Assessment of ocean energy systems as a source of energy for a proposed aquaculture ecosystem in Guam.

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I. Introduction

With the great Pacific Ocean surrounding the island of Guam, it seems that ocean energy systems (OES) could be a natural source of energy. Solar photovoltaic cells and wind turbine generators are the two renewable power sources currently interconnected to the island's grid. This paper discusses the use of ocean energy technology as another potential viable source of renewable power for the island by assessing the infrastructure requirements for OES, environmental considerations, and economic impact to the island.

In early 2023, Pacific Northwest National Laboratory (PNNL), in partnership with Sandia National Laboratories (Sandia) and the University of Guam (UOG), a public Land-grant and Sea Grant institution, initiated this study through funding from the United States Department of Energy (DOE) Water Power Technologies Office (WPTO). In addition to assessing the feasibility of using OES on the island, a secondary objective of the study is to obtain insights for a framework that could be used to assess OES deployment decisions.

With its pristine water, stable temperatures, high local demand, strategic location and US legal structure, Guam has good potential for aquaculture to be a growth sector for Guam's economy. [1] For this study, OES technology is evaluated as a source of electricity for a proposed Guam Aquaculture Innovation Center (GAIC). Two potential sites were assessed to build the GAIC facility, which is expected to include facilities within a 5-acre area for applied research involving assessment of local species for food and non-food production, evaluating commercial marine ornamentals, culture, and reproduction of species for reef restoration, aquaponics systems, incubation of aquaculture businesses, and developing marine hatchery technology for multiple species. The study leverages the strong interests of UOG's Guam Aquaculture Development and Training Center (GADTC) and Sea Grant to develop the aquaculture industry and explore how ocean energy can be leveraged.

This assessment evaluates two types of OES technology for use on Guam: ocean energy thermal conversion (OTEC) and wave energy converter (WEC). Guam's location in the tropical western Pacific Ocean makes it an ideal candidate for using OTEC and/or WEC systems as a steady source of clean energy to power the GAIC. Other use cases are also explored for leveraging OES as a clean energy source to benefit the island, such as powering a desalination plant, the island's electrical grid, or other industries, such as electrolysis for hydrogen generation.

A. Guam's surrounding ocean potential

Guam lies at the southern end of the Mariana Island archipelago and is surrounded by shallow fringing coral reefs and lagoons. In relatively near-shore waters, depths increase rapidly beyond 1000 m. Guam is the closest land mass to the Mariana Trench, where the ocean drops 6.8 miles (11,000 meters) below sea level and is the deepest point in the Pacific Ocean. The large difference in seawater temperature at sea level and depths of at least 1000 meters (greater than 25°C) make the island attractive for OTEC technology. [2,3] The assessment explores modern OTEC archetypes that range from floating offshore and nearshore platforms to onshore systems with pipelines to transport water to and from the ocean. [2] OTEC has been used to power aquaculture located in the Hawaii Ocean Science and Technology Park and the Natural Energy Laboratory in Hawaii.

Another OES technology explored in this study is the use of WEC systems in Guam. Insights from previous studies on WEC applications will be leveraged by the team, such as use for kelp processing [7], powering offshore platforms [8] and powering pumps for aquaculture [2]. Wave energy along Guam's shoreline is dependent on wind speed, wind direction and fetch length along the wind bearing. The south-eastern shores of Guam have the highest wave energy potential. WEC systems can float within the water column (e.g., oscillating water column) or on the surface, and can also be attached to structures, such as piers. WECs could be installed on the shore, nearshore or offshore. WECs have been used to power aquacultures in Scotland, Wales, Mexico, Cyprus, and Australia [2].

Other OES technology, such as tidal energy and ocean currents are not explored by this study at this time but may also have potential to as an ocean energy source of power.

B. Aquaculture Industry for Guam

During the COVID-19 pandemic, Guam experienced a major economic impact due to the complete halt of the tourism industry because of the mandatory travel restrictions in and out of the island reducing visitor numbers by more than 95%. [9] The pandemic also strained global supply chains, which challenged the island's import of food. The Government of Guam (GovGuam) recognized the need to diversify its economy and identify other means of generating income and acknowledged the potential economic growth that a successful aquaculture industry can bring to the island. Guam's aquaculture production from 1978-2018, with current production estimated at 210,000 pounds/year, is less than 5% of the total consumption of fish and seafood products in Guam. [1] GovGuam and UOG anticipate leveraging the island's natural resources (e.g., offshore marine, water, and land) and tropical climate to sustain this industry and increase aquaculture production to 1 million pounds. Aquaculture production is expected to account for 25% of the island's domestic fish and seafood consumption, replacing money spent on imported fish and seafood and providing an opportunity to generate revenue from exporting this commodity within the Micronesia and Western Pacific Ocean region. Integrating OES into the GAIC's electricity infrastructure will help sustain a new economic industry for the island through reliance on an abundant renewable source of power for the planned aquaculture.

II. Background

As the development of ocean renewable energy, such as offshore wind, waves and tides, becomes a viable source of clean energy for many markets, transition measures involve addressing concerns of the affected communities and ocean renewable energy stakeholders. Studies showed that economic development is strongly linked to the cultural fabric of the locality. Understanding the cultural implications would inform necessary ocean energy governance. [11] Thus, the methods used in this study primarily involve obtaining input and feedback from Guam's communities, as well as obtaining insights from the marine energy community, OTEC and WEC developers, and literature research involving use-cases of deploying OES in other countries and islanded communities.

A. Integrating Island Community Engagement and Outreach

Communities that are dependent on agriculture and fisheries maintain unique cultural activities and traditions and have often built resilience to cope with and adapt to developments and changes at the coast over generations. [13] Throughout the study, engagements with various Guam community and ocean energy stakeholders are scheduled at least once a quarter to discuss concerns and assess the responses that could impact energy governance. The engagements note perceptions, expectations, and concerns with the use of OES while at the same time consider the needs of policy and regulation designed to act in the national interest, industry development and path inter-dependencies, to deliver societal change towards transitioning to ocean renewable energy. [13]

The renewable energy sources currently used on Guam include two 60 MW solar photo-voltaic (PV) arrays farms and one 275 kW on-shore wind turbine generator. Ocean renewable energy would be a new type of clean energy source for the island. Most offshore energy exploration and production can result in opposition from communities living close to the coast. Because Guam is a small island (approximately 30 miles long and 4 to12 miles wide), the community is open to sharing perceptions, expectations, and concerns with OES as a viable energy source for the island.

The project engages with different groups within the Guam community, such as coastal and inland villages and fisheries; Government agencies and stakeholders, such as academia, electric utility provider, and Science & Technology Steering Committee; and the US military. The engagements are through formal meetings or town hall discussions. These community engagements will not only empower the local community and improve morale, but the project will gain valuable insights on social acceptance, cultural influences, and values on using the ocean as a source of power for the island.

B. Approach to Assess Infrastructure, Environmental and Economic Impacts

Guam presents environmental and physical challenges, such as the need to protect valuable coral reef and land. [1] Guam's environmental regulations are reviewed to assess the impact involving excavations, construction of wells or infrastructure structures, construction of piers/docks, use of suspended or anchored nets or cages sitting on or just above the substrate, and presence of onsite power generator systems [1], including discharge activities and import/export of aquaculture products. The study delineates Guam's environmental regulations involved with installation and operation of OES. Guam's regulatory programs applicable to aquaculture development and operations involve at least four agencies: Guam Land Use and Seashore Protection Commissions administered through the Department of Land Management; Guam Environmental Protection Agency, Division of Aquatic and Wildlife Resources of the Guam Department of Agriculture and the Guam Coastal Management Program at the Bureau of Statistics and Plans.

The infrastructure needs of installing and operating OTEC and WEC vary by developer designs. The infrastructure framework categories assessed in this study include technical feasibility, environmental, energy matching, resource matching, deployment capability and cybersecurity. The recent power disruption caused by

Category 4 Typhoon Mawar has now introduced a new concern with power sources withstanding natural events and availability post-event.

The cost of installing OTEC and WEC systems is a realistic economic factor that is considered in this study. 30-years ago, OTEC was initially explored in Guam as a means of seawater cooling to reduce electrical loads from air conditioning services. [4] The study concluded that installing OTEC would have been an economic burden. [4] Current OTEC and WEC developers are cognizant of the costs to deploy their systems. However, some of the economic benefits realized by developing an aquaculture industry on the island, such as food security, economic diversification beyond tourism industry, export revenues, employment, and investment opportunities, may outweigh the costs of installing OES technology. In addition, fossil fuel costs have increased significantly since the original feasibility study was commissioned in 2011. As a result, electricity costs have been rising in Guam. Other multi-uses for ocean energy, such as additional renewable energy generation to supplement existing solar farms (120 MW) and wind turbine generators (275 kW) for the island's grid, source of power for desalination systems, or powering other clean energy industries, could also be leveraged if OES could be a viable source of power.

III. DISCUSSION

This study is a 24-month project that commenced March 2023. During the April 2023 University of Guam Conference for Island Sustainability, an overview of the study was presented. [6] The Guam community expressed support for using ocean energy as another source of clean energy and was eager to learn more about OES. Discussions that were planned on June 2023 with Guam government leadership, GEDA and members of the Science & Technology Steering Committee were re-scheduled because of the destruction and power outages caused by Typhoon Mawar. Because ocean energy is a new concept to the island residents, educational series on OTEC and WEC designs, and current use cases are planned for community engagements.

C. Infrastructure Considerations

The power needs for the GAIC are not yet determined, so power capacity of OTEC and WEC systems would be scaled by design. There are many different OTEC archetypes, which include floating offshore and nearshore platforms to onshore systems with pipelines to transport the water to and from the ocean. [2] OTEC is ideal for use in aquaculture production in tropical and subtropical regions because of its ability to deliver deep seawater to the surface that is cold and rich with nutrient with fewer pathogens and bacteria, which support production of crustaceans, microalgae, ad shellfish. [2] Similarly, there are WEC systems deployed in Scotland, such as WaveNET, a floating array-based WEC that tracks orbital motion of fluid particles, capturing energy as it moves with the motion of the waves and converting it to electricity. A large scale commercial OTEC prototype could generate 105 kilowatts (kW) of electricity. The WEC modules range in capacity of 7.5 kW to 10-megawatt (MW) capacity. [2]

D. Environmental Considerations

Environmental reviews performed to-date revolve around assessing the impact on the surrounding ocean ecosystem (i.e., marine animals, fish, benthic organisms, etc.); island's shipping lanes and other maritime activities; changes to oceanographic water systems (e.g., turbidity and temperature); monitoring and permitting requirements, and deployment feasibility. Installation of piping up to depths of 1000 meters for OTEC systems would need to be assessed to prevent disruption of coral and marine life. Similarly, the placement of electrical cables for use of WEC in offshore platforms would need to be assessed to prevent impact on coral reefs and the fish and marine ecosystem.

Guam's coral reefs provide almost $17 million in protection to buildings and the local economy every year. [12]. Thus, protecting the island's coral reefs is a priority for the community. Educational workshops and interactive engagements are integral to informing island communities of installation and operational expectations for WEC and OTEC systems and minimizing environmental concerns. Reef education provides insights on protecting this valuable resource in Guam.

Guam's Coastal Management Program identifies the island's policies, rules, responsibilities, obligations, and relationships for protecting coastal zones, except for those coastal sections that are within Federal lands. [13] Installation of OES, whether on offshore platforms or onshore sites will have to adhere to Guam's Coastal Management Program.

Coastal habitats in Guam include a variety of coral-reef types, algal-dominated hard substrates, and small areas of seagrasses and very limited mangrove habitat. [15] Installation of pipes and electric cables may impact coastal resources due to potentially degrading water and habitat quality. Guam's Environmental Protection Agency conducts monitoring of physical, chemical, and bacteriological status of marine waters, as well as coral-reef condition assessments performed by the US National Oceanic and Atmospheric Administration (NOAA). [15] But there is still a general lack of quantitative baseline information for sediment and tissue pollutant concentrations for Guam marine waters. [15] Exposed sessile benthic forms, such as corals and macroalgae, and substrate type were quantitatively surveyed and recorded. [15] The benthic and fish community parameters were assessed at the two sites proposed in Guam's feasibility study: Tanguisson Beach and Pago Bay Reef. [1]. The benthic and fish index at the two sites are as follows:

- Tanquisson Beach: 3 meters bottom depth; Benthic H index of 4.36 and Fish H index of 3.74

- Pago Bay Reef: 4 meters bottom depth; Benthic H index of 3.50 and Fish H index of 2.72

Both sites are above the mean Benthic index of 3.2 and Fish index of 2.75.

The Guam Coastal Resilience Assessment provides insights to support effective decision-making that continues to build resilience for communities facing flood-related threats. [14] The Guam Coastal Resilience Assessment report identifies coastal areas where resilience projects would have the greatest potential to benefit human communities, fish, and wildlife. [14] Both Tanguisson Beach and Pago Bay Reef rank high in benefiting communities and wildlife.

E. *Economic Considerations*

The theoretical average annual energy available from ocean waves and currents is estimated to be approximately 1,445-Terawatt hour per year (TWh/year), which is approximately one-third of the nation's annual electricity usage. [10] The levelized cost of energy generated by OTEC and WEC systems is compared with the economic benefits of multi-uses for OTEC and WEC systems to power the GAIC and potentially other coastal communities through integration into the island's electrical grid. Other economic benefits that are explored for OTEC and WEC systems include the ability to provide emergency backup power for critical infrastructures systems (e.g., electricity, water, wastewater, desalination, communications) in the event of loss of normal power from the grid.

F. *Next Steps*

As the research continues to progress, more information will be reported on the feasibility of using OTEC and WEC technology as an energy source for the proposed aquaculture facility and assessing the infrastructure requirements to minimize the impact on the island's environmental and economy.

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