White Paper

WAVE ENERGY TECHNOLOGIES FOR CHILE

Critical Analysis

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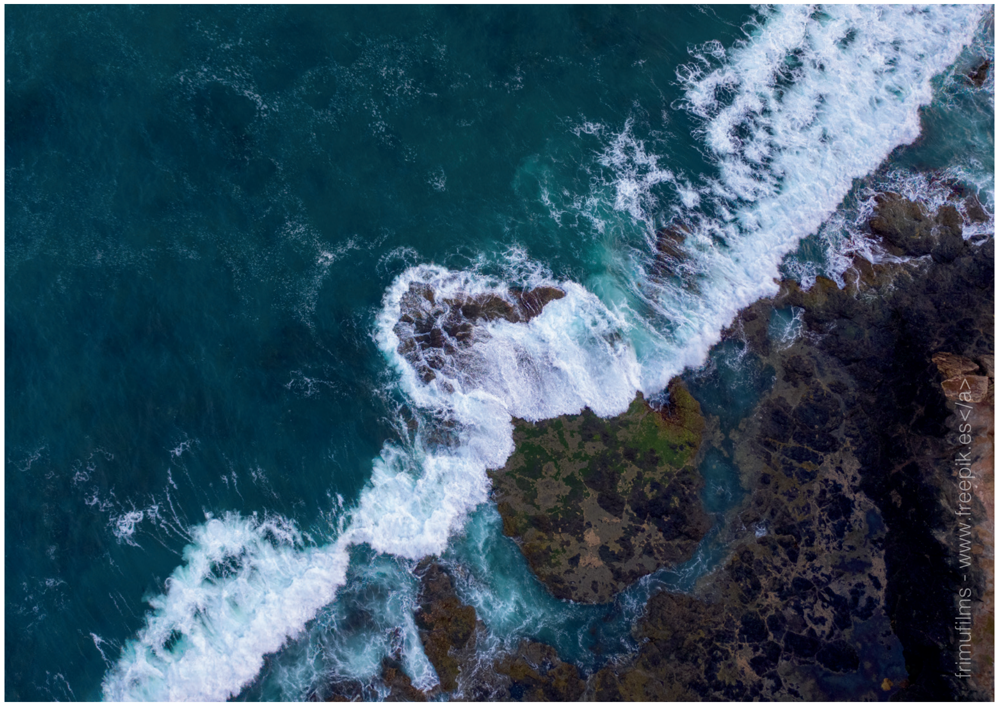
01. Introduction



Wave energy is a renewable energy source with great potential worldwide, with an estimated potential of 2985 GW considering only the coasts [1]. In Chile, a potential of up to 240 GW [2] is estimated, with a power density greater than 30 kW/m from latitude 27°S to the south. The current development of wave energy devices is at an early stage, due to multiple aspects such as its high costs at different phases of the projects and uncertainties about the performance of technologies. Currently, the levelized cost of energy (LCoE) is over 450 US$/MW and is expected to be between 100 and 200 US$/MWh by 2030 [3].

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Considering that most wave energy technologies are still under development and demonstration phases, the contribution of wave energy to the global energy matrix remains low.

One of the main challenges for the coming years is to reduce costs and improve reliability and performance of systems [4], in order to ensure commercially competitive energy costs. Among the main cost items, capital costs (CAPEX) and operating costs (OPEX) are distinguished, as shown in Fig. 1. The LCoE study prepared by MERIC and Fundación Chile in 2018 [5] presents the distribution of capital costs for a marine renewable energy project in Chile (Fig. 2).

The estimated cost of wave energy is far above other conventional or renewable power generation technologies [3] and must be reduced so that it can compete in the power generation market. The experience of developing other renewable energy production technologies shows us a path of cost reduction over time, as experience and volume of installed power increases.

To achieve this cost reduction in Chile, it is necessary, in addition to an active participation in the development of technologies, to face some additional challenges, particularly those related to supply chain, survival of extreme events sites availability, and coexistence of activities on the marine space. The document presented here, based on recent research and the experiences acquired throughout the execution of the MERIC project, seeks to contribute to some of these aspects and intends to be a useful guide for the selection of adequate wave energy technologies for the particular conditions of the Chilean coast.

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Fig. 1. General Diagram of stages related to CAPEX and OPEX

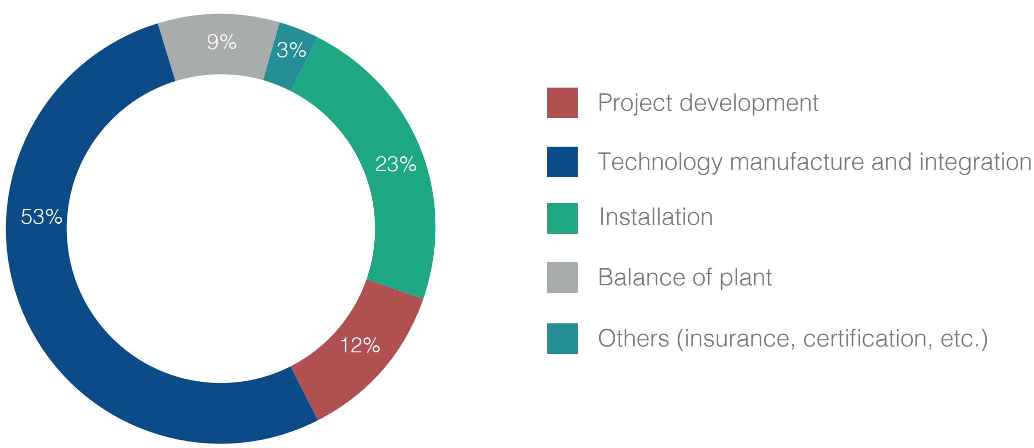

Fig. 2 Distribution of capital costs for a marine renewable energy project in Chile. Source: LCoE study for Marine Energy. MERIC, 2018

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2. Key Aspects of the Study

For the implementation of wave energy technology projects on a pre-commercial (and even commercial) scale, there are several key aspects, which have technical and economic implications and that can also generate various risks for the correct development of a project of this kind. Although these aspects have dimensions that cover environmental, social and legal matters as well, the present study will be limited to the technical and economic dimension, leaving other aspects to be addressed in future studies. Key aspects to be analyzed in this study will be related to selection and technical feasibility of sites in Chile, economic performance of technologies, vulnerability to extreme events and aspects related to technology life cycle, including manufacturing, installation, maintenance, and dismantling stages.

2.1. Site Selection in Chile

Chile possesses a vast coastline, which undoubtedly puts it among the most attractive countries for the installation of wave energy conversion systems. However, there are three key factors that substantially limit the feasibility of potential sites:

TECHNICAL FEASIBILITY OF SITES simultaneous existence of energy resources, demand and availability of technical infrastructure and services (ports, shipyards, vessels, electrical connection, among others) is a condition that, even globally, rarely occurs. This makes compromises unavoidable and, in some cases, may require heavy investments, which can significantly affect the general feasibility of a project.

BATHYMETRY: The installation depth of a wave energy converter can range from a few meters for on-shore technologies to hundreds of meters for floating devices. This aspect is relevant since, from an “access” point of view, e.g., maintenance a device installed directly on the coast allows effective and very low-cost maintenance compared to a device installed at great depth and far from the coast. Considering also the bathymetric characteristics in Chile, with a narrow continental shelf and, particularly in the north, a steep slope, the available space at a certain range of depths can limit the size of farms to be installed, if a device in question does not allow a wide range of depths for its installation and operation.

USE OF COASTAL AND MARITIME SPACES: On the Chilean coast, multiple activities coexist such as the management and exploitation of benthic resources, aquaculture, recreation, conservation, among others. Although not all the variables to be considered at this point are of a technical nature, this aspect is perhaps one of the most relevant and must be considered early in the projects, as well as in regional and national policies about the use of the maritime and coastal space.

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Based on the above, it is considered that – generally - floating technologies have a higher flexibility, being able to be installed at a greater range of depths, which reduces the potential impact on other users of the maritime space near and at the coast. Likewise, technologies that require very specific depth ranges have limited applicability in Chile, given the nature of the bathymetry. On the other hand, coastal technologies present a niche potential, with a high risk of competing with traditional uses, such as the management and extraction of benthic resources.

2.2. Economic Performance of Technologies

Considering that there are still no commercial-scale wave energy projects and that most technologies are in early stages of development, there are several methods to evaluate – in early stages of development – the potential economic performance of a technology. While the levelized cost of energy (LCoE) is the most common metric for assessing the economic performance of a particular technology or project in the field of marine energy [5], this is not possible or would be inaccurate in the early stages of a technology development [6]. In this context, various authors and entities have proposed simpler metrics, with the aim of comparing different technologies and inferring, in a qualitative way, their eventual economic performance. Among the most widely used methods in the field of energy are conversion efficiency and plant factor, a metric that has also found application in the field of wave energy (e.g. [7][8]). The main weakness of this type of metric is that it only considers energy production and not the capital and/or operating costs associated with the technology. To solve this aspect, simplified metrics have been proposed that include these aspects, such as TPL [9], [10] and ACE [5],both from NREL (National Renewable Energy Laboratory). Given the difficulty of comparing different technologies at different stages of development, there is still a discussion about the applicability of these types of metrics, in addition to a continuous refinement, which has been the subject of significant research in recent years [11] [12], [13].

For comparative purposes in preliminary stages, the TPL metric is the one that best addresses different aspects of a technology, which are classified in a taxonomy that considers the following capabilities:

C1: Have market competitive cost of energy
C2: Provide a secure investment opportunity
C3: Be reliable for grid operations
C4: Benefit society
C5: Be acceptable for permitting and certifications
C6: Be acceptable with respect to safety
C7: Be globally deployable

Each of these capabilities, in turn, is subdivided into sub-capabilities, which are detailed in [12].

Because this section does not seek to perform a detailed characterization of the performance of different technologies, but to compare in a simplified way the potential economic performance of different types of

[1] TPL (Technology Performance Level): comparative metric, which categorizes the performance of a technology on a scale of 1 to 9, analogous to the TRL scale (Technology Readiness Level), widely used in all types of technological developments.
[2] ACE (Average climate capture width to characteristic capital expenditure): metric that presents a relationship between the average energy production (obtained as a function of the efficiency of the device) and a characteristic expenditure of capital (obtained from an estimate of the mass of the device). This metric has been used in the wave energy prize contest launched by the U.S. Department of Energy between 2015 and 2017, although it has not seen greater adoption outside of that context.

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technologies using existing information, only the first TPL category (C1) will be evaluated. This category includes, among its subcategories, having a low CAPEX and OPEX, high energy production and high availability. According to the TPL method, each of these capabilities is evaluated as high (TPL 7-9), medium (TPL 4-6) or low (TPL 1-3), which is then refined to an exact TPL value in a second iteration, according to the criteria of the assessor. To obtain the final value, each of these capacities is weighted according to the recommendation of the authors of the method, which can be done with the aid of a spreadsheet that the authors make available [14].

2.3. Potential for integration

According to current research, the possibility of coexistence of wave energy generation and other on-site activities can play a crucial role in achieving economic viability for a project [15]. This integration can be both at platform level (a platform with multiple uses) or at site level (a site with multiple platforms) [16] and activities can consist of power generation (e.g. floating wind), local energy use (e.g. for ocean aquaculture, energy supply to scientific monitoring systems, isolated communities, etc.), collocation to take advantage of synergies or common use of pre-existing infrastructure (e.g. use of coastal or port infrastructure). En la fig. 3 se presenta un esquema que grafica estas distintas alternativas de integración.

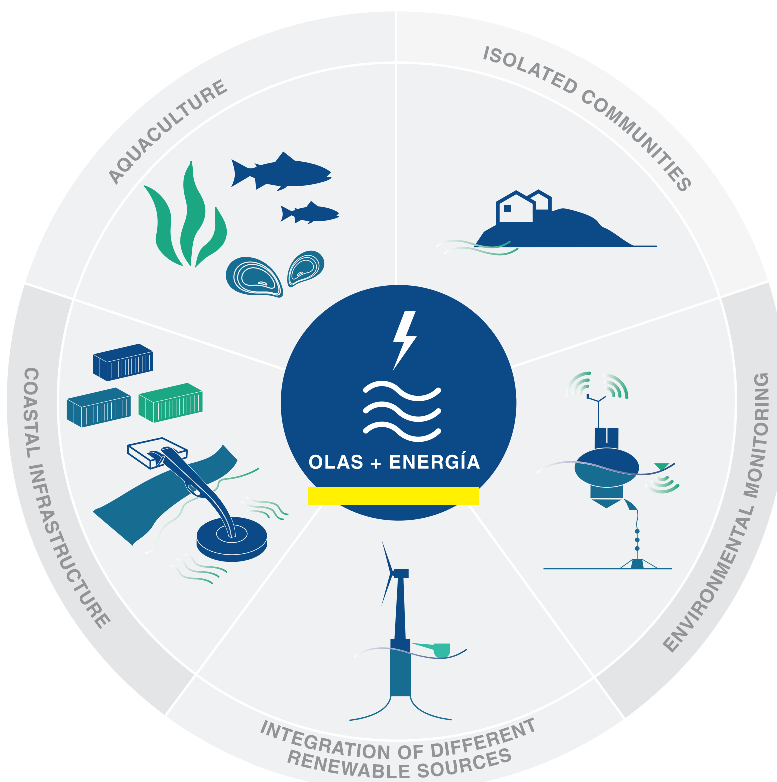

Fig. 3 Examples of integration potential for marine energy technologies with other uses such as aquaculture, isolated communities, monitoring, integration of multiple renewable energy sources and integration of devices with port and coastal infrastructure

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All these integration alternatives reduce cost of investment and/or operations and can generate access to sites that would otherwise be inaccessible to particular activities. Although this may represent very interesting opportunities, the environmental impact of the integration of these technologies has not yet been studied, and has only been analyzed theoretically in some projects, mainly in Europe [17].

Experience has shown that coastal wave energy technologies have a higher integration potential with port or coastal protection facilities [18]. In turn, floating technologies, in particular those using catenary mooring systems have a greater potential for integration with productive activities such as offshore aquaculture, when compared to technologies installed on the seabed or with those that use large or complex foundations. Open ocean aquaculture presents itself as a viable alternative for future development in Chile and in the world, being a crucial part of the Blue Economy concept [19] which allows to foresee important advances for the integration of marine energy devices with other economic activities.

Integration of coastal protection infrastructure with oscillating water column wave energy converter in Mutriku, Basqye Country, Spain.

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2.4. Survivability of Technologies under Extreme Events

Storm surge of August 8, 2015 in Caleta Portales, Valparaiso, Chile

According to the UK Energy Research Centre's definition, survivability corresponds to "the ability to survive predicted or unexpected extremes in wind, wave or tidal current conditions, or any combination" [20]. For the development of wave energy converters, the ability to survive has been identified as a key aspect and poses a highly relevant challenge for the industry [21]. According to Tiron et al. [22], the most relevant extreme events are storms or swells, tsunamis, breaking waves and extreme waves (rogue waves). The risk posed by these extreme events will be different for each technology, being the depth of installation one of the main differentiating factors [22], as well as the location of key components with respect to the sea level. This is of particular importance for technologies installed at the coast or at shallow depth, where tsunami events (or even meteotsunamis, according to more recent research [23]) are of great relevance.

There is a number of studies that analyze the effects of extreme waves on wave energy converters [24]–[28], as well as some that analyze the effect of tsunami waves or equivalents [29]–[31]. Among the most relevant consequences, loss of position due to failure in mooring systems (e.g. anchors, chains, etc.) or foundations (piles, supports, etc.), structural failures and failures in auxiliary systems (e.g. energy production, wiring, monitoring systems, etc.) can be identified, causing issues ranging from interruptions in energy production up to total losses. There are several design considerations to address these issues, including methods of analysis and dimensioning of structural components, the application of rules or regulations and specific survival configurations that reduce forces on a device during an extreme event. Because these considerations can have a significant impact on costs, it is important to understand and analyze these aspects, and thus properly select a technology and its configuration.

In the specific case of Chile, seismic and meteorological conditions impose a real probability of extreme events such as tsunamis and storms throughout the life of a device, in addition to uncertainty regarding the effects of climate change on the probability of occurrence of storms. In this context, it is highly relevant to deepen the knowledge on extreme events in Chile and their potential effects on wave energy converters.

[3] The analysis is based on the dynamics of a tsunami type (see e.g. chap. 1-3., p. 35 of [34]), which is used to establish a relationship between the maximum design forces and the force that would be produced in the event of a tsunami for different depths, considering the increase in the speed of the particles as the depth decreases.

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As for extreme weather events (storms, storm surges, etc.) and its effects on wave energy devices in Chile, there are preliminary investigations that present conclusions similar to the investigations carried out in other regions of the world [32]. On the other hand, there are studies on the effects of storms or swells on coastal infrastructure in Chile, which coincide on the need to implement permanent wave measurement capabilities, improve forecast models in coastal sectors, and deepen studies under different climate change scenarios [33].

Port of Talcahuano, Chile, after tsunami of February 27, 2010

For its part, the study of the effects of tsunami events in Chile has been mainly oriented to coastal and urban areas (e.g. [34]). Additionally, there are international studies that propose safety measures for anchored vessels [35],and although some of these measures and recommendations can be adapted to wave energy converters, it is necessary to carry out specific studies for selected areas, analyzing risks and the vulnerability for different types of converters or for different depths.

Considering the limited information available and the need to systematically expand research on extreme events in Chile and their implications for wave energy converters, the analysis presented here will be simplified by relating the risk of tsunami-related damages to the depth of installation, considering that installations at great depth (more than 50m) are exposed to a lower risk, intermediate depths (from 20m to 50m) are exposed to an intermediate risk and installations at low depths (less than 20m) are exposed to a higher risk. This criterion is based on preliminary analyses and is only referential, intending to illustrate the relevance of this aspect, making a more specific analysis for each technology necessary in further studies.

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2.5. Manufacturing, Installation, Maintenance and Decommissioning (MIMD)

To ensure technical and economic feasibility of future wave energy projects in Chile, it is expected that a relevant part of the manufacture of the structures will be carried out locally. Likewise, it is necessary to ensure that the installation, maintenance, and decommissioning can be carried out with the infrastructure and equipment available in Chile or, alternatively, consider scale economies that allow incorporating this equipment or this infrastructure in the long term.

The manufacture, installation, operation, maintenance and dismantling of a wave energy converter or a farm can be summarized in the diagram presented in fig. 4.

Fig. 4 Diagram of manufacturing, installation, operation, maintenance and dismantling of a wave energy device

Due to their design, dimensions, and mass, it can be assumed that the manufacture, assembly and integration of the main elements that compose most wave energy converters are not a major challenge for the shipyards found in Chile, although this undoubtedly requires a case-by-case analysis. Considering that both the facilities and the required supply chain currently exists in the local shipbuilding industry, it is possible to expect that costs and quality achieved can be competitive with the ones observed in other regions of the world [5].

As for marine installation, maintenance, and decommissioning operations, it can be assumed that, in some cases, these aspects may be a challenge for some technologies. Maintenance in the marine environment is more expensive, requires a greater amount of time and presents higher risks when compared to maintenance on land [36] [37]. In a wave energy conversion device, there are several subsystems that require maintenance, making strategies that minimize costs and risks mandatory. Additionally, devices generally have surfaces and components that must be protected from corrosion and biofouling, which makes maintenance in shipyards

[3] The analysis is based on the dynamics of a tsunami type (see e.g. chap. 1-3., p. 35 of [34]), which is used to establish a relationship between the maximum design forces and the force that would be produced in the event of a tsunami for different depths, considering the increase in the speed of the particles as the depth decreases.

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or other land facilities necessary. Considering that marine operations have a strong impact on the total cost of a project of these characteristics, their consideration is crucial when evaluating the feasibility of a technology for application in Chile.

Based on an analysis of various technologies currently available and infrastructure and equipment available in Chile, the following key aspects were identified in the installation, maintenance and dismantling of the systems:

REQUIREMENTS FOR LIFTING AND MOBILIZING DEVICES:

due to the size of most wave energy devices (equal or smaller than vessels and floating structures usually built in Chile), it is considered that there are ample options for lifting and mobilization on land. This cargo handling can be found both in fixed installations (cranes and heavy-duty carriages in ports, shipyards, etc.) and in mobile systems (various mobile crane and heavy transport services). As for the availability of transport options at sea, the options are limited. Chile does not have special vessels such as Heavy Lifting Ships or Anchor Handling Tug Supply (AHTS) vessels, normally used for transport operations of large elements on deck. Therefore, the options are limited to the use of pontoons or barges, with the consequent limitations that this implies. As for lifting operations at sea, options are limited to a single floating crane (Floating Crane "Yagana", with 350t of lifting capacity) and pontoons on which land mobile cranes can be installed. Further considering that none of these lifting options have been designed to perform operations under typical conditions found in the open sea off the Chilean coast, waiting for commensurate weather windows could significantly limit or delay these operations. Thus, it is considered that technologies that do not require offshore lifting operations or transport on deck (for example, those that can be towed afloat to the installation point or those that are installed directly on the coast) have greater compatibility with the limitations currently found in Chile.

Port maneuvers prior to the installation of MERIC's Open Sea Lab

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REQUIREMENTS FOR INSTALLATION AND MOORING:

a decisive aspect for the installation is the infrastructure to support marine operations, such as the selection of the port, the nearby support fleet and its equipment, which must be appropriate and compatible with each other. The selection of these should include aspects such as the design of the device, characteristics of the seabed and prevailing environmental conditions, plus installation methods and strategies available. Depending on local capacities and conditions, it is advisable to have a holistic view from the beginning of a project and during the operational planning. The early evaluation of aspects such as port selection, local vessels and support equipment can lead to significant cost reduction opportunities.

Depending on the type of technology, the requirements for the installation of the device and its mooring system can be very different from each other. Additionally, these are highly regulated (e.g. [38]). In the case of floating devices with conventional mooring systems (e.g. by catenary), precision requirements for anchor location and usual installation procedures are compatible with the most frequently found work vessels in Chile, such as tugboats, barges or pontoons. If the positioning requires high precision, but is limited to small elements (e.g. tension-legged mooring), it is possible to adapt local vessels or maneuvers to meet these requirements (e.g. [39]). For technologies that require high precision in the location of large components or for the installation of large mooring elements, the general practice is to use dynamic positioning (DP) vessels, which are not currently available in Chile. If this requirement is coupled to a lifting operation (for example, lifting a large foundation), the intervention of large offshore supply vessels (OSVs) may be necessary. These vessels are usually available in countries where oil & gas exploitation is carried out, which could make the project economically unfeasible in Chile. Given the above, it is considered that technologies that do not require high precision positioning have greater compatibility with the conditions currently present in Chile. In the medium term, the adaptation of vessels and/or maneuvers is considered equally feasible for the installation of small elements with high precision, which could also generate important synergies with the aquaculture industry.

Mooring components (anchor, auxiliary buoy and chain) for MERIC's Open Sea Lab installation

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REQUIREMENTS FOR MAINTENANCE:

within the frame of this analysis, two types of maintenance operations are identified: on-site maintenance and on-shore maintenance. As for onshore maintenance, the operation is expected to be similar to the installation and can entail a high cost. Therefore, it is observed as a trend that most devices are designed so that this type of maintenance is carried out with the largest possible time intervals (of several years), performing the rest of the maintenance on site. On-site maintenance can involve low-complexity underwater work such as inspections with ROVs (remotely operated underwater vehicles), to maintenance work that requires specialized divers (e.g. for deep diving, underwater welding, etc.), involving high costs and risks. Likewise, on-site maintenance may require inspection and maintenance work on board which, depending on its design, may require a transfer maneuver of personnel and/or equipment. There are several rules and standards that provide guidelines for the design, planning and execution of this type of marine operations [40]–[42], in which technical and environmental criteria are established and whose application can present challenges considering the typical conditions of waves and wind in Chile, as well as limitations imposed by the available support vessels and systems. In this context, it is considered that technologies that require minimal maintenance on land and that allow on-site maintenance with high safety standards have better compatibility with the environmental conditions found in Chile. In this same context, a holistic design that includes an adequate design and/or selection of maintenance vessels and support equipment is considered of great importance.

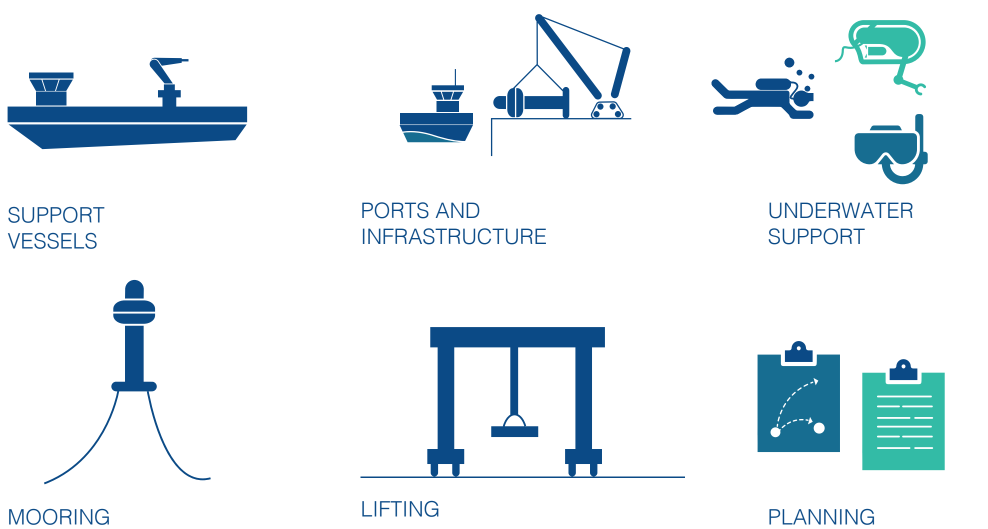

Fig. 5. Critical aspects in mobilization, installation, maintenance and decommissioning operations

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Preparation of MERIC's Open Sea Lab towing to installation site

2.6 Synthesis of Key Aspects to Analyze

Based on what was stated in previous sections, the selected key aspects to analyze, considering the current development of the technologies and the specific conditions in Chile, are the following:

1. Selection of sites, analyzing their potential for technical feasibility, bathymetry requirements and potential conflicts with other users of the coastal or maritime space.

2. Economic , performance, based on the C1 capacity ("have market competitive cost of energy ") of the TPL methodology presented in [13].

3. Survivability, based on a preliminary criteria relating damage by tsunamis and extreme events to the depth of installation and the location of critical components with respect to the water level.

4. Potential of integration with other uses,analyzing possible synergies that can reduce costs.
5. Lifting and mobilization requirements,
6. Installation requirements and
7. Maintenance requirements. These last three will be evaluated based on the local availability of the required equipment or infrastructure.

Although there are many more aspects that must be considered in a project, those presented here could generate relevant differences with respect to projects already executed or in execution in more industrialized countries, taking as a reference those countries where the largest number of installations (experimental or pre-commercial) of wave energy devices have been carried out.

03.

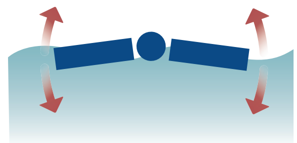
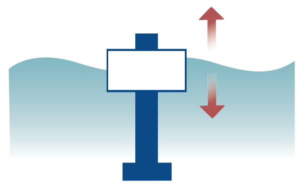
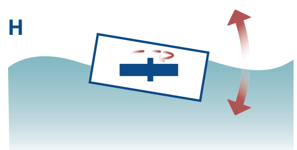
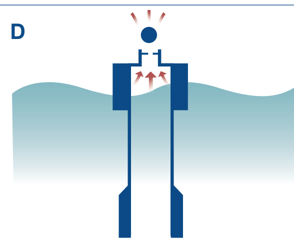
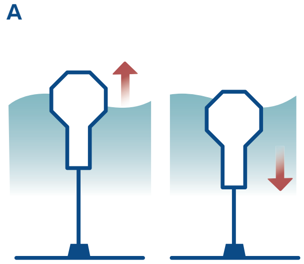
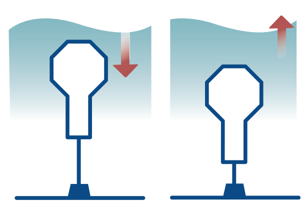
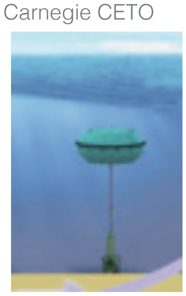
3. Classification of Wave Energy Technologies

Due to the great diversity that currently is observed among different devices, different types of classification based on various aspects such as their principle of operation, location with respect to the coast, relative position with respect to sea level, positioning system, size, and orientation, among others, can be found. Several publications on this subject can be found [43]–[49], among which the classification of the European Center of Marine Energy (EMEC) stands out. This classification identifies at least 8 different technology categories based on their operation principle and is widely used. Therfore, it has been taken as a reference for the purpose of this publication [50].

Within this analysis, an additional classification is needed, relating to critical aspects presented in the previous section (section 2). Considering that the positioning system is one of the most relevant characteristics for the previously defined key aspects, four categories have been identified, based on different positioning systems (floating with mooring system, floating with fixed element at the bottom (e.g., the PTO), bottom-fixed device and coastal device). For each of these four categories, several sub-categories have been differentiated, based on existing technologies, according to the classification proposed by EMEC [50]. Although the current evaluation only tries to analyze types of technologies and not specific technologies, there are certain aspects that make this objective complicated, due to the need to define some technical characteristics of the devices such as their dimensions, mass, or access modalities for maintenance. Therefore, examples of technologies that represent each category have been incorporated, which will be used as input data for the specific information required in the analysis. Table 1 presents the proposed classification. As can be seen, the sub-categories according to EMEC can appear in more than one of the proposed categories, taking into account that technologies with the same principle of operation can have different positioning systems.

The proposed classification will be used, in the next section, to evaluate the key aspects defined in the previous section.

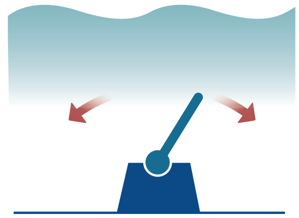
[4] Located in the Orkney Islands, in the north of Scotland, EMEC is the world's first and leading facility to demonstrate and test wave and tidal energy converters

CATEGORY	TYPE	CAT. EMEC EQUIVALENT		EXAMPLES	
1. FLOATING, WITH CONVENTIONAL MOORINGS	Attenuator	**A**		m-Ocean	
	Moored point absorber	**B**		OPT	
	Rotating mass	**H**		Wello	
	Floating OWC (oscillating water column)	**D**		Oceantec	
2. FLOATING, WITH BOTTOM-FIXED ELEMENT (E.G. PTO)	Point absorber with bottom-fixed PTO	**A**		CorPower	
	Pressure differential	**F**		Carnegie CETO	

3. BOTTOM-FIXED

Surge converter

C

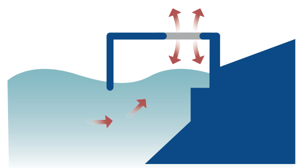


WaveRoller

4. COASTAL

On-shore oscillating water column (On-shore OWC)

D



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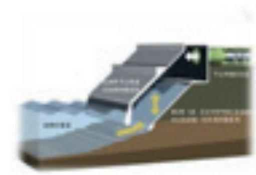
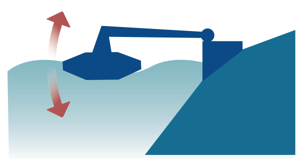


On-shore point absorber

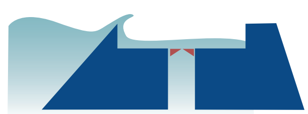
A



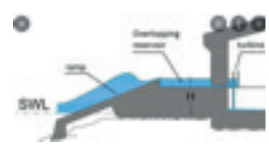
COPPE Brasil, BDM MD

On-shore overtopping device

E



OBREC



04. Analysis and Results

In previous sections, key aspects to be analyzed and the categories to group different technologies according to the positioning system used were defined. In this section, the criteria or metrics that will be used to analyze the different types of devices in the different areas will be defined. Additionally the obtained results are presented.

The number of aspects to consider in wave energy projects is enormous and requires a case-by-case evaluation. As previously mentioned, in this study only certain aspects have been selected which, in addition to being key, could represent the greatest differences between a project in Chile and in a reference country, focusing the analysis on those local conditions that might require more attention for developers. For each of the key aspects stated, a simple scale has been defined with three levels (low, medium, and high), reflecting a certain performance level. Table 2 shows the evaluation matrix elaborated for each of the aspects and a definition of each of the performance levels.

Based on this evaluation matrix, an analysis was carried out for each aspect and type of technology, obtaining the results presented in Table 3. While the evaluation of some aspects may contain some subjective elements due to its general nature, efforts were made to use all publicly available information at the time of development, in addition to using confidential information from suppliers or developers and conducting interviews with experts.

As can be seen, none of the types of technologies analyzed presents a high level of performance across all aspects, although a better performance is observed for floating technologies with conventional moorings (category 1). This is explained by the greater flexibility in terms of installation depth, expanding the availability of sites and reducing the damage risk of extreme events and lower requirements of lifting, mobilization, installation, and maintenance of technologies, compatible in large part with the capacities currently available in Chile.

As for floating technologies with fixed PTO at the sea bottom (category 2), a lower economic performance is observed, which is largely due to higher installation costs of the seabed foundation compared to conventional moorings. Since it requires specialized vessels or large lifting capacity for installation and / or maintenance, its implementation would not be currently feasible without significant modifications to its design or considerable investments to dispose of the required vessels.

For the bottom-fixed category (Cat. 3), the lack of flexibility in terms of installation depth limits the feasibility of sites and increases the damage risks related to extreme events, while sharing the installation and maintenance difficulties of the previous category.

Coastal installations (category 4) have inherent advantages in terms of installation and maintenance. Likewise, there is a lower viability of sites, mainly due to other uses of the coastal front, although it is eventually possible to take advantage of synergies with coastal infrastructure that fulfill other functions. One of the aspects

[5] Reference countries will be considered those that stand out for the number of wave energy projects or other marine energy technologies

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that could constitute its greatest disadvantage is a greater exposure under extreme events, both tsunamis and storm surges. This last aspect can be addressed through applied research, seeking to obtain designs and sizing methods that allow reducing the risks associated with this sort of events, which should go hand in hand with greater research on climate change and monitoring of environmental variables.

In general, it is observed that, considering conditions currently present in Chile and the current development of technologies in the world, those of floating type with conventional moorings (cat. 1) present advantages in the analyzed aspects. It is expected, in the medium and long term, that the designs of the technologies will tend to simplify their installation and maintenance methods and, local investment will be made in equipment and infrastructure, particularly in specialized vessels that allow installation and maintenance work in a more economical and safe way, which will open opportunities for other technology categories.

<table>
<tr><th>PERFORMANCE LEVEL</th><th>DISP. SITES</th><th>ECONOMIC PERFORMANCE</th><th>INTEGRATION POTENTIAL</th><th>RISK POR EXTREME EVENT</th><th>LIFTING AND MOBILIZATION</th><th>INSTALLATION AND/OR MOORING</th><th>MAINTENANCE</th></tr>
<tr><td></td><td>The technology has a low potential due to the limited availability of suitable sites in Chile</td><td>Low TPL C1 economic performance (between 1 and 3),</td><td>Technology has a low potential for integration</td><td>The technology requires modifications not yet possible, not yet studied or not yet economically feasible</td><td colspan="3">Local capabilities are not compatible with the requirements of the technology or required modifications are not yet possible, not yet studied or not yet economically feasible.</td></tr>
<tr><td></td><td>The technology could have potential due to the availability of sites, although there are certain limitations</td><td>Average TPL C1 economic performance (between 4 and 6)</td><td>The technology could have an integration potential that can make it attractive in the future</td><td>The technology will need to be studied and it is highly likely that its design will need to be modified.</td><td colspan="3">Local capacities are not yet compatible with the requirements of the technology, but these limitations can be addressed by modifying the design or methods of lifting, mobilization, installation, anchoring or maintenance.</td></tr>
<tr><td></td><td>Technology has potential due to the availability of sites</td><td>High TPL C1 economic performance (between 7 and 9).</td><td>The technology has an integration potential that makes it attractive for one or more applications</td><td>Technology can deal with expected extreme events without significant modifications to its design</td><td colspan="3">Local capabilities are compatible with the requirements of the technology today without significant modifications to the design or methods of lifting, mobilization, installation, anchoring or maintenance.</td></tr>
</table>

Tabla 2: Evaluation metric of key aspects analyzed

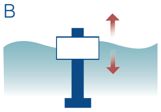
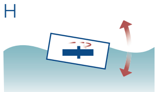
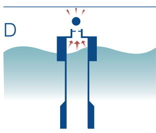
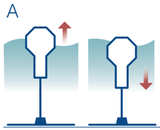
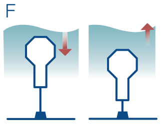
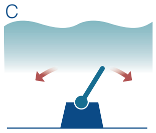
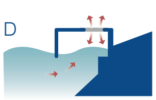
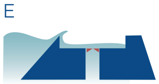
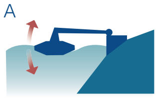
CATEGORY	SUB-CATEGORY (EMEC)	DESCRIPTION	VIABILITY OF SITES	ECONOMIC PERFORMANCE	INTEGRATION POTENTIAL	EXTREME EVENT RISK	LIFTING AND MOBILIZATION	INSTALLATION	MAINTENANCE
1. FLOTANTE, CON FONDEOS	A 	Attenuator	Green	Yellow	Yellow	Green	Green	Green	Yellow
	B 	Moored point absorber	Green	Yellow	Yellow	Green	Green	Green	Yellow
	H 	Rotating mass	Green	Yellow	Yellow	Green	Yellow	Green	Yellow
	D 	Floating OWC water column	Green	Yellow	Yellow	Green	Green	Green	Yellow
2. FLOATING, WITH BOTTOM-FIXED PTO	A 	Point absorber with fixed PTO	Green	Red	Yellow	Yellow	Green	Red	Red
	F 	Pressure differential	Green	Red	Yellow	Green	Green	Red	Red
3. BOTTOM-FIXED	C 	Oscillating plate (Surge convert)	Yellow	Red	Yellow	Red	Red	Red	Red
4. COASTAL	D 	Oscillating water column, coastal (On-shore OWC)	Red	Yellow	Green	Red	Green	Green	Green
	E 	On-shore point absorber	Red	Yellow	Green	Red	Green	Green	Green
	A 	On-shore overtopping	Red	Red	Green	Red	Green	Green	Green

Table 3. Evaluation results of key aspects

05. Conclusions

The analysis presented here seeks to identify, based on a series of critical aspects that could play a preponderant role when designing or adapting a wave energy technology to be installed in Chile, considering local aspects that could be critical and that are not necessarily evident at first glance. Considering the importance of aspects such as extreme events and the limitations of equipment and infrastructure in Chile, representative technologies were analyzed, categorizing them according to their connection system to the seabed. Based on an analysis of each of the aspects identified for each of the types of technologies selected, recommendations were generated regarding the results obtained.

The marine energy industry, and in particular the wave energy industry, is still under development, which makes it difficult to establish standardized metrics or procedures to evaluate or compare different devices, also considering that new technologies and significant improvements to existing ones are permanently presented. In this context, the work presented here attempts to demonstrate the importance of certain criteria for an initial evaluation of devices in a local context that imposes its own challenges and that, at the same time, may present unique opportunities in the future.

MERIC's Open Sea Lab, installed in front of the Marine Research Coastal station of Pontificia Universidad Católica de Chile (ECIM-PUC)

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About MERIC :

The Marine Energy Research and Innovation Center (MERIC) seeks to promote the development of the Blue Economy and the industry related to the sea in Chile, transforming its scientific knowledge in Technological Services and Applied R&D, generating new and innovative business opportunities. The center was created in 2015, in an alliance between the companies DCNS (today Naval Group, from France) and Enel Green Power (Italy), together with Pontificia Universidad Católica de Chile and Universidad Austral de Chile. The central objective is to turn Chile into a local and global reference for marine energy, accelerating the insertion of these technologies in the country, transforming the knowledge acquired in R + D + i of recent years into frontier technological services.

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