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Wave Energy in the Pacific Island Countries: A New Integrative Conceptual Framework for Potential Challenges in Harnessing Wave Energy

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Abstract: The Central and South Pacific have significant wave energy resources distributed through the region that are currently not being explored. Even though the wave energy resource in the Pacific has been studied, there is limited knowledge on the potential obstacles when inserting this new energy source into a unique and unexplored environment. Pacific Island countries (PICs) have distinctive characteristics that can become barriers to this technology, especially considering that local coastal and marine systems are fundamental for subsistence and local development. Thus, the success of a project relies on local acceptance. The current study developed an integrative conceptual framework for the PICs (ICFPICs) that derived from the integration of the elements of a political, economic, social, technological, environmental and legal (PESTEL) structured approach and further combined with a strengths, weaknesses, opportunities and threats (SWOT) approach to create a matrix that included relevant internal and external factors influencing a project. Four islands were analyzed through the ICFPICs to demonstrate the varying characteristics and challenges in the Pacific environment; the islands were Tubuai (French Polynesia), Viti Levu (Fiji), Rarotonga (Cook Islands), and 'Eua (Tonga). Applying the ICFPICs to each island shows that Tubuai has significant technological issues, Rarotonga has mostly economic issues, Viti Levu is the most developed island but also has several potential issues in the social sphere, while 'Eua has the fewest issues and is a viable candidate for further analysis. The ICFPICs can be used by decision makers, project developers, and stakeholders to recognize probable barriers when bringing wave energy technologies to the PICs and make informed decisions during the pre-feasibility stage.

Keywords: Pacific; wave energy; island environment; PESTEL; framework; SWOT

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Citation: Borges Posterari, J.; Waseda, T. Wave Energy in the Pacific Island Countries: A New Integrative Conceptual Framework for Potential Challenges in Harnessing Wave Energy. *Energies* **2022**, *15*, 2606. https://doi.org/10.3390/en15072606

Academic Editors: Eugen Rusu, Kostas Belibassakis, George Lavidas and Peter V. Schaeffer

Received: 18 October 2021
Accepted: 29 March 2022
Published: 2 April 2022

1. Introduction

The ocean is an abundant resource for island countries, and can be used as a source of energy in areas where natural resources are limited. The Pacific Island countries have a history of relying on importing diesel for energy purposes, which not only causes environmental concerns but also social and economic concerns. Diesel-based electricity in these countries is often associated with fluctuating prices and high electricity tariffs. Harnessing energy from the ocean is one of the alternatives to establishing energy security and strengthening resilient development, and includes wave energy, ocean current energy, tidal energy, and ocean thermal energy. There is limited literature available on resource assessment for currents, tidal, and thermal energy for the Pacific Ocean; however, there are recent studies on wave energy that show several potential sites within selected Pacific Island countries.

When it comes to wave energy in the Pacific Islands, so far two main studies have assessed and quantified the resource in different locations. The variables analyzed, data source, and methods used were distinct for both studies, nonetheless, they have shown that wave energy is a possibility for different locations inside the Pacific. In 1996, a study by Barstow and Falnes [1], using buoy measurements and GEOSAT satellite altimeter observations, analyzed the wave climate and wave energy resource for seven PICs (Cook Islands, Tonga, Fiji, Samoa, Vanuatu, Tuvalu, and Kiribati). They also included a state of the art review of wave energy technologies, environmental and political considerations, demography data, and energy needs in the selected countries.

The last study on this field was conducted in 2015, by Bosserelle et al. [2], and expanded the domain for wave energy resource assessment and analyzed 33 islands from 12 different countries. This assessment was carried out using the Centre for Australian Weather and Climate Research (CAWCR) wave hindcast, containing data from 1979 to 2010 with a resolution of 7 km around the Pacific Islands. This hindcast was validated by measurements from Pacific buoys and used to calculate wave statistics for the Pacific domain (Figure 1).

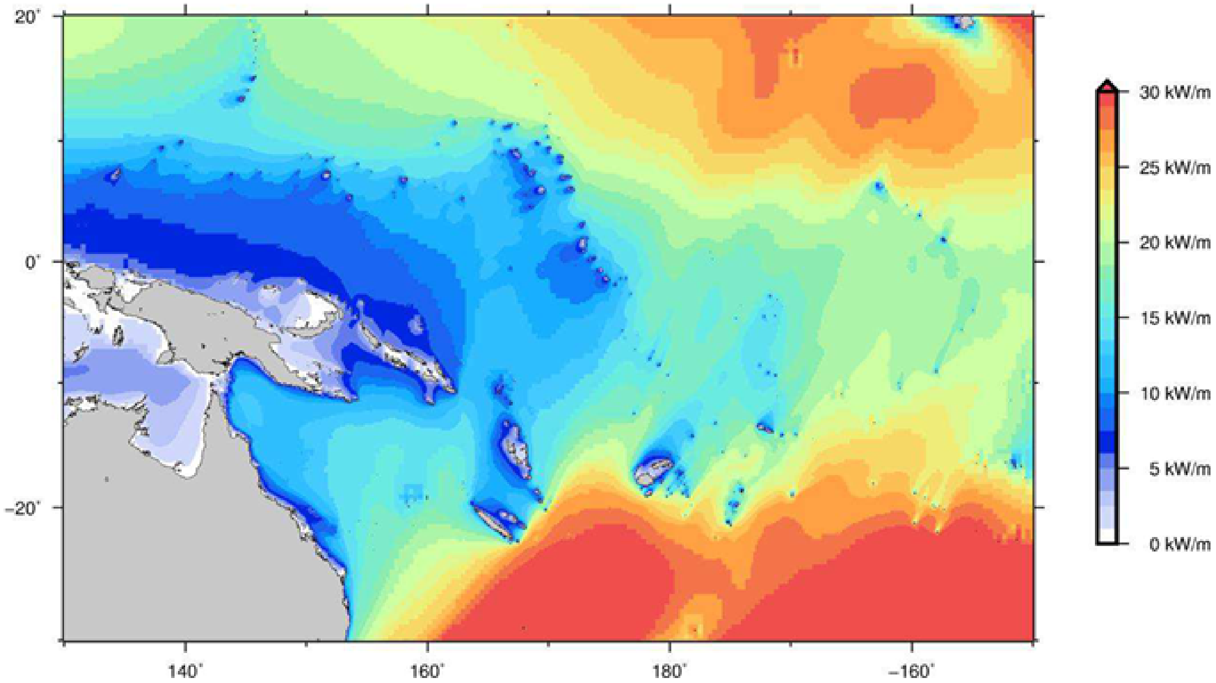

Figure 1. Average wave power in the Pacific (kW/m): reproduced from [2], Waves and Coasts in the Pacific, published by Pacific Community (SPC) 2015.

The South Pacific area shows significant potential for the deployment of wave energy converters based on the resource analysis and could be further explored to meet the renewable energy goals of the Pacific countries. Nevertheless, characterizing the resource itself does not provide enough information on the suitability of potential sites or the feasibility of wave energy at a specific location. As part of the site screening stage of a wave energy project, it is required to identify any potential challenges that could hinder the feasibility of installing and operating a wave energy converter. The project development process should assess the available data and their suitability to inform the initial feasibility of the project. Any data gaps and their relevance should be highlighted to identify, define, and prioritize the requirements for further and more detailed surveys [3]. This is done through a pre-feasibility study, which includes a preliminary resource assessment, as well as an overview of any potential obstacles for a project.

The nature of these obstacles can vary and, so far, there has been no predefined guideline on how to identify them. Combining all relevant information without a defined structure is a challenge since wave energy has direct and indirect relationships with different fields. Even though there is a lack of structured frameworks for the proposed scope, there is a significant amount of literature on different stages of a wave energy project, such as environmental impact assessment (EIA). An example would be the study by Mendonza et al. [4] that proposed a framework for environmental impacts on ocean energy devices, suggesting interactions between devices and the environment that should be considered for different devices. Their study mostly focused on the environmental dimension, which is in accordance with EIAs, while the present study focuses on the six PESTEL dimensions.

It is essential to gather pertinent information in the early stages of a project to increase the chances of success, especially in a new environment where wave energy has not been previously introduced. Two traditional concepts from the marketing and business fields that could be adapted to wave energy pre-feasibility studies are PESTEL and SWOT. These are two well-established decision- making tools that can structure information from a holistic perspective and assess unknown variables; however, there is limited literature on how to adapt them into the marine energy field. In this study we demonstrated how PESTEL and SWOT approaches can assist ocean wave energy projects in the Pacific to move forward. This has never been discussed in the literature and the presented framework can also be adapted to tidal, current, and thermal energy technologies in other regions.

1.1. PESTEL

PESTEL analysis has been evolving through the years as an integrative approach and can be found in different forms of literature. The origin of this approach is considered to be the book "Scanning the Business Environment" by Francis J. Aguilar [5], where the concept of economic, political, social and technological analysis (EPST) was first introduced. The acronym was later changed by Arnold Brown, becoming STEP, which was a rearrangement of the order of the words. The environmental factor was added subsequently becoming then social, economic, technical, political, and environmental (STEPE) factors. In general terms, the concept of environment involves far, near, and internal environments, including all types of factors related to the activities of the company [6]. The last addition to the acronym was the legal dimension, solidifying the concept of PESTEL that we have today. Even though the acronym can vary in the literature, the main idea behind it remains the same: provide the underlying structure for macro external environment analysis. PESTEL is commonly used for business and marketing research, being particularly useful to structure data and information that enables the company to predict situations and circumstances that it might encounter in the future [6].

Throughout the years, PESTEL has been adapted into different fields and its use has been expanded, even reaching the renewable energy sector. When it comes to the marine energy sector, the ocean energy converters have not fully reached market viability and are mostly in the research & development (R&D) stage. Thus, we are still not fully aware of the potential obstacles that are expected in new environments where ocean energy research does not exist. For this reason, there have been studies in the marine renewable energy field that incorporate the structure of PESTEL to conduct resource and feasibility analysis. Examples include the analysis done by Sandberg et al. [7] in 2016 regarding critical factors for wave energy converters in off-grid luxury resorts and small utilities, as well as a study on risk identification for the tidal industry using PESTEL by Kolios and Read [8] in 2013. Both papers utilize the PESTEL approach, however, the topics of interest are specific parts of the marine energy industry, and the outputs also differ. Sandberg et al. focused on the scenario of luxury resorts and small utilities and how viable wave energy would be; by contrast, Kolios and Read chose to focus on a literature review and a case study-oriented approach on the risks for the tidal industry.

1.2. SWOT and the PESTEL-SWOT Approaches

SWOT Analysis is a simple but powerful tool for sizing up an organization's resource capabilities and deficiencies, its market opportunities, and the external threats to its future [9]. It is a strategic planning framework that stands for strengths, weaknesses, opportunities, and threats. Strengths and weaknesses are internal factors and attributes of the organization, while opportunities and threats are external factors and attributes of the environment [10]. Heinz Weihrich [11] first introduced the concept of a matrix that identifies threats, opportunities, weaknesses, and strengths, naming it the TOWS matrix. Even though the matrix name varies in the literature, SWOT is a very well-known strategic and flexible framework that identifies key issues affecting business. Its adaption to different fields has been broadened, and it is possible to find studies applying SWOT to healthcare, agriculture, and tourism, among others. Within the marine energy field, Stingheru et al. [12] conducted a SWOT analysis of the European marine energy sector; this study highlighted positive and negative influences of harnessing marine energy at a European level to promote marine renewable energy.

It is also possible to combine PESTEL and SWOT to create a matrix that finds the strengths, weaknesses, opportunities, and threats by going through the external factors associated with PESTEL elements. Since the SWOT itself is a general matrix, the structure provided by PESTEL is useful for finding relevant external factors. The combined analyses of PESTEL and SWOT have not been adapted to marine energy technologies, nevertheless, they have been used for other renewable energy studies in the past. Damasceno and Abreu [13] created a PESTEL-SWOT evaluation method for the wind energy sector that assessed the favorable conditions and challenges for the wind energy market to expand in Brazil. Moreover, there is a study from Shadman et al. [14] utilizing stakeholder engagement, PESTEL, and SWOT analysis to assess the role of renewable energy for energy security in Malaysia. Finally, Islam and Mamun [15] have researched the possibilities and challenges of implementing renewable energy in island countries by utilizing both the PESTEL and SWOT approaches; their study did not focus on any particular region or technology, instead providing a broad view on the strengths, weaknesses, opportunities, and threats for renewable energy in developing and developed nations.

1.3. Novelty and Objectives

Wave energy is approached in several disciplines with a focus on different project stages, creating clusters of information that are interconnected, yet seldom integrated into the literature. This study applies concepts of interdisciplinary research into wave energy in the context of Pacific Island countries, combining a diverse range of elements from the PESTEL dimensions into a framework. Inserting wave energy into a new location will not only have technological and economic repercussions but will also affect the local environment and society. An integrative framework enables us to represent the diversity of issues and delineate the important variables that can turn a project unfeasible or create fundamental dissents between decision makers and stakeholders.

The options for the economic development of the PICs are restricted by limited natural resources, remoteness, and small land size. Local communities rely on sustainable use of their local resources for subsistence and income, which makes coastal and marine resources paramount to the local economy, society, and culture. Marine energy development is highly susceptible to local acceptance in this region, thus, identifying conflicts of use through a general framework will be crucial. There are four main objectives behind this study:

1. Review the literature on wave energy harnessing and the Pacific Islands environment;
2. Identify the potential challenges and important factors for wave energy in the Pacific;
3. Structure the information found using the PESTEL approach by combining elements into the relevant clusters—the ICFPICs;
4. Create a SWOT matrix using the identified factors from the ICFPICs as external factors.

The outcomes include a cluster diagram that represents the ICFPICs, a decision tree for the process of utilizing the framework, and a SWOT diagram constructed based on the information gathered. Section 2 describes the materials and methods for this study, including the resources used to construct the ICFPICs and the methodologies applied. Section 3 presents the results, which incorporates the ICFPICs diagram, a user-friendly decision tree, and a combined SWOT-PESTEL matrix. Discussions and case studies for

Pacific Island countries can be found in Section 4, while conclusions are summarized in Section 5.

2. Materials and Methods

2.1. Materials

2.1.1. Wave Energy Guidelines

With regards to project development on wave energy, the main guideline is "Guidelines for Project Development in the Marine Energy Industry" by EMEC [3], which also includes important information regarding feasibility assessment. Additional supporting documents are: "Protocols for wave and tidal resource assessment" [16], and "Impacts upon marine energy stakeholders" [17] by EquiMar Project; "Wave Energy Technology Brief" [18], "Renewable Energy Technology Innovation Policy" [19], "A Path to Prosperity: Renewable Energy for Islands" [20], and "Renewable Energy Opportunities For Island Tourism" [21] by IRENA; "Documentary summary of the environmental impact of renewable marine energy" [22], and "Civil society involvement and social acceptability of marine energy projects" [23] by MERiFIC.

2.1.2. Pacific Island Countries Reports

All the reports used here came from the two main organizations in the Pacific, which are the Pacific Community (SPC) and the Secretariat of the Pacific Regional Environment Programme(SPREP). These included: SPREP Annual Report [24], Status and Trends of Coral Reefs of the Pacific [25], Pacific Regional Energy Assessment [26], Pacific Marine Climate Change Report Card [27], and Pacific Community Results Reports [28]. Each document provided information on the current or latest status of the environmental, social, and economic sectors. They were the basis of understanding the local vulnerabilities and intricacies that should be considered during a project.

2.2. Methods

2.2.1. Integrated Conceptual Framework for the Pacific Island Countries

By studying the concepts behind wave energy harnessing and the Pacific environment, it was possible to construct an integrated conceptual framework for the Pacific Island countries (ICFPICs). The ICFPICs is integrative since it integrates knowledge and concepts from different fields and organize variables connected to a central idea; it is also a conceptual framework considering that all the information here gathered stems from literature reviews and methodological assumptions. After reviewing the available documents, guidelines, and reports, every item considered to be a potential challenge was categorized using the PESTEL approach and fit into a cluster diagram. Each PESTEL dimension was structured into separate clusters that revolved around a core concept, and where elements shared similar characteristics.

2.2.2. PESTEL-SWOT Combined Analysis

The ICFPICs provided an overview of the relevant elements for wave energy in the Pacific, which were be combined with the SWOT analysis to point towards the related internal and external factors. Each item from the ICFPICs was analyzed from the perspective of strengths, weaknesses, opportunities, and threats, resulting in a PESTEL-SWOT combined matrix. In this case, strengths and weaknesses were related to wave energy, representing the internal factors; opportunities and threats were external factors, being related to the macro-environmental variables that could justify or hinder a project. The resulting matrix shows the possible factors for each category and should be further adapted to individual case studies.

3. Results

Each division of the framework is explained below and further divided into important factors. Further information on each PESTEL element can be found in Appendix A, where the reasoning behind their connection to wave energy in the Pacific is explained.

The decision to invest in renewable energy, regardless of the source, is still connected to the political sphere of a country. This is particularly important for wave energy or marine technologies as a whole, considering their long lifecycle and higher investment rate of return. For the political sector, the main factors are political stability, renewable energy targets, and government support.

How affordable the energy is, the risks, and the benefits involved are all essential parts of the feasibility study of a wave energy project. The main concepts to be analyzed here are the cost of energy, the risks of the project, and the feed-in tariff. Therefore, for the economic sector, the main factors are economic stability, cost of energy, feed-in tariff, risk assessment, and access to funds.

Social aspects of an island nation are fairly complex; they are usually associated with the local environment and local economy making it an intricate task to classify which factors only belong to the social sphere. For instance, exploring natural resources, such as sand, can be for home construction or for export. For this study, social factors are all the activities that involve the local society, either to make profits or for subsistence purposes. For the social sector, the main factors are offshore mining, tourism, navigation, fishery, aquaculture, recreation sites, cultural and world heritage sites, and local acceptance.

The processes of building, maintaining, and connecting a WEC to the grid require additional infrastructure and resources. Bringing the device from the supplier to the potential site is a long process that relies on a port for logistic purposes, and also on specialists and qualified workers. In addition to that, if the main objective is to supply electricity to the main grid, suitable grid infrastructure is required to minimize installation costs. Therefore, for the technological sector, the main factors are electricity supply and demand, electricity grid, seaports, expertise, and logistics.

The island environment provides essential services to the local communities and therefore is a crucial element when analyzing the feasibility of any type of development. Wave energy converters are placed in the ocean, where there might be located important marine species or coral reefs. These devices might also be subjected to extreme weather scenarios and this factor will be accentuated if the WEC is situated in a hazard-prone area. For the environmental sector, the main factors are natural hazards, biodiversity, and coral reefs.

Lastly, there are mainly two forms of legal concerns regarding wave energy, which are related to the physical space and energy regulations. There are offshore zones that are either prohibited from being accessed or under protection, including areas being utilized as military bases, conservation areas, or the boundaries of the EEZ. Each country also has its own regulations when it comes to the generation of electricity and these should be accounted for. For the legal sector, the main factors are regulations, maritime zones, marine protected areas, military zones, and dependent territories.

3.1. Integrative Conceptual Framework for the PICs (ICFPICs)

Figure 2 shows an illustration of all the PESTEL components combined and each of their related factors. There is a total of 29 potential obstacles that were identified through the previous stages, and these are grouped by categories on the resulting visual representation. Each item should be further analyzed for a particular location by gathering relevant information and by mapping barriers when applicable.

To facilitate the process of utilizing the ICFPICs, a decision tree was created (Figure 3). The purpose is to assist the user in identifying potential challenges and determining which actions to take afterward. As an example, the tree starts with the ICFPICs item aquaculture, which is shown here as "Presence of aquaculture activities"; for this item, decision makers need to verify if it will present a challenge to the project and follow the necessary steps. In brief, for each challenge encountered the solutions will vary between five main options: changing the location of the site, conducting further analysis, consulting stakeholders, including additional costs to the project, and canceling or postponing the project. This is a generic tool that gives an overview of the process; however, it should be adapted to each case study and could potentially include additional steps or solutions.

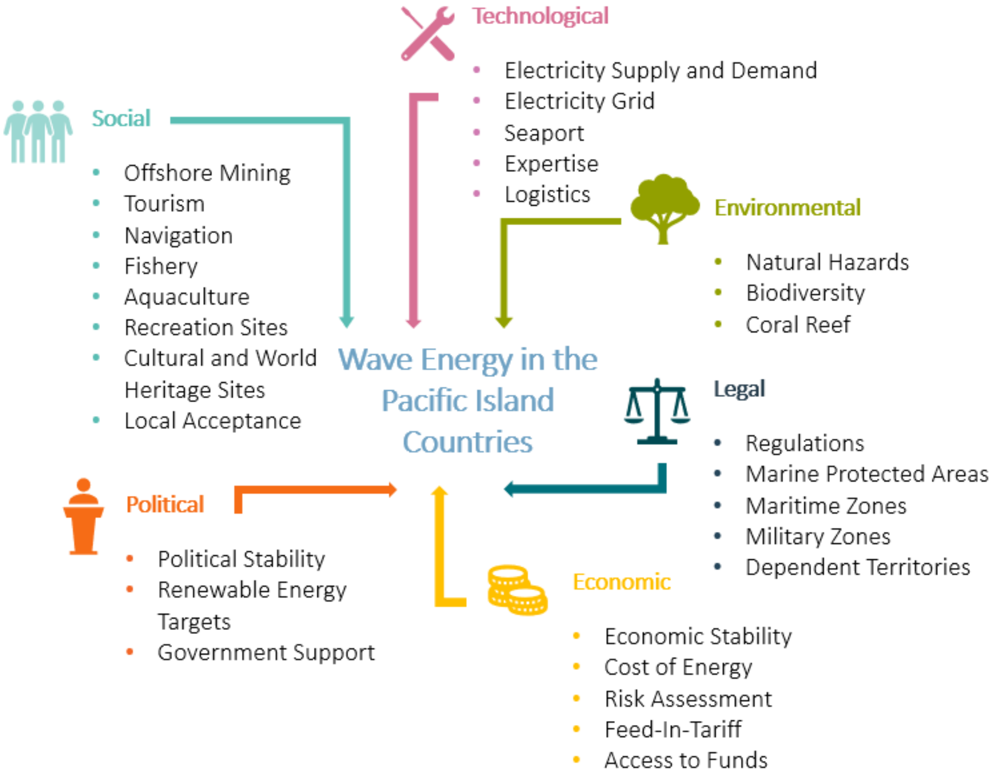

Figure 2. Integrative conceptual framework for harnessing wave energy in the PICs (ICFPICs).

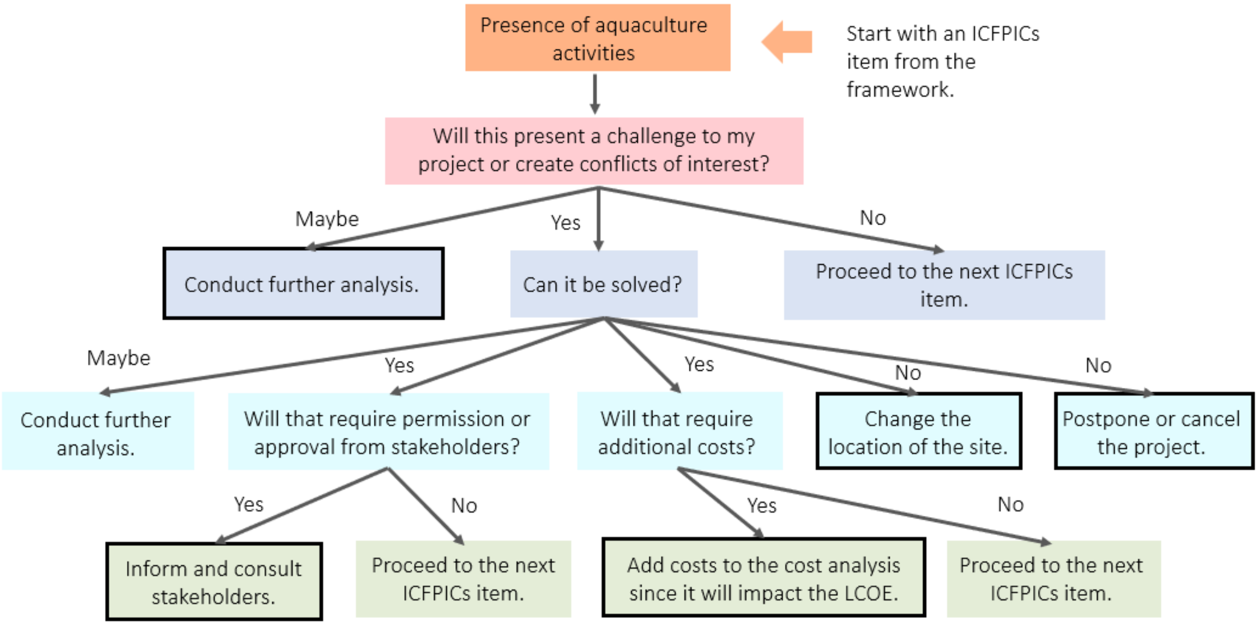

Figure 3. Decision tree exemplifying the process of utilizing the ICFPICs for a wave energy project in the Pacific environment; highlighted boxes are the main outcomes from the process.

3.2. The Combined PESTEL-SWOT Analysis

To demonstrate how PESTEL-SWOT analysis can be utilized, every item from the ICFPICs was studied as an external factor and fitted into a SWOT matrix (Table 1). Wave energy was surveyed in the context of the energy resource to be harnessed, and how it would contribute to the local society. The resulting matrix should be adapted to different case studies and provides a run-through of the feasibility of a wave energy project. Strengths and weaknesses are related to the process of installing, operating, and maintaining a wave energy converter device, which is mostly technological. Opportunities and threats are covered by the political, environmental, social, technological, economic, and legal categories.

Table 1. PESTEL-SWOT analysis combined; elements in the ICFPICs were used to create a SWOT matrix.

Strengths	**Weaknesses**
Alternative to importing fossil fuels. Robust structures that can survive harsh environments. Possibility of having a competitive cost of energy. Increases resilience through low-carbon development. Increases energy security by diversifying sources of energy. Island nations have ample ocean resources. High annual energy production that can cover energy demands of small islands. Several WEC devices are available to suit the local wave climate and geophysical conditions.	High discount rates. Uncertainty and risks are bound to the project. The wave energy sector is at the development stage. Significant distance from suppliers to the Pacific Island countries. Expertise is required to install, operate, and maintain the device. Lack of electricity grid in remote islands. A seaport is required to handle the equipment shipping.
Opportunities	**Threats**
Feed-in tariff scheme in practice. Local government support. Funding opportunities. Renewable energy targets. High wave energy resources distribution. Low seasonal, annual, and inter-annual variability. Multiple suitable locations for wave energy harnessing. Energy output can be used to power desalination plants. Job creation for different fields of expertise and training opportunities. Progress in the Sustainable Development Goals achievement through Goal 7.	Lack of regulation of wave energy. Marine protected areas, maritime zones, and military zones limiting the location of a WEC. Frequency of natural hazards such as hurricanes. Potential dangers to local biodiversity and coral reefs. Lack of sovereignty and additional bureaucracy. Political instability and economic instability. Presence of fishing, aquaculture, touristic, recreational, and offshore mining sites. Cultural and World Heritage sites with natural and cultural values. Lack of approval from the local communities.

4. Discussion

PICs face unique challenges and have distinct traits, such as narrow-based economies, limited natural resources, fragile ecosystems, reliance on subsistence activities, and remoteness from major markets. Thus, having a framework that encompasses regional characteristics is important when identifying challenges. The ICFPICs created here focused on wave energy on a regional level and is unique in the sense that such a concept has not been attempted yet.

There are different prospective applications for the ICFPICs; it can serve as a tool to identify potential challenges to a project, it can be used to identify key stakeholders, and lastly, it can be combined with the SWOT approach, giving an overview of both the barriers and opportunities for wave energy in the Pacific Island countries. The information gathered during the process of utilizing the framework is useful to create a SWOT matrix, which in turn will give an overview of the feasibility of a wave energy project by further categorizing the data into strengths, weaknesses, opportunities, and threats.

4.1. The ICFPICS Demonstrated for Four Case Studies

Four distinct Pacific Islands were selected to demonstrate how the ICFPICs can be utilized, and the potential challenges identified for every island are shown in Figures 4–7. The process included researching each item presented in the ICFPICs cluster diagram (Figure 2) and verifying if it was considered as a potential challenge. The analysis was based on country reports, regional reports, and official statements. Every item in Table 2 either posed a threat to a wave energy project on the island or could not be further verified; items that are not included were found to be non-threatening.

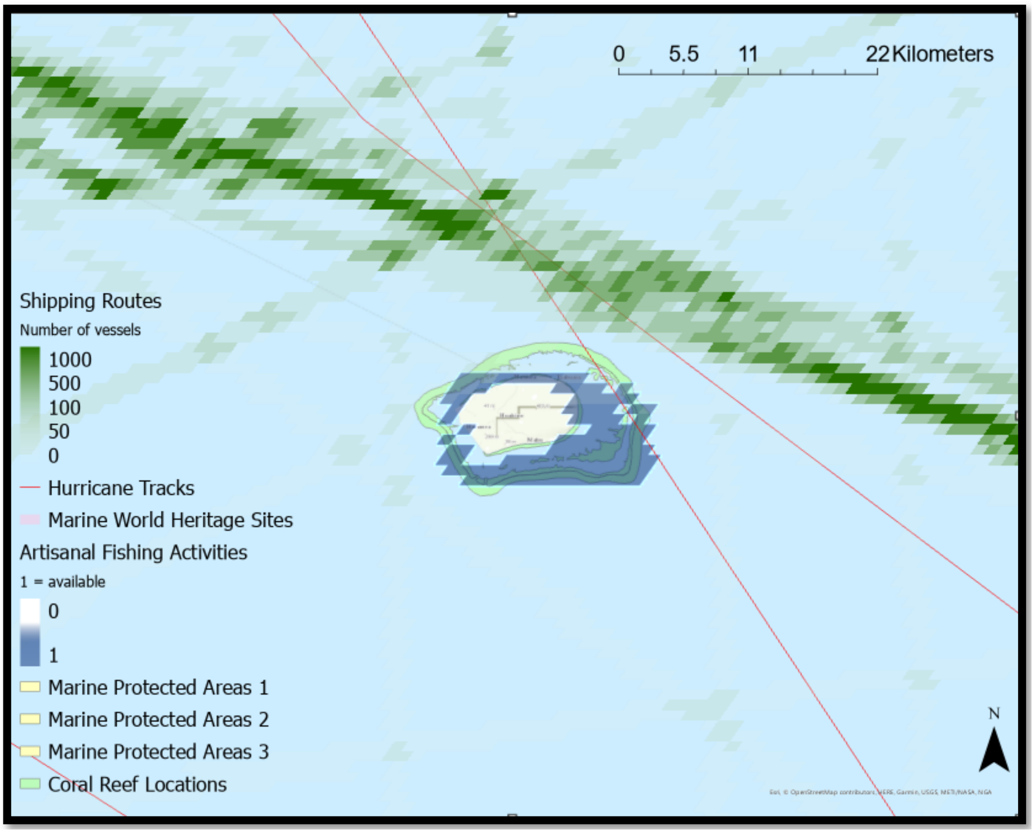

Figure 4. Map for Tubuai demonstrating challenges found through spatial analysis. The shipping routes are shown using a green color scale to represent the number of vessels that traveled through this area for one year (each raster has a 920 m^2 area). Artisanal fishing activities are present in the blue shaded areas. The remaining layers are colored separately, red for hurricane tracks, yellow for marine protected areas, light green for coral reefs, and pink for marine world heritage sites.

Tubuai is part of the Austral island group in French Polynesia, Viti Levu is the main island of Fiji, Rarotonga is the main island of the Cook Islands, and 'Eua is part of the Kingdom of Tonga. The analysis results demonstrate how each island has different characteristics and, consequently, different challenges. All four islands have established renewable energy targets, no signs of political instability, and no electricity grid available; however, since marine energy is relatively new, there is no information regarding government support. Cost of energy and risk are both unknown factors since resource assessment, risk assessment, and further analysis are needed. Additional common challenges were found to be the distance from the main markets, causing logistics issues, a lack of marine energy regulations, the presence of coral reefs, potential natural hazards, and a rich marine biodiversity environment. It is also important to note that access to funds and local acceptance will rely on the outputs from resource assessment and cost analysis, thereby being a potential barrier. The maps presented here were created using databases for protected areas [29], marine World Heritage Sites [30], coral reefs [31], hurricane tracks [32], and marine activities [33].

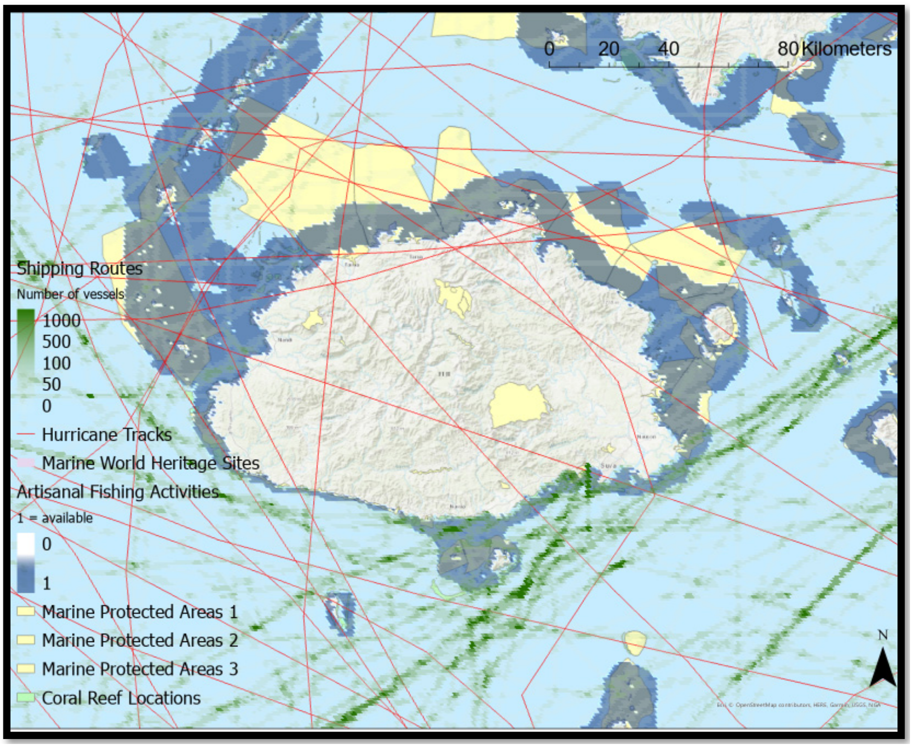

Figure 5. Map for Viti Levu demonstrating challenges found through spatial analysis. Color layers as per explained in Figure 4's caption.

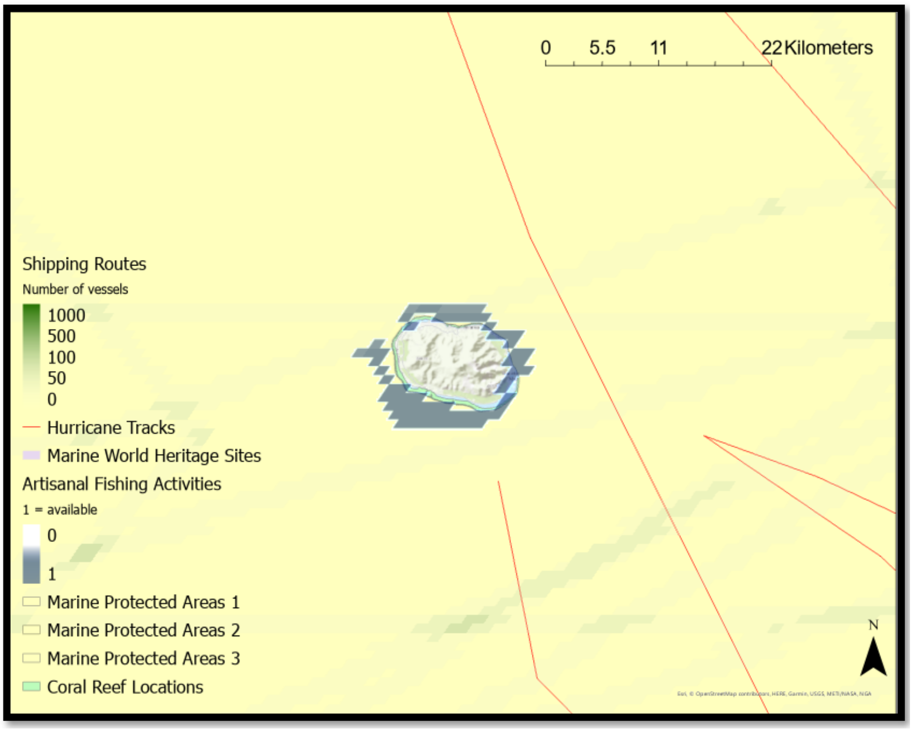

Figure 6. Map for Rarotonga demonstrating challenges found through spatial analysis. Color layers as per explained in Figure 4's caption.

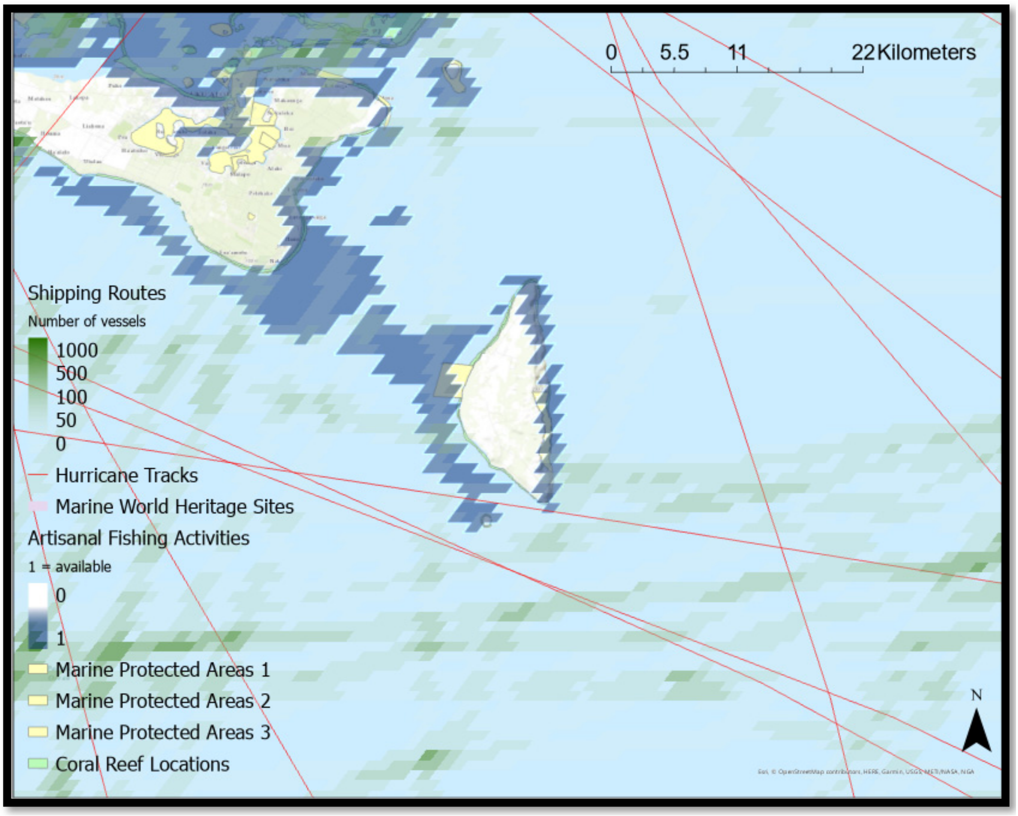

Figure 7. Map for 'Eua demonstrating challenges found through spatial analysis. Color layers as per explained in Figure 4's caption.

Tubuai is the most remote island among the selected sites, it is located in the south of French Polynesia with a population of approximately 2200 [34]. Due to the small population size, the energy demand is also low, and the technological aspects of wave energy might be a challenge. The Tubuai harbor has been expanded in 2014, yet, it has limited uses and might not accommodate large shipments. Even though there are touristic and recreational sites on the island, the influx of tourists is low; in 2013 it was recorded a total of 1899 visitors [34] for all Austral islands combined. The Historical Hurricane Tracks by the National Oceanic and Atmospheric Administration shows that there have been 11 storms in a 100 km radius around the island since 1970; only three so far have been classified as hurricanes. Additional challenges are the fishing activities, a large coral reef area surrounding the island, a proposed Marine Reserve zone for the Austral islands [35], artisanal fishing activities nearshore, high influx of vessels to the North, and the fact that French Polynesia is a Dependent Territory.

Tubuai is part of the Austral Island group in French Polynesia, Viti Levu is the main island of Fiji, Rarotonga is the main island of the Cook Islands, and 'Eua is part of the Kingdom of Tonga. The results of the analysis demonstrate how each island has different characteristics and, consequently, different challenges. All four islands have established renewable energy targets, no signs of political instability, and no electricity grid available; however, since marine energy is relatively new, there is no information regarding government support. Cost of energy and risk are both unknown factors since resource assessment, risk assessment, and further analysis are needed. Additional common challenges were found to be the distance from the main markets, causing logistics issues, a lack of marine energy regulations, the presence of coral reefs, potential natural hazards, and a rich marine biodiversity environment. It is also important to note that access to funds and local acceptance relies on the outputs from resource assessment and cost analysis, thereby being a potential barrier. The maps presented here were created using databases for protected areas [29], marine World Heritage Sites [30], coral reefs [31], hurricane tracks [32], and marine activities [33].

Table 2. Identified challenges for each island based on the ICFPICs.

	Tubuai (French Polynesia)	Viti Levu (Fiji)	Rarotonga (Cook Islands)	'Eua (Tonga)
Political	government support	government support	government support	government support
Economic	cost of energy risk assessment access to funds	cost of energy risk assessment access to funds	cost of energy risk assessment access to funds economic stability feed-in tariff	cost of energy risk assessment access to funds
Social	tourism fishery recreational sites local acceptance	tourism fishery recreational sites local acceptance offshore mining navigation aquaculture cultural and World Heritage Sites	tourism fishery recreational sites local acceptance offshore mining navigation aquaculture	tourism fishery recreational sites local acceptance
Technological	logistics expertise electricity supply and demand seaport electricity grid	logistics	logistics expertise	logistics expertise electricity supply and demand
Environmental	natural hazards biodiversity coral reef	natural hazards biodiversity coral reef	natural hazards biodiversity coral reef	natural hazards biodiversity coral reef
Legal	regulations maritime zones dependent territories	regulations marine protected areas military zones	regulations marine protected areas	regulations marine protected areas

Tubuai is the most remote island among the selected sites; it is located in the south of French Polynesia with a population of approximately 2200 [34]. Due to the small population size, the energy demand is also low, and the technological aspects of wave energy might be a challenge. The Tubuai harbor was expanded in 2014, yet it has limited uses and might not accommodate large shipments. Even though there are touristic and recreational sites on the island, the influx of tourists is low; in 2013 a total of 1899 visitors were recorded [34] for all Austral Islands combined. The Historical Hurricane Tracks by the National Oceanic and Atmospheric Administration shows that there have been 11 storms in a 100 km radius around the island since 1970; only three so far have been classified as hurricanes. Additional challenges are the fishing activities, a large coral reef area surrounding the island, a proposed marine reserve zone for the Austral Islands [35], artisanal fishing activities nearshore, a high influx of vessels to the North, and the fact that French Polynesia is a dependent territory.

Viti Levu is the largest island in Fiji and, therefore, an important place for social and economic activities. As of 2017, all eight provinces of Viti Levu combined (Ba, Ra, Nadroga-Navosa, Naitasiri, Tailevu, Namosi, Rewa, and Serua) accounted for 662,205 inhabitants [36]. In addition to the tourism and fishing industries, there is a possibility of aquaculture and deep-sea mining activities. Due to its development and high population status, Viti Levu has seaports, an electricity grid, high demand, and expertise available. Nevertheless, Fiji's geographical location makes it susceptible to environmental hazards; cyclones are a common occurrence, and there have been 45 storms in a 100 km radius around the island since 1956, including two category 5 hurricanes. Further challenges include the presence of a cultural World Heritage Site named Levuka Historical Port Town [37], a significant coral reef zone, several active shipping routes surrounding the island, and several marine protected areas. Additionally, the presence of the Fijian Navy and the location of its fleet should be considered for any offshore development. Despite the technological and economic advantages, Viti Levu is bound by environmental, legal, and social challenges.

Even though Rarotonga is the main island of the Cook Islands group, it has a small population size of approximately 10,572, according to the Cook Islands Demographic Profile 2006–2011 [38]. The economic stability is undefined, as are any feed-in tariff schemes or government programs to subside renewable energy. For the social aspect, there are potential sites for deep-sea mining in the exclusive economic zone, fishing activities, touristic attractions, recreational sites, nearshore corals, and navigation routes in the west, east, and south. Unlike Viti Levu, Rarotonga is not at the risk of intense hurricane events; nevertheless, there have been 21 storms tracked in a 100 km radius that should be considered, even though they were mostly tropical storms. Lastly, the Cook Islands are dedicating their entire exclusive economic zone, Marae Moana, an area of 1.9 million square kilometers (550,000 square nautical miles) to protection, conservation, and integrated management [39], which might lead to conflicts with the legal, environmental, and social sectors.

The last site, 'Eua, stood out among the selected islands due to having fewer potential challenges. 'Eua has small tourism, fishery, and maritime sectors; it also has a well-maintained electricity grid, a seaport, and the possibility of a feed-in tariff scheme. When it comes to the electricity supply factor, the small population size of fewer than 5000 residents might become an issue. Thus, one of the key elements to bring wave energy to 'Eua is balancing the energy output around the local demand to justify costs. The ICFPICs also identified possible challenges related to the presence of protected areas on the island, the need for expertise, and annual hurricane occurrences. Since 1958, there have been 47 category 1 or above hurricanes, which also included 3 category 4 hurricane events. Lastly, artisanal fishing activities are present in the west and east of 'Eua, as well as a high influx of vessels towards the west and south of the island. However, there are viable sites nearshore in the south that could be explored, especially considering that higher wave energy resources are found within this area.

In these examples, each island presented different challenges in the economic, social, technological, environmental, and legal categories, demonstrating the diversity of the Pacific Island countries. For instance, it would be particularly difficult to bring wave energy to Tubuai due to technological and environmental constraints being prevalent. Nevertheless, larger islands such as Viti Levu and Rarotonga can still present challenges, such as environmental hazards and conflicts of use of the offshore area. If we consider the minimum distance to avoid the obstacles presented in Figures 4–7, 'Eua has the lowest at 0.1 km, Rarotonga has the highest at 378.35 km, while Tubuai and Viti Levu have, respectively, 2.17 km and 1.39 km minimum distance. This means that 'Eua could potentially have onshore, nearshore, and offshore wave energy converter devices, increasing the diversity of options.

4.2. Further Analysis of 'Eua Island

The ICFPICs was applied for an in-depth analysis of the island of 'Eua. Furthermore, data obtained from Tongan governmental agencies and local institutions were used for this analysis to increase representation reliability. Data related to the fisheries, biodiversity, and tourism sectors were taken from Ministry of Fisheries [40], Marine and Coastal Biodiversity Management in Pacific Island Countries (MACBIO) [41], and Ministry of Tourism [42] sources, respectively. Each category from the ICFPICs is further explained below.

Political: Tonga experienced serious rioting in the capital Nuku'alofa in 2006 but adopted a democratic constitution in 2010 and appears to have returned to its earlier pattern of long-term political stability [43]. In addition to that, Tonga has already committed to achieving 50% renewable energy generation by 2020 and 70% by 2030, which is a motivator for wave energy to be further studied.

Economic: The cost of energy and the qualitative and quantitative risks need to be assessed in order to analyze if economic factors will be an obstacle for wave energy. Nevertheless, the final results will also depend on how the cost range compares to the current energy sources and to the average costs in the world; the cost alone cannot convey enough information, which is why the cost and risk analysis are necessary steps to identify any potential concerns.

Social: There are no documented offshore mining and aquaculture activities or heritage sites for the island of ʻEua. There are, however, villages that date back thousands of years and have cultural value, including Ohonua, Tufuvai, Pangai, Houma and Haʻatua. The island has only one port, which is situated at ʻOhonua and connects ʻEua to the Tongatapu island, the main route of the local ferries. When it comes to fisheries, ʻEua does not have a significant export rate and according to the latest statistics [44], only 12% of the households practice fishing for consumption or for sale. Nevertheless, there are sites near ʻEua using fish aggregating devices that have been deployed to increase fish production. Lastly, because of the presence of humpback whales, ʻEua is a fairly touristic island, with touristic activities being mainly whale watching, cave diving, and snorkeling.

Technological: The electrification rate for the Kingdom of Tonga is high and close to 100%, which also includes ʻEua. The network in ʻEua was also rebuilt in 2017 and was able to withstand Cyclone Gita, according to the TPL Annual Report from 2018 [45]. Therefore, grid-related issues are not a main concern. They also have the ʻOhonua port that serves as a navigation route between islands and for cargo transportation, which can be used for WEC shipments and related services. When it comes to expertise, however, there might be a lack of qualified professionals to work on the installation and maintenance of a WEC, considering that offshore development is non-existent in ʻEua. This would require additional funds but would open job opportunities and motivate public acceptance.

Environmental: ʻEua is situated in an area where hurricanes are relatively common occurrences. The cyclone season in Tonga is from November to April, however, the peak time for tropical cyclones in Tonga is from January to March with most events occurring in February [46]. The presence of cyclones should be accounted for in risk quantification and the cyclone season should be avoided in installation and maintenance procedures. Biodiversity is also another potential issue, with the humpback whales pathing around Tonga once a year from July to October, including around ʻEua. Pelagic sharks are also present on this island and are protected by the Kingdom of Tonga National Plan of Action (NPOA) Shark Plan [47]. In regard to corals, ʻEua has low coral reef resources, which are limited to the shallow areas around the island.

Legal: There are few regulations for marine energy in Tonga considering the lack of projects in this field. There are, however, important policies related to renewable energy, including: Renewable Energy Act 2009, Electricity Act 2007, Environment Impact Assessment Act 2003, Spatial Planning and Management Act 2012, and Petroleum Act. There are no documented maritime zones for ʻEua and there is also no military base in this area, which should not pose any risk to the project in terms of conflicts of use. The EEZ of ʻEua is relatively large, and it is unlikely that any wave energy development would trespass this area. There are, however, two marine protected areas in the island: ʻEua National Park and Tufuvai.

To better understand the boundaries for wave energy on the island of ʻEua, a map was created to add important locations found through the ICFPICs. The factors that could be mapped are present at Figure 8, which includes locations for fishing spots, touristic and recreational spots, important villages, the ʻOhonua port, and the ferry route between Tongatapu and ʻEua. Areas where the presence of humpback whales and pelagic sharks have been observed were also added, as well as the coral reef sites. Since the ʻEuan population is mostly concentrated on the west coast, while a large part of the east coast is within the ʻEua National Park limits, the east coast was not considered for site selection.

Four sites representing the north, northwest, southwest and south were selected as potential WEC sites and are shown as "Analysis Points" on the map. The selection process included bathymetry analysis as well as proximity to the main populated districts. Table 3 provides an overview of the local wave climate and wave energy resource for each point, using annual climatology data from the CAWCR wave hindcast [48].

Table 3. Wave climate and wave energy parameters for each point.

	Point 1	**Point 2**	**Point 3**	**Point 4**
Mean Wave Height (m)	1.50	1.19	1.28	1.78
Mean Wave Period (s)	8.65	9.19	9.23	8.76
Mean Wave Energy Flux (kW/m)	10.94	11.02	12.96	19.66
Inter-Annual Variability (%)	7.75	9.52	9.13	5.87
Seasonal Variability (%)	14.67	29.99	30.89	24.77

Points 1 and 2 have the most constraints, being surrounded by fishing areas, beaches, and pelagic sharks. Furthermore, point 2 also has the port nearby, being in close proximity to the ferry route. The only obstacle identified for points 3 and 4 is the possible presence of pelagic sharks, which makes these sites the most suitable for wave energy harnessing in terms of feasibility factors. Presence of coral reefs should only be a concern for shallow areas nearshore, until approximately 5 m depth in most parts. Nonetheless, there is also the distance from grid-connected areas factor to be considered; point 4 is the furthest from any residential area and, therefore, requires longer transmission lines. When it comes to the physical resource, point 4 has the highest mean wave energy flux and the lowest inter-annual variability, being a strong candidate for a WEC, followed by point 3. Seasonal variability seems to be an issue for the most of 'Eua, including points 2–4.

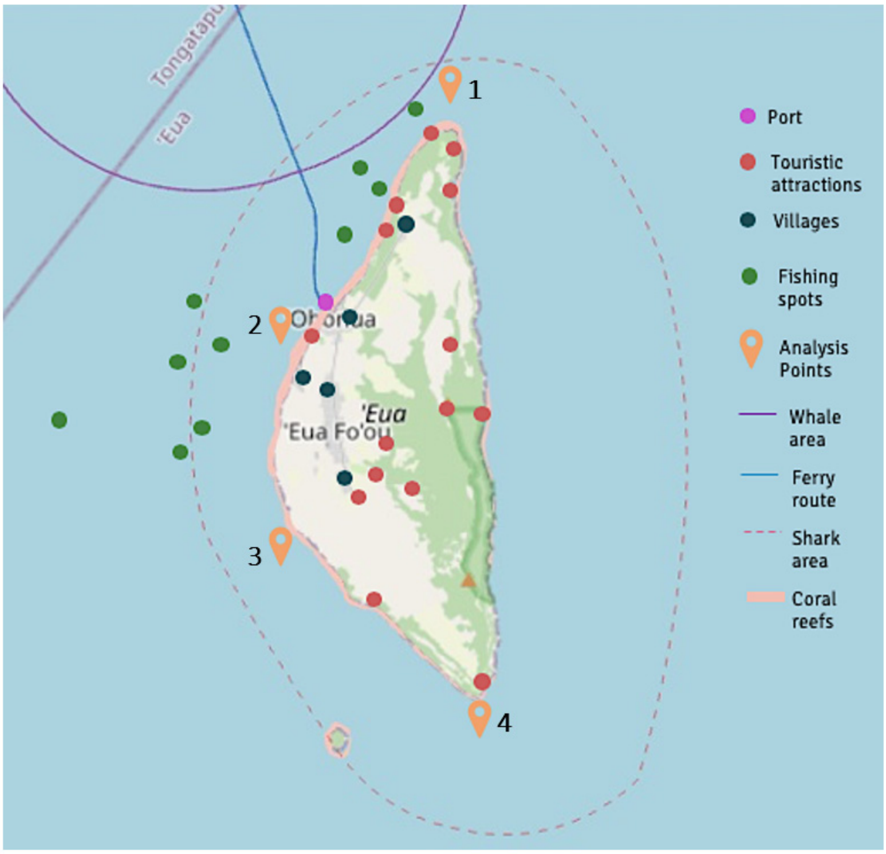

Figure 8. Map of 'Eua containing important sites and possible constraints. The map graphically presents the result of the PESTEL analysis and the potential sites for a WEC.

5. Conclusions

The Pacific region has already been shown to be promising in terms of wave energy resources even while the external factors remain unknown. This study proposed a framework that has an essential role in identifying scenarios where wave energy is considered feasible, making it a useful tool for project developers and decision makers. Figure 9 summarizes the functions of the ICFPICs and how it relates to its final goal. The framework allows the user to identify potential challenges and external factors through the ICFPICs elements, facilitating the process of defining suitable sites based on the results found before committing resources for site-specific feasibility studies and technical assessments.

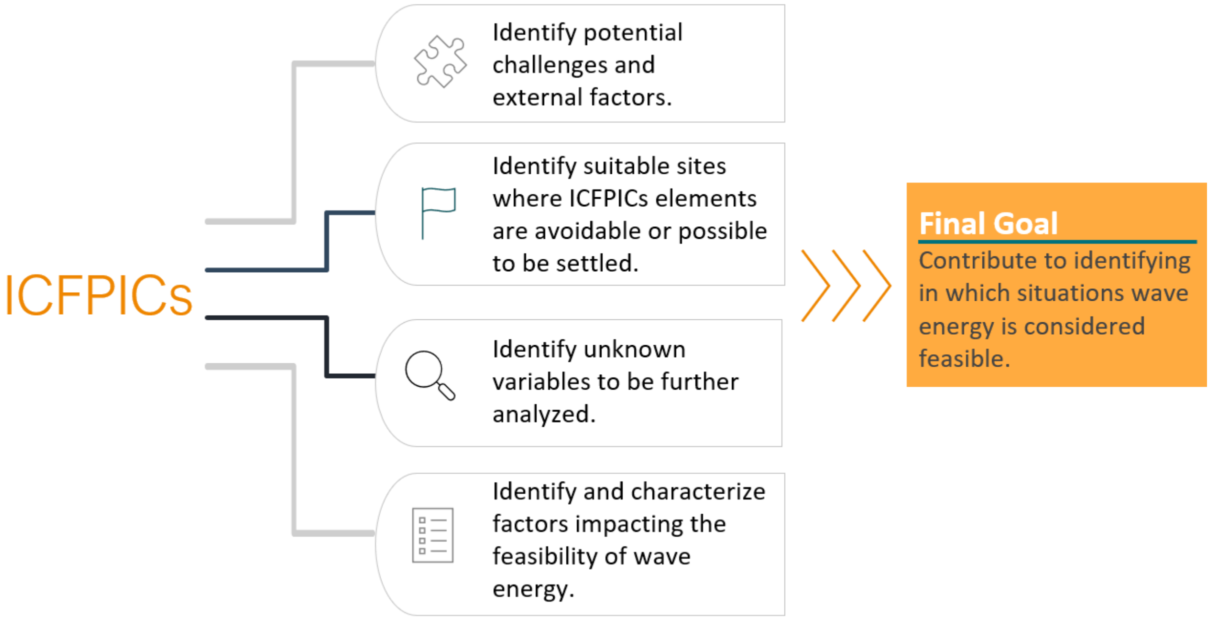

Figure 9. Diagram summarizing the functions of the ICFPICs.

It is recommended to conduct resource and cost analysis alongside the ICFPICs to assess the overall feasibility of a project. While the framework created here is useful for early assessments to provide a general overview of relevant factors, it should not replace further project stages such as environmental impact assessment, for instance. Given that the ICFPICs is flexible in its use and can tackle different issues, the user is also encouraged to adapt it to new locations and different marine energy technologies, such as tidal, current, and ocean thermal energy.

The four study cases presented earlier exemplified how the ICFPICs can find suitable locations and compare different scenarios for wave energy. All four islands are located in areas with high wave energy resources, nevertheless, several issues that could deem wave energy unfeasible were found. As a future step, there is value in ‘Eua for wave energy harnessing, considering its favorable conditions found through a first assessment. Following this study, resource assessment, risk assessment, and cost analysis studies are suggested for ‘Eua.

Possible obstacles found for wave energy in ‘Eua are related to the local biodiversity, tourism, natural hazards, cost of energy, and economic risk. According to preliminary results, the coastal areas near Ha’atu’a (point 3) and Li ’Anga Huo ’A Maui (point 4) are recommended as potential WEC sites. Moreover, the levelized cost of energy (LCOE) should be quantified considering the risks of unplanned maintenance due to natural hazards, overhaul, wave climate variability, and uncertain shipping costs for the WEC infrastructure. The cost analysis also needs to include possible variability for the costs of a singular WEC device, as well as conversion rates and discount rates. Even though further quantitate analysis is necessary, with the ICFPICs it was possible to identify feasible scenarios for wave energy in different areas of ‘Eua, as well as to characterize potential obstacles.

Author Contributions: Conceptualization, J.B.P.; funding acquisition, T.W.; methodology, J.B.P.; supervision, T.W.; writing—original draft, J.B.P.; writing—review & editing, T.W. All authors have read and agreed to the published version of the manuscript.

Funding: A part of this study was funded through the Science and Technology Research Partnership for Sustainable Development (SATREPS) program between Japan and Malaysia, titled "Development of Advanced Hybrid Ocean Thermal Energy Conversion (OTEC) Technology for Low Carbon Society and Sustainable Energy System: First Experimental OTEC Plant of Malaysia".

Data Availability Statement: Publicly available datasets were analyzed in this study. CAWCR Wave Hindcast can be found here: https://doi.org/10.4225/08/523168703DCC5 (accessed on 30 December 2021). The World Database on Protected Areas can be found here: https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA (accessed on 14 December 2021). The World Marine Heritage Sites can be found here: https://www.marineregions.org/ (accessed on 13 December 2021). The Global distribution of warm-water coral reefs can be found here: https://doi.org/10.34892/t2wk-5t34 (accessed on 15 March 2022). The NOAA's International Best Track Archive for Climate Stewardship can be found here: https://www.ncei.noaa.gov/products/international-best-track-archive?name=ib-v4-access (accessed on 25 January 2022). Marine Activities data can be found here: https://knb.ecoinformatics.org/view/doi:10.5063/F1S180FS (accessed on 14 December 2021).

Acknowledgments: The authors would like to acknowledge SATREPS and its members, as well as The University of Tokyo and our research group "Applied Physical Oceanography" for their support during this study. Lastly, we would like to acknowledge the Kingdom of Tonga for recognizing this study and providing a research permit.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1. Potential Challenges

Appendix A.1.1. Political

Political Stability: Strong institutions and political leadership with the capacity to plan and manage policies and investments that support climate smart development are an essential building block of low carbon, climate resilient societies [49]. Therefore, the political stability of a country becomes an important variable when looking into wave energy for the Pacific Islands.

Renewable Energy Targets: Nations that have already established renewable energy targets are more likely to invest in wave energy technologies. Since most of the PICs have already committed to transitioning to renewable energy, this factor is going to serve as a motivation for wave energy to be utilized. However, wave energy has higher costs when compared to more traditional technologies and the absence of renewable energy targets might hamper a project.

Government Support: Wave energy currently needs government support for research and development (R&D) to compete with more mature technologies, such as wind and solar. However, this factor is also important for countries that have the potential for wave energy, since having support from the local government can facilitate the project. A cooperative agreement between government and developers will enable information sharing, which is essential to the pre-feasibility and feasibility stages where technical information is needed on a local scale. Having government approval is mandatory, nevertheless, different levels of support will either ease the process of project development or create additional hindrances.

Appendix A.1.2. Economic

Economic Stability: The economic stability of a country has a direct impact on the cost of energy, which is an important metric to analyze the viability of wave energy. Unstable economies can lead to high and unpredictable inflation, depreciation of the currency, lower investment opportunities, and low economic growth. The two main outcomes that can affect the viability of wave energy are the high exchange rates and unstable markets. Technology suppliers are outside the Pacific Island countries territory; therefore, the long-term wave energy project will be conducted using foreign currencies that might change in the future, altering projections. Furthermore, if there is negative economic growth, investors might refuse to start a project; given that the life cycle of a device is 25 years on average, any market uncertainties will reduce investor confidence and long-term stability is favorable.

Cost of Energy: This is the total costs for the generation of energy during the lifecycle of a device, including the capital, operation, maintenance, and decommissioning expenditures. Cost of energy (CoE) is one of the main indices to assess the economic feasibility of a project; another important index is the levelized cost of energy (LCOE), which can be calculated assuming different discount rates to levelize the costs for present value. Economic indices show how the costs for wave energy can compare to different sources of energy, including diesel generation, which is the main source for the PICs. If the costs are high, it will be more difficult to justify a wave energy project. Furthermore, there are factors within the CoE that should be included in the analysis, such as the distance to the shore, distance from the source point to the electricity grid, and water depth. Each one of the aforementioned factors can significantly increase the initial costs and is crucial when choosing a wave energy converter device. Additional important variables would be the discount rate and the conversion rate—considering that wave energy is still under development discount rates are expected to be high, moreover, the PICs will be importing the device, and conversion rates can fluctuate and generate a loss.

Feed-In Tariff: A FIT is a governmental incentive that ensures a premium fixed price for energy generated to the grid, making calculations of viability more predictable [7]. The FIT can make a project more appealing to investors and end-users by reducing price volatility and creating more opportunities for the renewable energy sector. On the same note, a lack of FIT schemes can hinder the chances of receiving funds and outside investment.

Risk Assessment: Any long-term investment will be bound to have risks related to different stages of the project. Risk assessment provides an understanding of risks, their causes, consequences, and their probabilities [50]. For wave energy projects, the risk is an important factor since it will influence economic parameters, such as Cost of energy (CoE) and levelized cost of energy (LCOE). Risks can take different forms, such as political and regulatory risk; counterparty, grid, and transmission link risk; currency, liquidity, and refinancing risk; as well as resource risk [51]. A qualitative and quantitative risk assessment should be performed to understand the source of the risks as well as their impact on the economic viability of the project.

Access to Funds: Ocean energy technologies demand high long-term investments, which are mostly due to the equipment costs, installation process, and discount rates. The Pacific Islands have a specific environment that creates drivers for ocean energy, such as high diesel costs and high ocean resources. Nevertheless, the high capital costs associated with these technologies preclude these island nations from constructing ocean energy facilities; financial and technical assistance must come from developed nations [52]. Access to funds is an important factor to justify a project, and lack thereof could impede or postpone the process significantly.

Appendix A.1.3. Social

Offshore Mining: According to Inniss et al. [53], “Marine mining has occurred for many years, with most commercial ventures focusing on aggregates, diamonds, tin, magnesium, salt, sulfur, gold, and heavy minerals. Activities have generally been confined to the shallow nearshore (less than 50 m water depth), but the industry is evolving and mining in deeper water looks set to proceed, with phosphate, massive sulfide deposits, manganese nodules, and cobalt-rich crusts regarded as potential future prospects”. Pacific Island countries (PICs) are heavily dependent on natural resources and likely to remain so for the near future, making resource management an issue of critical importance for economic development [54]. Any project development must consider the presence of natural resources offshore and verify if there are any ocean policies regarding the use of these sites.

Tourism: Tourism represents a key driver of global economic growth and is a crucial component of the effort to alleviate poverty and achieve the other development objectives in many developing countries [21]. In the Pacific, tourism is a key sector of the local economy and is one of the main contributors to the gross domestic product. Tourism sector development offers Pacific Island countries a path to economic security that dovetails with broader development goals around infrastructure and employment [55]. For this reason, wave energy should not interfere with the tourism industry of any potential site and should seek the approval of possible stakeholders. Areas that are being used for diving, snorkeling, swimming, or that have any touristic purposes, ought to be mapped and circumvented.

Navigation: Islands are more reliant on marine transportation for commercial and non-commercial shipping due to lack of resources, dependence on international trade, and remoteness factors. There is the possibility of utilizing a WEC in the port structure since the port is an ideal location for a wave energy converter based on the overtopping principle as it can be easily integrated into the mound ruble without compromising the success of the project [56]. Nevertheless, if the WEC being studied will not be used as such, the proposed development should account for effects on navigation channels and seek to not interfere with main shipping routes.

Fishery: Fishery is one of the most crucial sectors of several islands inside the Pacific, considering its importance to the local economy and the subsistence of the local communities. Much of the region's nutrition, welfare, culture, employment, and recreation is based on the living resources in the zone between the shoreline and the outer reefs. The continuation of current lifestyles, the opportunities for future development, and food security are all highly dependent on coastal fisheries resources [57]. Considering the key role of the fishery sector, it will be imperative to map fishing areas and choose a site that does not coincide with this activity.

Aquaculture: According to Adams et al. [58], "Profitable aquaculture of penaeid shrimps and blacklip pearl oysters has now been established in some areas of the Pacific by commercial interests. Stand-alone enterprises producing penaeid shrimps for export markets are firmly established in New Caledonia, Fiji, and the Solomon Islands". The aquaculture sector in these countries is significant to their economy, nevertheless, there are still other examples of aquaculture activities being developed at different PICs which should also be accounted for. When choosing a suitable site for wave energy it is important to identify any aquaculture farms to avoid conflicts of use.

Recreation Sites: Recreation sites include the presence of beach areas or sites that are being used for sports, leisure, and additional activities that do not suit the previous factors. These can be used by both locals and tourists and could further be categorized as tourism; nevertheless, considering that several Pacific Islands do not have a high flux of tourists this will be then defined as a category of its own and will serve to identify important recreation sites.

Cultural and World Heritage Sites: Mixed cultural and natural World Heritage sites have both outstanding natural and cultural values and so are included on the World Heritage List according to a combination of cultural and natural heritage criteria [59]. These sites require tourism management and have regulations regarding the types of activities that are allowed, which means that using heritage sites for energy purposes or interfering with its lands is unviable. It is also important to note that aside from UNESCO Heritage Sites, any area with cultural value will create obstacles for project development.

Local Acceptance: People tend to accept renewable energy due to environmental issues (reduction of pollution by producing clean energy), but questions arise about environmental impacts, mainly those related to marine mammals, landscape/seascape changes, and noise [60]. It is important to consult key stakeholders, including members of the community, to share the benefits and potential impacts of the project and allow them to voice their opinions. A consensus between the local population and decision-makers can be achieved through stakeholder engagement plans to avoid any future conflicts of interest.

Appendix A.1.4. Technological

Electricity Supply and Demand: Each wave energy converter is capable of supplying a limited annual energy output; the actual output will vary depending on the local climate characteristics and if it is a singular device or an array of devices. To compensate for the high initial costs, it is common to establish a wave energy farm with high energy outputs. Nevertheless, Pacific Island countries encompass thousands of islands with varying population sizes, including remote islands with less than 1000 inhabitants. For a wave energy project to be viable, the chosen device needs to account for the relationship between energy output and energy demand, whilst keeping the costs competitive. For this reason, islands with higher population densities are more suitable locations.

Electricity Grid: Since islands with small-scale grid systems are more affected by fluctuations in renewable energy power supply than other areas connected to larger-scale grids, grid stability is a particularly important issue when increasing the renewable energy penetration rate in these areas [20]. Nevertheless, several islands still lack the basic infrastructure for grid connection and there are communities that are not yet connected to the grid. For this reason, not only is the stability of a grid an important aspect when studying the possibility of bringing wave energy to a site, but the presence of grid infrastructure is also crucial. The building of or improvement of an electricity grid will add costs to the installation process and can be detrimental to the feasibility of a project.

Seaports: Ports have an essential role in maritime logistic chains as they are the places where the cargoes are handled [57]. They also play an important role when it comes to wave energy since WECs are relatively large structures and might need several weeks for transportation and large-scale vessels. The process of receiving materials and supplies for a WEC will therefore require a port for operation; in case there is no infrastructure available, additional investment costs might be required.

Expertise: Even though having expertise available is preferred, the offshore industry in the Pacific is not yet developed and it is most likely that training programs will be necessary to conduct and maintain a wave energy project. The expertise factor is relatively complex, and even though the lack of expertise creates extra initial costs, it also benefits the local economy by creating job opportunities. Therefore, costs will increase but the chances of achieving public acceptance will be higher.

Logistics: Wave energy technologies are currently being developed in a limited number of countries, which might create supply-related drawbacks. Dedicated suppliers are not yet abundant due to the relatively small scale of the industry but suppliers in related applications may have the capacity to modify their existing products/services to supply the marine energy sector [61]. Due to the remoteness factor of Pacific Island countries, there will likely be additional costs in the process of importing, installing, and maintaining a wave energy converter device; the need for special vessels that will travel long distances will increase the initial, maintenance, and operation costs.

Appendix A.1.5. Environmental

Natural Hazards: Even though there is a lack of studies on the relationship between natural hazards and wave energy, it is well-known that storms can cause extreme wave events which might have an adverse impact on offshore structures. During storms and other extreme events, the stresses induced on the foundations, moorings, pylons, and sub-structures, etc., can exceed the design stress-causing failure of the device [62]. It is important to identify hazard-prone areas as well as the type and frequency of natural hazards to have a better understanding of risks. If a site has frequent storms this might add to unplanned maintenance costs and therefore may increase the overall costs of a project. For this factor, important variables include the number of past disaster events, frequency of natural hazards, as well as their intensity and proximity to the island. In the case of hurricanes, for instance, it is necessary to analyze the hurricane tracks, hurricane categories, frequency of events, wind speed, distance from the center of the storm to the island, and the number of events that caused damages and turned into disasters.

Biodiversity: Marine biodiversity plays an important role in the livelihood of the local population as well as in the environmental cycle. It is at present not clear what the scaling-up from the limited observations on individual or small clusters of devices to commercial-scale arrays will mean in terms of environmental effects and whether or not the effects observed to date are directly applicable [63]. Thus, since the effects on the local environment are still uncertain, areas that are rich in biodiversity should be avoided for wave energy projects to minimize the chance of negative impacts. It is also important to identify local protected species, endangered species, and key species during this stage to avoid incorporating areas of their natural habitat. This information will be used for early assessments: however, an EIA study will be required for further analysis and for identifying interactions between a WEC and the local environment.

Coral Reef: According to Moritz et al. [25], "The tropical Pacific region holds approximately 25% (about 66,000 km^2) of the global coral reef area. Spread across such a large area, these reefs vary considerably in terms of proximity to continents, reef structure, and biodiversity, as well as frequency and intensity of natural disturbances". Thus, the PICs hold a significant percentage of the global coral reef resources, which are also extremely valuable for the local environments and provide essential services. As to prevent any possible harmful interaction with the corals, a wave energy project should avoid utilizing areas with such environments for potential sites.

Appendix A.1.6. Legal

Regulations: Even though countries are expected to have regulations concerning the energy sector, the lack of specific regulations for marine energy might bring additional barriers or bureaucratic procedures. Since marine energy is not yet consolidated in the Pacific, there will be a high chance of encountering a lack of regulations for this market, and consultations with local government will be necessary to establish boundaries and define associated fees.

Marine Protected Areas: A marine protected area (MPA) is an area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, and historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment [64]. There are different levels of protection, which result in different regulations regarding marine activities. Usually, marine exploration is prohibited in MPAs, while tourism and shipping activities might be limited. It is advisable to keep renewable energy generation outside the MPA boundaries to avoid any impact during the construction, operation, and decommissioning stages.

Maritime Zones: According to Goodall [65], "maritime zones are areas of ocean or sea which are or will be subject to national or international authority. They are delimited as parts of the seabed, water column and sea surface, the subdivision being on the grounds of political jurisdiction relating to the use and ownership of marine resources". These areas can include resource exploration, protected areas for marine species, disputed territories, and the exclusive economic zone (EEZ) boundary. To avoid any project constraints, maritime zones should be avoided and the WEC should remain inside the EEZ.

Military Zones: The Pacific Islands are strategically positioned between Eastern Asia and North America, which has sparked interest from different nations through the last decades. Due to their importance in terms of geographical position, it is possible to find military zones in the Pacific or agreements for future bases. For instance, The United States of America has air and naval bases in Guam and an intercontinental ballistic missile test site in Kwajalein Atoll in the Marshall Islands, which also supports space surveillance activities [66]. Utilizing these areas might either be prohibited or require an agreement between developers, local government, and responding authorities for the military zone.

Dependent Territories: There are still several Pacific Island Territories whose government does not hold full sovereignty and any developments on those areas will need to respond to different legislations. Those territories can be associated with the United States of America, France, Australia, the United Kingdom, and New Zealand; their levels of sovereignty might differ as well as their federal relationships. Bringing wave energy to these areas will require public acceptance from the local communities as well as from different governments, which might create additional difficulties.

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