest that in 2009, Igiugig was more ready for river current energy in some categories than others (Fig. 4). According to our desktop application, Igiugig's readiness in 2009 was highest in the governance category with 58 points, which aligns with Igiugig's demonstrated ability to adapt to environmental and social change [46,51]. The governance score is nearly twice that of the technical and economic categories, which were the community's next strongest categories of readiness (33 and 31 points, respectively). Based on our co-author's experience, the lowest scoring category in 2009 was strategic readiness (13 points). The results for the financial, environmental, and social categories were intermediate in 2009. At this early stage of exploring river current energy in Igiugig, our co-author selected 'Not Sure' as an answer to 104 questions across all seven categories. While 'not sure' responses receive a score of zero and indicate 'not ready', these responses are important because they illuminate dimensions in which there is an opportunity to strengthen readiness by gathering additional information (see Section 3. Metrics of Readiness). Note that for the retrospective application in Igiugig, these responses to the questions are intended to capture our co-authors' knowledge of the river-current energy effort based on their work with Igiugig in 2009. They are not meant to capture diverse perceptions or experiences of community members at that time (see the beginning of Section 4 and the Discussion for more information on the goals and limitations of this desktop, retrospective application).

The high governance score in 2009 relative to other categories stems in part from Igiugig's political interest in river current energy and the presence of a political champion (policy subcategory). In addition, consultation of the relevant agencies contributed to its strength in the regulatory subcategory. Moreover, local management of the energy system, general engagement of agencies with Indigenous Peoples, and well-established processes to solicit feedback from the community all contributed to Igiugig's high score in the management and engagement subcategory. Despite the community's strength in several subcategories of governance, the results suggest that in 2009, Igiugig still had an opportunity to strengthen its readiness with respect to legal, policy, and regulatory aspects (Fig. 5a).

From 2009 to 2018, the scores increased markedly for all categories except governance (which was already relatively high) and economic (which remained relatively low) (Fig. 4). The improvements across all readiness categories were not the result of a dominating increase in one associated subcategory, but from higher scores in multiple or all subcategories within each category (Fig. 5b). Most subcategories in the strategic, financial, environmental, technical, and social categories more than doubled in score.

Recall that for some questions, a higher score may result from a change in response from 'not sure' to 'yes' or 'no' and indeed, our co-author answered 'not sure' for only 40 questions in 2018 compared to over twice as many in 2009. However, a reduction in 'not sure' responses is not the only influence on the readiness score. For some questions, a higher score results from a change in 'no' or 'not sure' to 'yes' and in

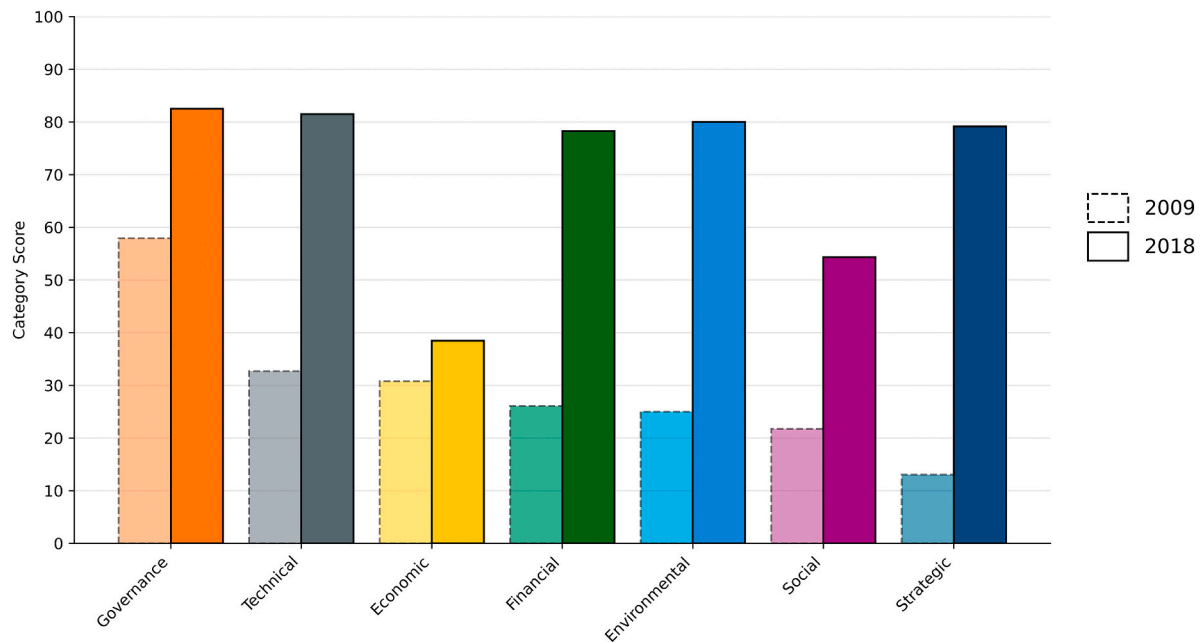


Fig. 4. Results from the metrics of readiness at two time points from the perspective of our co-author based on their experience working on the river current energy project in Igiugig, Alaska. Scores for all categories are out of 100 (Appendix B). Bars with dashed lines and lighter color represent scores from 2009 and bars with solid lines and darker color represent scores from 2018.

other cases an increase in readiness along a scale of 1–5. Thus, we cannot identify a single main driver of increased readiness across categories. Instead, in the following paragraphs, we highlight numerous factors that contributed to Igiugig's increased interest and preparedness for marine energy. These factors also contributed to increased understanding of the social, environmental, economic, governance, strategic, financial, and technical dimensions of readiness in Igiugig on the part of our co-author. Collectively, the efforts below constitute nine years of community leadership, technical support, and collaborative decision-making informed by thorough scientific assessments and values-sensitive engagement.

The largest increase in readiness occurred in the strategic category, which more than quadrupled in points during this time frame (Fig. 4). From 2009 to 2018 strategic readiness increased in all four subcategories: goal setting, planning, outreach and engagement, and evaluation (Fig. 6a). These increases can be attributed to actions including the establishment of goals for river current energy, development of a strategic energy plan, and identification of opportunities for community engagement. During this time frame, researchers from the University of Washington, PNNL, NLR and other institutions supported projects that likely improved strategic readiness as well. Growing support from community leaders and decision-makers also generated a higher score for strategic readiness in 2018 than in 2009.

Our results also reflect the great strides toward financial readiness that Igiugig made between 2009 and 2018 (from 25 to 80 points). Increases were noted across all three subcategories: risk, funding, and ownership (Fig. 6b). By 2018, the community and developer had gathered information on community ownership preferences and models [77], generated estimates for total capital expenditures, annual operating costs, and the baseline levelized cost of energy [95], and assessed other risks and benefits [96,97].

The influx in funding from AEA in 2010 in turn helped to support studies that progressed environmental and technical readiness [77,81,98–101]. From 2009 to 2018, various entities, including ORPC, consultants, and the national laboratories, conducted a suite of studies related to the riverbed and sockeye salmon. Igiugig also engaged in conversations that elevated Traditional Ecological Knowledge (TEK) into decision-making and explored potential interactions between river

current energy and other uses and users of natural resources and TEK [77,102]. According to our co-author's responses to the metrics, these activities helped to increase the scores for the siting/design and permitting subcategories of environmental readiness (Fig. 6c).

Similarly, several advancements were made in technical readiness through research conducted by national laboratories in collaboration with DOE and ORPC [81,98,103]. Focal topics included characterization of the initial site conditions to inform the design and installation of a hydrokinetic turbine, resource characterization, feasibility studies—including exploration of ice flow over the device—and preferences for device design (resource subcategory). The community also strengthened their knowledge and collected further data related to existing capacity, technology development, and workforce subcategories (Fig. 6d).

While much of the community's effort during the 2009–2018 period was directed toward environmental, technical, financial, and strategic aspects of river current energy in Igiugig, our desktop application also suggests a concomitant increase in social dimensions of readiness (Fig. 6e). For the 2009 time step our co-author answered “not sure” to more than three-quarters of the questions in the social category, perhaps reflecting the initial focus of the developer, DOE, and researchers on the technical and environmental dimensions of the project. In 2018, the number of questions in the social category for which our co-author lacked information had dropped to less than half. Readiness increased through greater shared knowledge about the community's core values and more information becoming available about community composition, community perceptions of changes to natural and cultural resources, and community culture. According to the metrics, in 2018 there remained opportunities to strengthen understanding of community perceptions of renewable energy and public confidence.

The economic category of readiness had the smallest increase from 2009 to 2018, from 31 to 38 points (Fig. 4). The score for the energy cost subcategory stayed the same between years. In both 2009 and 2018, access to information on utility bills and associated data (e.g., energy consumption, cost etc.) was a relative strength in terms of readiness. In contrast, there was a lack of information about the community's willingness to pay if the electricity from river current energy came at a premium. The only economic subcategory that increased in 2018 was “impacts” (Fig. 6f). According to our co-author, in 2018 the community

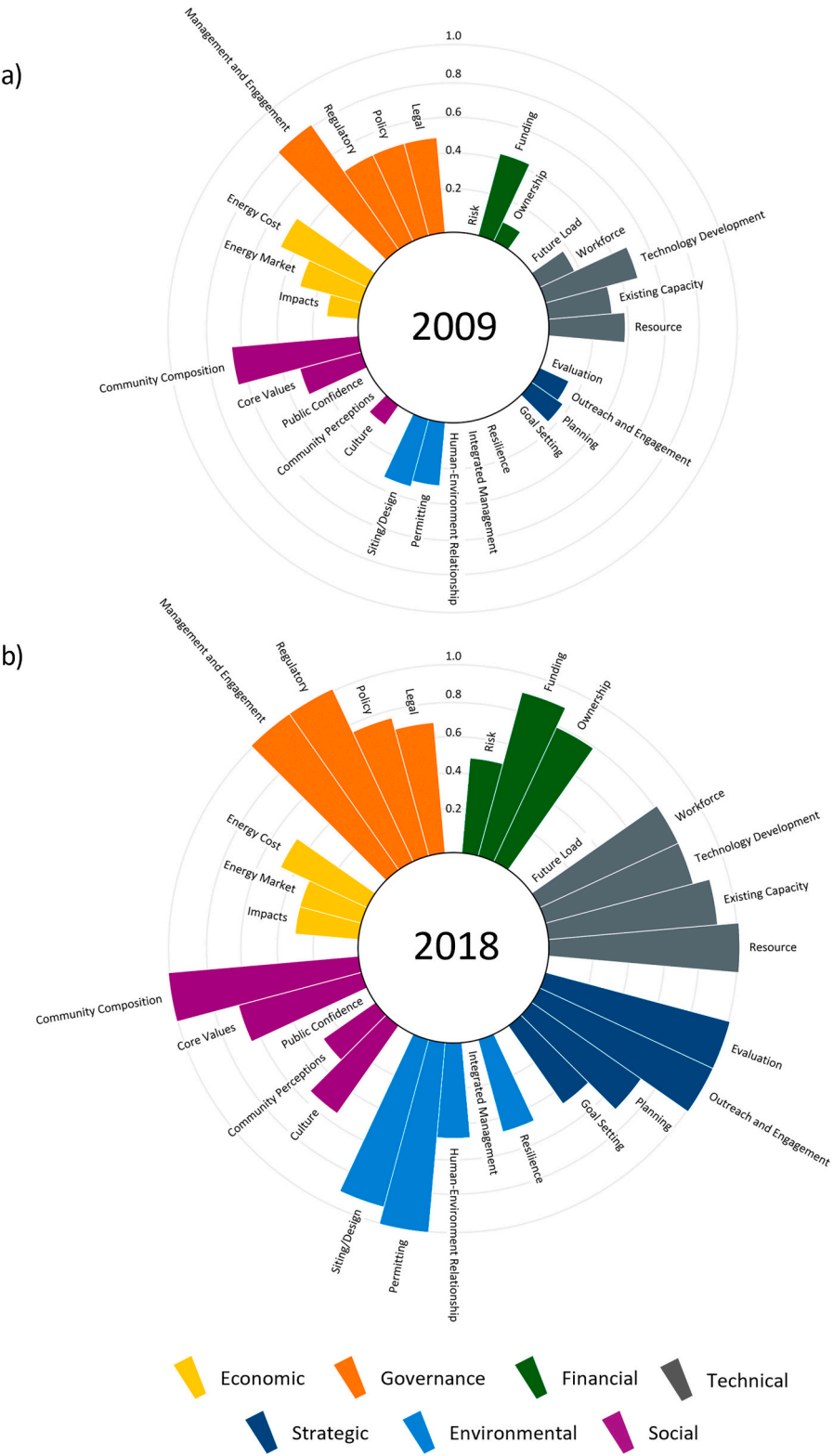


Fig. 5. Results for Igiugig desktop application for a) 2009 and b) 2018 by subcategory. Bars represent percent of total points available for each subcategory.

saw potential for job opportunities with marine energy and the various institutions involved in the project had begun to assess long-term economic impacts related to river current energy (i.e., jobs, supply chain development, commercial and tourism revenues, etc.). However, uncertainty related to energy costs, energy market, and other potential

impacts from demonstrating river current energy remained, with more than half of the questions in the economic category answered ‘not sure’ in both 2009 and 2018. The modest improvement in economic readiness could be in part because faces many barriers to economic development typical of remote communities in Alaska that are difficult to overcome

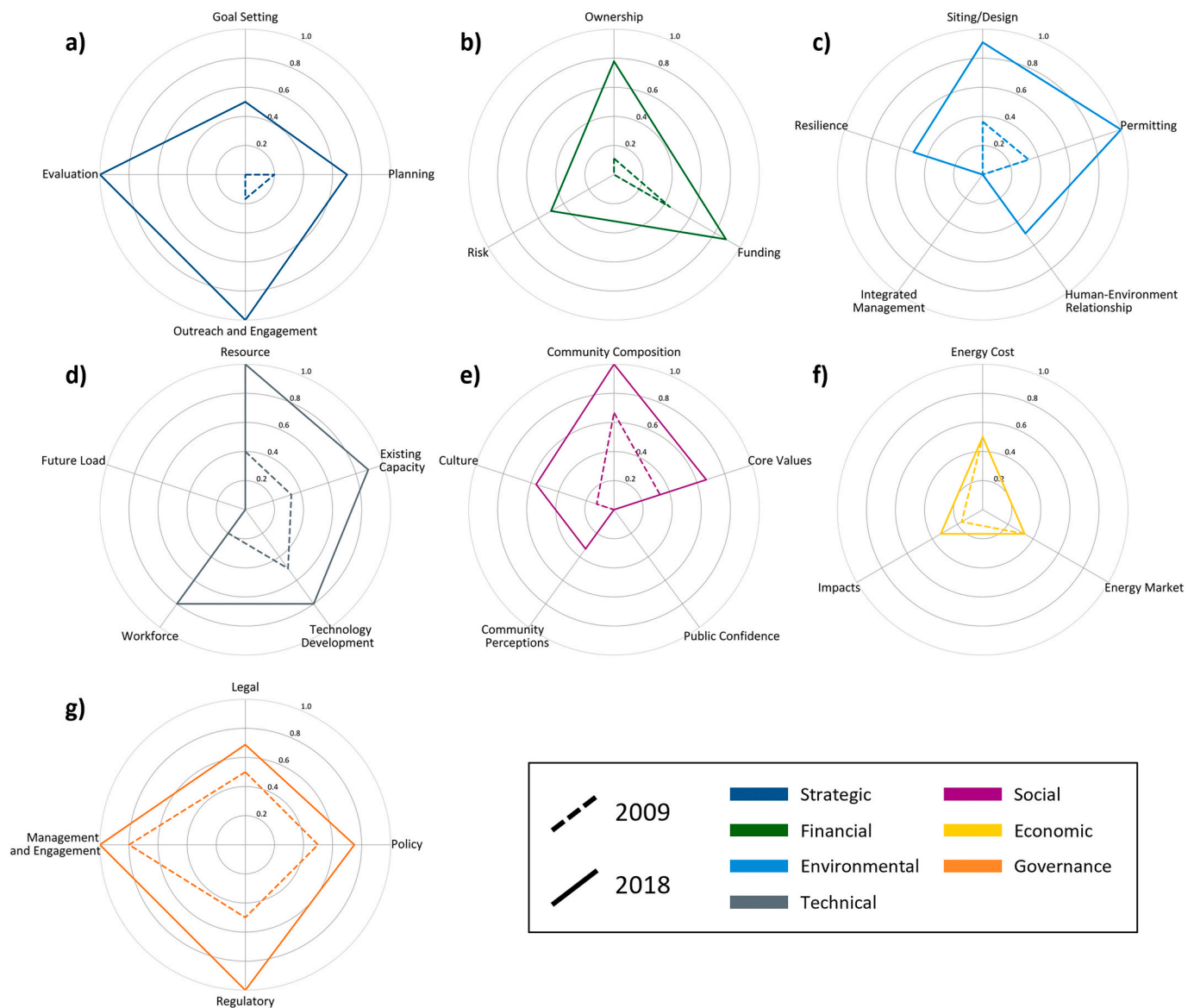


Fig. 6. Results for Igiugig desktop application for 2009 (dashed line) and 2018 (solid line) by subcategory, with one spider chart for each category: a) Strategic, b) Financial, c) Environmental, d) Technical, e) Social, f) Economic, g) Governance. While these data are the same as those depicted in Fig. 5, we include Fig. 6 because it allows for easier comparison between subcategories as reported in the latter part of the Results. The two figures also provide different options that could be used to display results for future applications of the metrics of readiness.

[10,46,51,54].

Finally, although Igiugig already scored highly in governance in 2009, several metrics within this category increased over the following decade (Fig. 6g). By 2018, various institutions involved in the river current energy project had assessed policy and regulatory barriers within the community and were continuing to advance consultation of relevant Tribal, state, federal, local, and regional governments and agencies (regulatory subcategory). According to our co-author, local understanding of the political opportunities to build support for river current energy and the state and local clean energy mandates and legally enforceable goals had grown in 2018 as compared to 2009 (legal subcategory).

5. Discussion

This paper describes a transparent, repeatable, interdisciplinary, and broadly applicable approach for understanding the readiness of rural and remote communities for marine energy. Previous studies have made

great strides in strengthening knowledge around and advancing readiness in diverse contexts [54,63–65,69,104–106]. However, ours is the first to develop a holistic framework and metrics of readiness for marine energy at the community scale. Here, we introduce the framework and test the metrics with a retrospective, desktop analysis for Igiugig, Alaska, one of the few communities in the U.S. to have deployed a river current energy device. We find that the metrics capture a diversity of topics relevant to a real-world, community-based, marine energy project. Our results also show that changes in readiness over time can be driven by strategic planning, improved knowledge of siting and permitting processes, resource assessment, familiarity with regulatory barriers, exploration of ownership models and risk, and attention to social factors, such as public perception, that influence readiness (Fig. 5). We envision future applications of the metrics, early in an energy development process, could help inform planning and guide action toward improving readiness by fostering engagement with community members and dedicating attention to topics traditionally excluded from energy planning. The framework also includes dimensions of readiness that are

generalizable beyond marine energy and could be applicable to rural and remote communities interested in other renewable energy technologies.

By taking a holistic approach and incorporating metrics that consider seven categories of readiness (Fig. 1), our framework builds on and advances previous studies that consider technical readiness alone or readiness in only a couple of dimensions [107]. Recent research has emphasized the need for interdisciplinary approaches to address complex challenges associated with deploying marine energy devices in water bodies of particular importance to local communities [30,34,40,49,108–111]. For example, Caballero et al. [40] discuss the lack of systematic consideration of human dimensions during project design and Dreyer et al. [34] suggest that integrating social science research with technical and economic stages of innovation could help to shed light on the psychology of residents and other interested parties. Considering technical and financial components exclusively ignores the social and cultural relationships between a community and their energy sources [112]. Expanding the concept of readiness may lead to opportunities for more creative, place-based solutions that recognize community values and aim to achieve local goals [4,110,113].

Our metrics also aim to recognize and strengthen knowledge about relationships between marine energy, communities, and ecosystems [111,114]. For example, they highlight environmental topics—such as resilience to extreme weather events, integrated management, and ecosystems services—that may not be explicitly addressed in permitting processes, but are of broader importance to the public [1,115,116]. These relationships can be particularly relevant for the readiness of rural and remote communities where human livelihoods and cultural practices are deeply connected to local ecosystems. Strengthening knowledge and communication about relationships between marine energy, resilience, and ecosystem services may help to prevent unintended consequences of development decisions, shape outcomes that are more likely to realize multiple benefits for rural and remote communities, and foster local support [49,111,117].

Past projects illustrate the need for an interdisciplinary approach and framework for understanding readiness because of the variety of interacting barriers that can impede marine energy demonstrations and deployments [34,118,119]. For example, environmental studies and regulatory requirements constitute a high percentage of project costs [119] and these factors may collide with social dynamics involving a lack of information or demand for further information about a project [56]. In the case of Admiralty Inlet in Puget Sound, WA, a FERC pilot project license was issued in 2014 to test a tidal energy device. However, the project did not advance due to escalating costs [34], partially related to siting concerns with a nearby fiber optic cable, as well as socio-environmental pressures, and technical challenges that led to an increase in the cost of materials [56]. Jenkins and Beaver [41] and Dreyer et al. [56] describe a wide variety of concerns expressed by state agencies, municipalities, community-based organizations, Tribes, and other residents, including potential effects on wildlife, such as the Southern Resident Killer Whale population (*Orcinus orca*), costs to rate payers, engineering, public safety, and infringement on Tribal fishing rights. As another example, in 2025 the Washington Department of Commerce rescinded funding from the Aquantis Tidal Energy Project after multiple Tribal Nations expressed concerns about the influence of the installation and other project related work on their treaty-protected waterways and fishing rights [120]. This project, and other recent communications between Tribal Nations and the Washington Department of Commerce highlight the state's responsibility to consult with Tribes about potential effects of marine energy projects on cultural resources rather than delegating this work to contractors [121]. The framework and metrics we developed go beyond obvious political and regulatory challenges (e.g., conservation and fishing concerns for orca and salmon). They highlight for the project team, funders, and other decision-makers, the full breadth of governance, social, environmental, economic, financial, technical, and strategic elements of community

readiness, and offer a repeatable approach for tracking readiness through time. Utilization of the metrics of readiness could aid in identifying such multi-faceted challenges early in the development process and prevent costly project setbacks, in part because the metrics have the potential to foster communication and collaboration among interested parties using a holistic and participatory approach (see Section 3. Metrics of Readiness and further discussion below).

While we were unable to test the real-time utility of the metrics through the retrospective application, our results showing Igiugig's strength in governance (in 2009) and strategic and social readiness (in 2018) align with a large body of research on the importance of participatory processes in a variety of sectors [113,122–124]. Participatory processes involve bringing together groups of scientists, community-based organizations, and national, state, and local governmental organizations to inform planning and decision-making [125]. Research and practice in fisheries management, environmental conservation, sustainable development, strategic energy planning, and other decision contexts show participatory processes are more likely to address local community interests, lead to positive perceptions of the decision-making process, and ultimately realize project goals for implementation [110,126–130]. The community's stewardship of energy planning efforts in Igiugig from the beginning likely set the groundwork for the deployment of the river current energy device in the Kvichak River years later [51]—a lesson that has influenced the community-driven approaches to renewable energy development adopted by U.S. DOE in more recent years.

Our application of the metrics of readiness to Igiugig at two distinct points in time enabled us to investigate changes in readiness for a community with a strong interest in marine energy, an operational river current energy device, and a developer that engaged significantly with the community throughout the development process. It also allowed us to test whether our interdisciplinary framework captured the variety of dimensions that seem to be important for understanding how prepared and interested a community is in practice (not just according to previous research and theory). For example, in the early stages of river current energy development in Igiugig, ORCP, U.S. DOE, and other funders and researchers were focused primarily on feasibility and impacts to salmon populations [81,99–101,103]. They understood that environmental permitting, licensing, and compliance for marine energy can take more than a decade and requires extensive supporting research and data [118,131]. The developer also recognized and honored the community's leadership and the cultural and subsistence significance of salmon to Igiugig [83]. Our results suggest that the technical and environmental information that resulted from these early studies was critically important to the project's increase in readiness over time, as well as the community's interest and preparedness for river current energy. The results also suggest that our metrics capture topics related to siting, design, and feasibility that reflect environmental, technical, and social readiness in practice [128].

In future iterations of the metrics, some of these topics may deserve further attention. Recent reports emphasize both the importance of renewable energy integration for project success in remote Alaskan communities and the challenges related to interconnection requirements [84,94]. Our co-author answered 'yes' to related questions in the technical category in 2018 (e.g., Have needed infrastructure upgrades been assessed or completed? Has the grid been evaluated for compatibility with marine energy?). However, reported recommendations from the community suggest a need to build out technical metrics related to integration of different renewable energy technologies, interconnection, and microgrid requirements as well as support for addressing these issues in future projects [84,94].

According to our co-author's responses to the metrics, readiness in Igiugig more than doubled in five out of seven categories over nearly a decade (Fig. 4). These results illustrate that—much like community resilience, transformation, and adaptation—readiness is best viewed as a continuum and a process [6,132], rather than a static series of 'yes', 'no',

or ‘not sure’ responses to a suite of metrics. However, some aspects of readiness may be more innate to a particular community or group of communities and more difficult to bolster or modify through interventions, which we also aim to account for in our framework. One example of these characteristics is flexibility, which is explored by Gram-Hanssen [51] in the context of transformational social change in Igiugig. She defines flexibility “not [...] as bending uncritically to various pressures, but rather as a conscious engagement with different perspectives and approaches to change.” Through her work on narratives, she finds that Igiugig is enacting transformational change such that its community systems differ from what is otherwise common in the region and across the state. In a geographical context often characterized by social and economic disparity, Igiugig is diversifying its economy and energy sources, fostering opportunities to keep youth living in the community, and increasing youth engagement with Yup’ik worldviews, language, and cultural practices. She explores how an Indigenous worldview may help to foster flexibility through community cohesion, collective leadership, and enacting alternatives; however, she is clear that calling for more flexibility is not the same as encouraging Indigenous communities to bend to external pressures, which can be especially problematic given their experiences with colonialism [51]. Igiugig seems to draw on multiple cultures and consider divergent viewpoints while sharing a common goal that emphasizes relationships between cultural heritage and positive social change, a characteristic that our co-author came to understand by 2018 (Fig. 6e; answered ‘Yes’ to the question “Does the community have the capacity to initiate change?”).

The desktop assessment for Igiugig allowed us to explore whether we comprehensively captured different dimensions of readiness and the feasibility of answering 150 questions for a real location and project. We found that a single person with knowledge of a community-based marine energy effort, amassed over nearly a decade, was able to respond to all the questions across seven different dimensions of readiness in less than a few hours. However, our application was limited in that only one person—with a certain set of experiences related to river current energy in Igiugig—answered the questions and did so retrospectively, more than 15 years after some events occurred. Due to time, resource, and capacity constraints—and a desire to avoid burdening the community with a retrospective application—we did not ask Igiugig community members nor federal researchers involved in past studies to provide responses to the metrics. While the authors strongly value participatory and transdisciplinary research, we are very aware of engagement fatigue and the importance of avoiding repeated research engagements when the outcomes may not lead to any change experienced by those engaged [73–75].

In the context of this paper, our single-person, retrospective approach to applying the metrics limits our ability to understand the drivers of change in readiness over the decade between time steps. While our results highlight some of the major changes the community underwent related to readiness, they are limited by the intrinsic imperfections of recollection and the difficulty of establishing cause and effect in a dynamic community. For example, in 2009, our co-author was more familiar with the technical feasibility studies and potential impacts to salmon than the developer, U.S. DOE, and researchers were focused on at that time, than the visioning and broader community planning efforts Igiugig began in 2000. Thus, our co-author answered “not sure” for several questions in the strategic category in 2009 that a community member may have answered “yes” to instead. While this finding highlights the limitations of our retrospective analysis for understanding broader community readiness in 2009, it also demonstrates the

importance of ‘not sure’ responses for highlighting readiness dimensions that may need more attention by a project team or information gathering from a particular set of interested parties. Moreover, while many of questions within the metrics of readiness are subjective, the framework is in fact designed to place considerable value on the respondent’s knowledge of factors that influence their own readiness or reflect the respondent’s knowledge of the community [133]. Indeed, many of the metrics are scored based on whether the respondent has information about a topic (rather than the content of the information). As a somewhat subjective framework, the metrics of readiness make use of respondents’ perceptions or “internal judgment” of their own readiness [133,134]. One challenge that could arise, especially in a collaborative process, is the issue of social desirability bias, which could lead to respondents answering the questions in a way that is perceived to be socially acceptable [135].

Future applications of the metrics of readiness would benefit from the experience and expertise of a team of people consisting of community leaders, researchers, and funders working collaboratively to answer the questions. Not only would the answers to the responses be more comprehensive, but the process itself would strengthen the project team’s knowledge of multiple dimensions of readiness. Providing time and space to explore discrepancies or differences in responses helps build consensus within the community and/or community-based project team. Surfacing differences in responses in a collaborative way can also increase community readiness through the flow and sharing of information. In this way, the metrics could serve as a ‘boundary object’ that can help scientists and communities work together to develop innovative solutions—such as marine energy—to infrastructure and energy challenges in rural and remote areas [49,126,136].

In future applications, the metrics of readiness have the potential to serve as a benchmark that can help a community and project team understand their strengths and opportunities for growth. We envision the metrics utilized by collaborative, community-based project teams to lay out a path to increase community readiness for marine energy through additional analyses, data collection, capacity building, engagement, and other activities. Examples of the types of analyses and capacity-building activities that could support each category of readiness are described below.

- **Technical:** high-resolution resource characterization using down-scaled models or field measurements, siting assessment, risk assessment, workforce development recommendations, completion of energy load profiles, interconnection/grid analysis, independent reviews to provide objective assessments of existing project documents.
- **Financial:** identification of new grants, estimation of capital and operating expenses for a proposed project, calculation of levelized cost of energy, and financial modeling to calculate project payback periods and net present values.
- **Governance:** educational activities around the required permitting process, engagement with local and state government agencies, recommendations for changes in local policy to facilitate marine energy development.
- **Economic:** completion of a workforce impact assessment, assessment of willingness to pay, techno-economic analyses to examine costs, benefits, risks, uncertainties, and timeframes to evaluate energy technologies.

- **Social:** demographics assessment, public perceptions study, translation of messaging and information provided to more accessible modes.
- **Environmental:** desktop analyses of protected species and habitats, seabed study, ecosystem service modeling, cumulative effects assessment, energy resilience and natural hazards assessment.
- **Strategic:** development of a community vision, creation of a sustainable development plan, development of an outreach and engagement plan, coordination of engagement activities, development of a funding or financing strategy, development of a monitoring and evaluation plan, design of alternative scenarios for energy development.

6. Conclusion

Our interdisciplinary framework has the potential to advance understanding and strengthen readiness for marine energy in rural and remote communities. The application to river current energy in Igiugig, Alaska demonstrates the metrics encompass diverse dimensions of readiness that reflect changes in governance, social, economic, environmental, strategic, technical and financial conditions over time. For rural and remote communities that have an interest in marine energy and face similar challenges to Igiugig, our results highlight the importance of a strong local policy environment, community leaders as innovative energy champions, and the value of community-led energy planning. The results also indicate a need for increased understanding of 1) public confidence in local government, developers, and utilities; 2) cumulative impacts and environmental effects of marine energy; and 3) the projected future energy generation and energy storage needs. Future applications of the metrics early in a planning process could help to prioritize activities and investments, while repeating the questions later in the process could demonstrate progress and highlight further opportunities for strengthening readiness. What is needed next is a test of metrics in real time, conducted by an interdisciplinary team in close collaboration with a community exploring local opportunities for marine energy. A more process-oriented application will test not only the relevance of the metrics for marine energy demonstration, but also their utility in supporting rural and remote communities in achieving energy independence and resilience goals. Such an on-the-ground application would also provide additional opportunities for improving the metrics based on community feedback.

We anticipate that the readiness journey for different communities will vary greatly. Some communities may make large rapid strides with consolidated investments; others may progress more slowly and sequentially, while still others may increase their readiness in spurts with targeted technical assistance. Completing the metrics of readiness at an early stage may prompt conversations among community members and project teams that could streamline planning and permitting processes, as well as enable proactive communities to work ahead of project development by anticipating needs. Additionally, certain events beyond a community's control, including elections, natural disasters, or other major events, may also lead to shifting priorities and the alteration of different categories of readiness. The metrics could also be applied to

multiple communities at one point in time to better understand differences in communities' needs for technical assistance and capacity building, as well as how to prioritize funding to address readiness more holistically. Ultimately, the metrics of readiness have the potential to support collaborative project teams in realizing marine energy development that is in line with a community's values, goals, and needs.

CRediT authorship contribution statement

K. Arkema: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **K. Grantham:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **D. Rose:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **K. Morrice:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Conceptualization. **A. Shereda:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation. **E. Boos:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **M. Seward:** Writing – review & editing, Project administration, Investigation. **A. Trueworthy:** Writing – review & editing, Methodology, Investigation, Conceptualization. **C. Jones:** Writing – review & editing, Methodology, Investigation, Conceptualization. **T. Greco:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization. **M. Behrmann:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation. **R. Keshishian:** Writing – review & editing, Project administration, Investigation. **S. Geerlofs:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **M. Gear:** Writing – review & editing, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Approach to developing the metrics of readiness

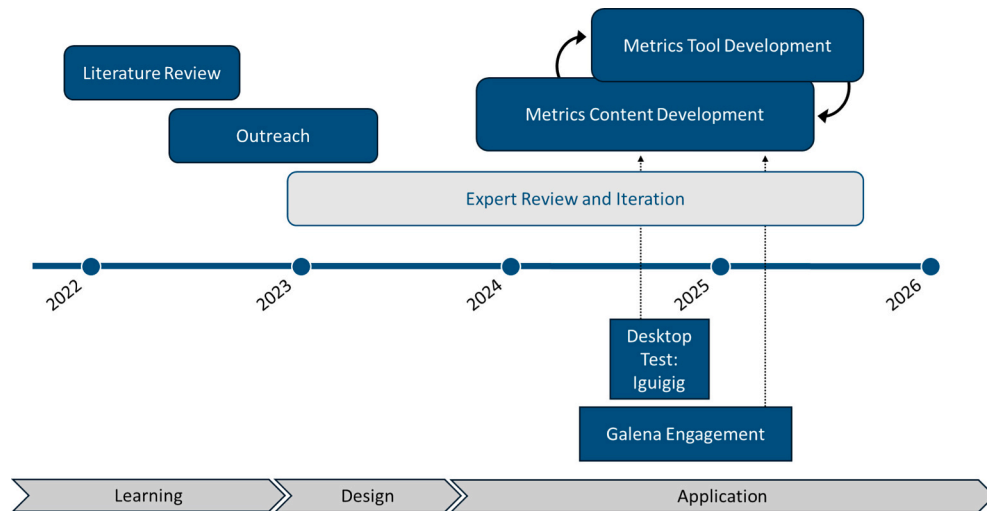


Fig. A1. provides a visual overview of the approach taken to develop the metrics of readiness as applied to Igiugig in this work from 2022 to 2025.

Appendix B. Metrics of readiness questions

The full list of questions in the metrics of readiness as used in the Igiugig desktop application is available in the tables below. The recommendations component of the metrics was not utilized for Igiugig, due to the retroactive nature of the analysis, but is available on request and will be discussed in future work.

Technical			
Subcategory	Question	Answer Options	Scoring
Resource	1. Have marine energy resources that are available to the community been identified? e.g., wave, tidal, ocean current, thermal gradient, salinity gradient, riverine	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	2. Are resource characterization data for marine energy available at the project site?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	3. Does timing of marine energy power generation (daily or seasonal) match consumption?	Yes No Not Sure NA	If Yes, 2 points If No, 2 points If not sure, 0 points
	4. Have technologies that might work with the identified resource(s) been identified?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	5. Have factors that influence the feasibility of installing identified technologies been considered?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	6. Has the community discussed aspects and preferences for device design?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
Existing Capacity	7. Has information on the community's energy load profile been collected?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	8. Are other renewable or carbon-free energy technologies already installed or being implemented?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	9. Has the grid been evaluated for compatibility with marine energy?	Yes No	If Yes, 2 points If No, 0 points

(continued on next page)

(continued)

Technical			
Subcategory	Question	Answer Options	Scoring
	10. Are spare parts for existing grid/utility infrastructure easy to obtain?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	11. Are vessels available with capabilities for installation of marine energy?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	12. Are local weather forecasts available and relatively accurate?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
	13. Is there an Acoustic Doppler Current Profiler (ADCP) or similar device onsite or that could be acquired for site characterization and operational planning?	NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	14. Is there access to the water (e.g., boat launch, pier) at or near the project site for deployment activities?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
Technology Development	15. Have needed infrastructure upgrades been assessed or completed?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	16. How willing and able are local utilities to make upgrades and improvements to existing infrastructure? On a scale of 1 meaning the least willing or able, 5 meaning the most willing and able.	Upgrades are needed	All 2 points
		Upgrades are not needed	Not sure 0 points
		Upgrades are completed	
	17. Does the utility have the technological capacity to integrate marine energy generation?	Not Sure	
		NA	
		Yes	If Yes, 2 points
	18. Has the community discussed acceptable TRL (technology readiness level) and do they understand the tradeoffs of low-TRL projects?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	19. Does the community have prior experience in technology development or evaluation?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
Workforce	20. Are there sources of local or Traditional Knowledge that could aid project development or operation?	NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	21. Have the requirements to maintain marine energy devices long-term been identified and compared to existing capacity (person-hours, expertise, equipment, etc.)?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	22. Is local labor available for predevelopment and construction?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	23. Do community members currently have the skill set/training that can be applied to build, operate, and/or maintain marine energy technologies?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
	24. Is training available nearby to build these skill sets?	NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	25. Has the safety of the proposed project and alternatives been assessed in design and siting?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points

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Technical			
Subcategory	Question	Answer Options	Scoring
Future Load	26. Have the future electricity needs of the community based on projected growth or development been quantified?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	27. Have additional energy storage needs been quantified?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
Financial			
Subcategory	Question	Answer Options	Scoring
Ownership	1. Have community preferences for ownership of the marine energy project been determined?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	2. Have different models of ownership and associated levels of risk been discussed with the community?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	3. Has the CapEx of the project been estimated?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	4. Has the OpEx of the project been estimated (including staffing, expenses, etc.)?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	5. Have the energy costs (\$/kWh) for the project been estimated?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	6. Have the CapEx, OpEx, risks, benefits, and associated uncertainty been shared with the community?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	7. Has the return on investment (ROI) been determined for the project?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	8. Has the project's levelized cost of energy (LCOE) been provided by the developer?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	9. Does the community currently receive subsidies for electricity, regardless of the generation resource(s) it is derived from?	Yes	If Yes, 2 points
		No	If No, 2 points
		Not Sure	If not sure, 0 points
		NA	
Funding	10. Is there access to financial resources to support predevelopment activities (i.e., hiring expertise, early engagement activities, third party consultants)?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	11. Are there known external sources of financing (e.g., public grants, foundation grants, private investment) that the community could apply for to support project development, operations or other needs related to pursuing a project?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	12. Is local government funding available to support project operations or other project needs beyond the sources identified in question 11?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	13. Does the community have the ability to financially contribute to the project through direct investment or unique project ownership structures?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	14. Does the community have staff capacity to apply for grants?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	15. Does the community have sufficient creditworthiness to access low cost capital / lending?	Yes	If Yes, 2 points
		No	If No, 0 points

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Financial			
Subcategory	Question	Answer Options	Scoring
	16. Are there tax incentives available (federal, state, local, etc.) for marine energy development?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 2 points
	17. Are there local financial institutions that could be or are already engaged in renewable energy financing?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 2 points
	18. Does the community have experience with public-private partnerships for funding projects?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
Risk	19. Has the community considered the potential financial risk for developing a marine energy project?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	20. Has risk mitigation (i.e., ownership, insurance) been considered to avoid potential community-related risks and attract private investors?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
Governance			
Subcategory	Question	Answer Options	Scoring
Legal	1. Do the organizations/entities involved in the marine energy project have the legal authority to pursue this effort?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	2. Does the community understand the permits and/or FERC license and the associated timeline to develop a marine energy project?	Yes	If Yes, 2 points
		No	If No, 1 points
		Not Sure	If not sure, 0 points
		NA	
	3. Are there any legal, regulatory, or contractual restrictions that could prevent marine energy development?	Yes	If Yes, 1 points
		No	If No, 2 points
		Not Sure	If not sure, 0 points
		NA	
	4. Have Indigenous legal rights been considered?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	5. Is the project located on or near federally recognized or unrecognized Tribal lands?	Yes	If Yes, 2 points
		No	If No, 2 points
		Not Sure	If not sure, 0 points
		NA	
	6. Have potential impacts to Tribal treaty rights been assessed, if applicable?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
7. Are there any existing state or local clean energy mandates or legally enforceable goals?	Yes	If Yes, 2 points	
	No	If No, 1 points	
	Not Sure	If not sure, 0 points	
	NA		
8. Is there a Renewable Portfolio Standard for clean energy?	Yes	If Yes, 2 points	
	No	If No, 2 points	
	Not Sure	If not sure, 0 points	
	NA		
Policy	9. Are there renewable energy policy drivers that include marine energy?	Yes	If Yes, 2 points
		No	If No, 1 points
		Not Sure	If not sure, 0 points
		NA	
	10. Is the local government experienced with laws, policies, or programs related to renewable energy development?	Yes	If Yes, 2 points
		Somewhat	If Somewhat, 1 point
		No	If No, 0 points
		Not Sure	If Not sure, 0 points
	11. Is there political will or a political champion for marine energy?	NA	
		Yes	If Yes, 2 points
		No	If No, 1 points

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Governance			
Subcategory	Question	Answer Options	Scoring
Regulatory	12. Is there political opportunity to build support for or facilitate marine energy?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 1 points
		Not Sure	If not sure, 0 points
	NA		
	13. Have policy or regulatory barriers within the community been assessed?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	14. Have relevant agencies, including federal, state, local, and regional, been consulted?	No	If No, 0 points
Not Sure		If not sure, 0 points	
NA			
Yes		If Yes, 2 points	
No		If No, 0 points	
15. Have relevant Tribes been consulted to identify and resolve issues?	Not Sure	If not sure, 0 points	
	NA		
Management and Engagement	16. Do local or state government agencies involved in this project regularly engage with Indigenous Peoples in the area?	Yes	If Yes, 2 points
		No	If No, 1 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	17. Does the community manage its own energy (i.e., as a co-op or as an independent power producer)?	No	If No, 2 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 2 points
	18. Does the community currently have municipal energy systems?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 2 points
		Not Sure	If not sure, 0 points
	19. Has the community recently implemented any community-wide development projects?	NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
Not Sure		If not sure, 0 points	
NA			
20. Are there well-established processes to solicit feedback and engage with the community at the local or state level?	No	If No, 0 points	
	Not Sure	If not sure, 0 points	
	NA		
Economic			
Subcategory	Question	Answer Options	Scoring
Energy Cost	1. Are utility bills and associated data (i.e., energy consumption patterns, electricity or fuel costs, and rate tiers/structures, seasonal/time of day variability) easily available and understood by the project team?	Yes	If Yes, 2 points
		No	If No, 1 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	2. Have the project's impacts on household energy burden been assessed?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 2 points
	3. Is the electricity rate / fuel cost higher than the regional rate/cost?	Not Sure	If not sure, 0 points
		NA	
Yes		If Yes, 2 points	
No		If No, 0 points	
Not Sure		If not sure, 0 points	
4. Has the community's willingness to pay been assessed for end users if electricity from renewable sources comes at premium cost?	NA		
Energy Market	5. Is there a low incidence of delinquent customer payments within the community?	Yes	If Yes, 2 points
		No	If No, 2 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	6. Is the local electricity / fuel market viewed by community members as competitive and fair?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	

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Economic			
Subcategory	Question	Answer Options	Scoring
Impacts	7. Does the current energy market (e.g., utility-based electrical or thermal services, private or third-party electricity or fuel provider) support renewable energy generation growth?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	8. Are the goals of the community related to economic development well-understood?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	9. Does the community see potential for job opportunities with marine energy?	Yes	If Yes, 2 points
		No	If No, 2 points
		Not Sure	If not sure, 0 points
		NA	
	10. Have long term economic impacts (i.e., jobs, supply chain development, commercial and tourism revenues) from the marine energy project been assessed?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	11. Have the project's impacts on local taxes been assessed?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	12. Is there an understanding of the project's potential impact on property values?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	13. Have mechanisms (e.g., compensation, mitigation, local hiring agreements) been discussed to distribute costs and benefits with the community?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
Social			
Subcategory	Question	Answer Options	Scoring
Community Composition	1. Does the community have a sizable Indigenous population?	Yes	If Yes, 2 points
		No	If No, 2 points
		Not Sure	If not sure, 0 points
		NA	
	2. Are population dynamics of the community well understood? (e.g., long term growth or decline, seasonal fluctuations)	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	3. Are the historic relationship(s) between different community groups (e.g., fishers, local businesses, Indigenous populations) and renewable energy understood?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
Core Values	4. Are the motivations of the community in relation to renewable energy understood?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	5. To what extent do community members consider future generations in decision-making?	High	If High or Medium, 2 points
		Medium	
		Low	If Low, 1 points
		Not Sure	If not sure, 0 points
	6. To what extent are viewsheds, including seascapes and landscapes, important to the community?	High	
		Medium	
		Low	If any, 2 points
		Not Sure	If not sure, 0 points
	7. To what extent do community members feel emotionally, spiritually, and/or culturally attached to certain locations (e.g., parks, beaches, rivers, the ocean)?	High	
		Medium	
		Low	If any, 2 points
			If not sure, 0 points

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Social			
Subcategory	Question	Answer Options	Scoring
Public Confidence	8. Is marine energy development being considered in any areas to which community members have a strong emotional, cultural, or spiritual attachment?	Not Sure	
		NA	
		Yes	If Yes, 2 points
		No	If No, 2 points
	9. Does the community have a strong sense of self-determination?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	10. To what extent is there public confidence or trust in local government and public participation processes?	Not Sure	If not sure, 0 points
		NA	
		High	If High or Medium, 2 points
		Medium	If Low, 1 points
Community Perceptions	11. To what extent is there public confidence or trust in renewable energy developers?	Low	If not sure, 0 points
		Not Sure	
		NA	
		High	If High or Medium, 2 points
	12. To what extent is there public confidence or trust in the local utility?	Medium	If Low, 1 points
		Low	If not sure, 0 points
		Not Sure	If NA, 2 points
		NA	
	13. Are the community's perceptions on renewable energy understood?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
Culture	14. Are the community's perceptions on marine energy understood?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	15. Are the community's perceptions on changes to cultural resources and/or cultural values understood?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	16. Has a full description of the social and economic situation relevant to the Indigenous Communities (including demographic information, living standards and livelihoods) been conducted?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
Culture	17. Are members of the community regularly involved in community activities and/or local politics?	Yes	If Yes, 2 points
		No	If No, 2 points
		Not Sure	If not sure, 0 points
		NA	
	18. Is there a network of institutions or organizations within the community that is interested in renewable energy development?	Yes	If Yes, 2 points
		No	If No, 1 points
		Not Sure	If not sure, 0 points
		NA	
	19. What degree of social cohesion exists within the community?	High	If any, 2 points
		Medium	If not sure, 0 points
		Low	
		Not Sure	
	20. Does the community have capacity to initiate change?	NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
Culture	21. How socially active are the youth in the community?	NA	
		Very Active	
		Active	If any, 2 points
		Not Active	If not sure, 0 points
	22. Have sources and types of information that are valued and trusted by the community been identified (e.g., VHF channel, radio, newsletter, etc.)?	Not Sure	
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	

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Social			
Subcategory	Question	Answer Options	Scoring
	23. Do community members have difficulty accessing messaging and information sources related to renewable energy?	Yes No Not Sure NA	If Yes, 1 points If No, 2 points If not sure, 0 points
Environmental			
Subcategory	Question	Answer Options	Scoring
	1. Have potential environmental effects or conflicts with other marine uses been identified for the possible type(s) of marine energy devices?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	2. Have environmental considerations for cabling offshore been examined?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	3. Has Traditional Ecological Knowledge been utilized in collecting environmental information for siting or project design?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	4. Has an assessment of land use, including ancestral or traditional Indigenous uses and official or customary resource uses been completed to identify potential conflict areas?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	5. Are there marine protected areas in the project area?	Yes No Not Sure NA	If Yes, 2 points If No, 2 points If not sure, 0 points
Siting/Design	6. Has a detailed riverbed or seabed study been conducted for the project area?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	7. Are there historical and/or archaeological sites located in the project area?	Yes No Not Sure NA	If Yes, 2 points If No, 2 points If not sure, 0 points
	8. Have protected species been identified in the project area? (e.g., ESA-listed species)	Yes No Not Sure NA	If Yes, 2 points If No, 2 points If not sure, 0 points
	9. Have other economic and/or culturally important species been identified in the project area?	Yes No Not Sure NA	If Yes, 2 points If No, 2 points If not sure, 0 points
	10. Have critical habitats or other important habitats (e.g., Essential Fish Habitat) been identified in the project area?	Yes No Not Sure NA	If Yes, 2 points If No, 2 points If not sure, 0 points
	11. Have terrestrial habitats where cables from the project may pass through been considered?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	12. Has a baseline environmental assessment been completed for the proposed marine energy project?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	13. Is information from past environmental assessments in the area available?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	14. Have the necessary environmental permits been identified for the proposed marine energy project?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
	15. Have the environmental regulatory procedures, timelines, and requirements been identified for the proposed marine energy project?	Yes No Not Sure NA	If Yes, 2 points If No, 0 points If not sure, 0 points
Permitting	16. Have monitoring plans for identified environmental impacts been developed?	Yes No	If Yes, 2 points If No, 0 points

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Environmental			
Subcategory	Question	Answer Options	Scoring
Human-Environment Relationship	17. Have potential mitigation efforts to address environmental impacts been discussed with regulatory agencies?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
	NA		
	18. Have the benefits of nearby terrestrial and marine ecosystems (i.e., ecosystem services) for the community been identified?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
	19. Have the effects of marine energy on these socio-economic values of ecosystems (including secondary effects) been assessed?	Yes	If Yes, 2 points
No		If No, 0 points	
Not Sure		If not sure, 0 points	
NA			
Integrated Management	20. Have the cumulative effects of future energy development and non-energy activities been discussed?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	21. Have effects to the ecosystem from marine energy development been considered holistically through a process such as ecosystem-based management?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
Resilience	22. Are risks to the community’s energy infrastructure from natural hazards well understood?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	23. Have critical community facilities been assessed recently for resilience to natural disasters, pollution, and other environmental threats?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
Strategic			
Subcategory	Question	Answer Options	Scoring
Goal Setting	1. Has the community vision or mission statement been documented?	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	2. Have the priorities and/or goals of the community related to energy been identified?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	3. Are there defined time horizons associated with the community’s energy goals?	Not Sure	If not sure, 0 points
		NA	
Yes		If Yes, 2 points	
No		If No, 0 points	
Not Sure		If not sure, 0 points	
4. Have goals for marine energy development been documented?	Yes	If Yes, 2 points	
	No	If No, 0 points	
	Not Sure	If not sure, 0 points	
	NA		
Planning	5. Have any sustainable development plans been completed by the community? e.g., climate adaptation plan, sustainability plan, resilience plan	Yes	If Yes, 2 points
		No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
	6. Has a strategic energy plan been developed?	No	If No, 0 points
		Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	7. Have clear links been identified between the strategic energy plan and the project plan?	Not Sure	If not sure, 0 points
		NA	
Yes		If Yes, 2 points	
No		If No, 0 points	
Not Sure		If not sure, 0 points	
8. Has the community considered alternative options (e.g., siting, device designs) related to marine energy?	Yes	If Yes, 2 points	
	No	If No, 0 points	

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Strategic			
Subcategory	Question	Answer Options	Scoring
	9. Have conflicts with other users been considered and characterized (e.g., temporally, spatially) for the marine energy project in these alternative options?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	10. Has a team been developed/formalized to carry forward the planning process for the marine energy project?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	11. What is the planning team's past experience with policy and regulatory engagement for projects of this type?	Not Sure	If not sure, 0 points
		NA	
		High	High: 2 points
		Medium	Medium: 2 points
		Low	Low: 1 point
		Not Sure	Not sure: 0 points
Outreach and Engagement	12. Has a community champion for the project been identified?	Not Sure	
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	13. Are there existing community capacity building activities underway?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	14. Has a community skill assessment or community asset mapping (technical and non technical) been conducted?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	15. Have the key community groups, decision-makers and Tribes that may be interested in or affected by marine energy (e.g., vulnerable/marginalized populations, Indigenous populations, fishers, local businesses) and need to be engaged been identified?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	16. Has an outreach and engagement plan been developed for the project?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	17. Have existing or novel opportunities for community engagement been identified?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	18. Have any barriers to public participation been identified?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	19. Have efforts been taken to engage with Indigenous Communities and exchange information in the process of marine energy development?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
Evaluation	20. Is there support from community leaders and decision-makers for the project?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	21. Is information gathered from engagement going to be incorporated or used to inform energy planning decisions?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	22. Are there defined go/no-gos, milestones, and timelines for the project?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	23. Are there risk management plans in place?	Not Sure	If not sure, 0 points
		NA	
		Yes	If Yes, 2 points
		No	If No, 0 points
	24. Are there metrics or mechanisms to evaluate project progress and outcomes?	Not Sure	If not sure, 0 points
		NA	

Appendix C. Igiugig desktop application

Table C1

Scores by time and category for the Igiugig desktop application. Category points are standardized to be out of 100.

	2009	2018
Technical	33	81
Financial	25	80
Governance	58	83
Economic	31	38
Social	22	54
Environmental	26	78
Strategic	13	79

Table C2

Points by time and subcategory for the Igiugig desktop application. Total possible points may vary if there are NA responses.

	2009	2018	Total Possible
Technical			
Resource	4	12	12
Existing Capacity	6	16	18
Technology Development	5	8	10
Workforce	2	8	10
Future Load	0	0	4
Financial			
Ownership	2	14	18
Funding	8	16	18
Risk	0	2	4
Governance			
Legal	8	11	16
Policy	4	6	8
Regulatory	2	6	6
Management and Engagement	8	10	10
Economic			
Energy Cost	4	4	8
Energy Market	2	2	6
Impacts	2	4	12
Social			
Community Composition	4	6	6
Core Values	4	8	12
Public Confidence	0	0	6
Community Perceptions	0	2	6
Culture	2	9	16
Environmental			
Siting/Design	8	20	22
Permitting	4	12	12
Human-Environment Relationship	0	2	4
Integrated Management	0	0	4
Resilience	0	2	4
Strategic			
Goal Setting	0	4	8
Planning	4	14	20
Outreach and Engagement	2	14	14
Evaluation	0	6	6

Data availability

Data will be made available on request.

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