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Sectoral Analysis of the Fundamental Criteria for the Evaluation of the Viability of Wave Energy Generation Facilities in Ports—Application of the Delphi Methodology

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Abstract: Nearly 40% of the world's population lives within 100 kilometres of the coast with the risk that this implies in terms of exposure to the effects of climate change. Ocean energy, according to the IPCC (Intergovernmental Panel on Climate Change) in 2019, has been identified as one of the measures for mitigating these effects. In addition, ocean energy can play an essential role in achieving some of the SDGs (Sustainable Development Goals) set at the Paris Climate Summit in 2015, namely SDG 7 (clean and affordable energy) and SDG 13 (climate action) and could have a substantial impact on others such as SDG 1 (poverty eradication), SDG 2 (end hunger), SDG 5 (gender equality), SDG 6 (universal energy access), SDG 8 (promote sustainable economic growth), SDG 9 (build resilient infrastructure), SDG 14 (sustainable conservation of oceans and seas) and SDG 17 (promote sustainable development cooperation). There are several projects under development around the world aimed at extracting energy from waves. However, to date, no technology has been found that, in general terms, is superior to others. There are several conditioning factors that prevent this type of energy from reaching the level of maturity of other marine renewable energies. These are mainly economic, technological, environmental, and regulatory, to mention the most important. This article aims to analyse the approaches that other researchers have adopted to evaluate wave energy projects and, through a prospective method of expert consultation such as the Delphi methodology, will present the most generally accepted criteria for successful wave energy projects. Subsequently, the validity of these results will be analysed for the case of the use of the energy produced for self-consumption in ports.

Keywords: clean energy; wave energy; renewable energy; wave energy converter; SDG

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1. Introduction

Throughout history many devices have been proposed to harness the energy generated from the gravitational motion of waves, [1–6], however, it was not until the late 1970s that larger publicly funded R&D (Research and Development) projects were initiated. Recently, following the 1997 Kyoto protocol on the reduction of CO_2 emissions into the atmosphere, interest in wave energy has grown again globally in many countries.

Renewable energy was a major priority in the COP26 (Conference of the Parties nr. 26) agenda, with high expectations over what would ultimately be named the Glasgow Climate Pact in accelerating the transition.

The use of the energy resource is conditioned by the collection technology, the evacuation strategy, the physical and meteorological conditions of the location, the compatibility of uses with maritime navigation and the infrastructural conditions [7].

According to studies carried out throughout history with respect to this renewable energy, it is known that the amount of energy that can be obtained from it is proportional to the period of oscillation of the waves, as well as to the square of the amplitude of these [8,9]. These studies have concluded that the waves' characteristics are optimal for wave energy in sea areas with depths between 40 and 100 metres.

Although there are previous studies on the use of wave energy in many locations worldwide, these are not very conclusive in terms of defining the critical variables to be evaluated to undertake with sufficient certainty wave power generation projects that can compete with wind or photovoltaic energy in terms of performance and price of energy. Studies of the theoretical energy resource that can be extracted from the oscillatory motion of the waves are a different matter.

Compared to other ocean energy in early stages of implementation, the TRL (Technology Readiness Level) of wave energy in general is lower than that of tidal energy, and the majority of its deployments are restricted to demonstration and pilot projects [10]. As a result of this situation, there is currently only 2.5 MW (Megawatts) of installed capacity. However, following the trend in tidal energy, wave energy devices are increasing in size and power, and some 100 MW are expected to be installed in the coming years [11].

The global energy potential represented by waves reaching all coasts of the world has been estimated to be in the order of 1 TW (Terawatt) (1 TW = 10^{12} W (watts)) [12] or in terms of energy a resource potential of around 29,000 TWh (terawatts hour)/year. Moreover, the fact that wave energy is more persistent than wind energy, stimulate the motivation and hope to develop the still rather undeveloped wave energy technology to a prosperous level of maturity in the future. If the technology can be successfully developed, the market potential is enormous. By 2030, at least 1 GW (Gigawatt) of ocean energy (being the wave energy part of it) should be installed in Europe and it is foreseen that this renewable energy deployment goes on by reaching at least 40 GW of installed capacity by 2050 [13]. Consequently, the effort and investment that is being made and facilitated by government institutions to develop this type of technology more quickly is clear, however, to date, few commercial-scale projects are currently working. The new EU (European Union) Renewable Energy Financing Mechanism, published in September 2020 and in force since 2021, will make it easier for EU Member States to work together to finance and deploy renewable energy projects—either as a host or as a contributing country. For this reason, it is necessary to obtain the experience acquired by the experts involved in this type of project to facilitate the implementation of systems for generating electricity from waves.

Among the wave energy projects to be developed, it is necessary to highlight those dedicated to the self-consumption of energy in ports. Given the growing need for green energy that will arise in the coming years in ports due to their progressive decarbonisation, wave energy is a candidate with a good chance of success.

In this paper, we will focus on identifying the critical variables that define the viability of a wave energy project in order to make it easier for investors to participate in wave energy generation projects and thus come closer to the commercialisation of renewable energy at competitive prices similar to those of other technologies for extracting renewable energy from other sources. The results from this research will make it easier for ports to undertake the necessary investments to be able to install wave energy generation facilities for self-consumption within their facilities. To do so, we will start in Section 2 with a review of the existing literature and the different approaches taken by other authors and the methodology applied in this research. Section 3 will show the results obtained, which will be discussed in Section 4, followed by Section 5, which will be devoted to conclusions.

2. Materials and Methodology

2.1. State of the Art of Previous Multi-Criteria Analysis Studies for the Evaluation of Ocean Energy Generation Projects

There are still no criteria generally accepted by all experts related to ocean energy extraction projects; however, there are tools, guidelines and bibliography that try to indicate to the developers of this type of projects the critical points to be considered in the evaluation of their feasibility.

The criteria for the assessment of ocean energy extraction projects are varied, so the existing literature addressing this issue has been consulted. The criteria evaluated in this literature traditionally approach the problem from a perspective more related to technology, resource availability and other more scientific than purely economic aspects, and do not have the explicit approval of the developers. Based on these publications, which are the result of scientific studies, developers have designed their devices and have included in the list of criteria those related to purely economic feasibility criteria, which are the ones that attract the interest of investors.

In this respect, we will give below some of the references that have inspired the elaboration of this article and the research behind it. To facilitate reading, we present the results of the literature review in a table format, see Table 1 below.

Table 1. Review of existing literature related to the selection of criteria for the assessment of wave energy installations. Own elaboration.

Source	Methodology	Objectives	Approach	Results	Authors' Remarks
[14]	MCA [1]	Identification of best locations to deploy wave energy production facilities	It analyses the influence of physical conditions, the uses of the study area and the climate conditions on the selection of suitable areas for wave energy extraction	A function dependent on several criteria was defined in which each criterion was given a different weight according to its importance	It only assessed criteria related to the location and climate, neglecting all other technology and economical related ones
[15]	MCA	Selection of most suitable areas for wave energy devices deployment	Five main criteria were assessed for the evaluation of the potential locations	18 sub-criteria were identified and weighed for the definition of multi-parameter functions to rank the potential locations	The location potential is thoroughly assessed, but it missed the influence of economic, logistics and social criteria
[16]	MCA	It defines optimal location-device pairs by defining a decision-making process	It analyses several criteria, including converter information based on previous literature relevant sectorial guides, wave climate, resource availability and all relevant information related to the study area	After applying this decision-making process to 30 different types of devices, the results are inconclusive and point to further research considering the effect of the wave directionality	The need for more accurate economic data from developers and do not conclude that the same methodology could be replicable in other areas of the planet
[17]	MCA	Obtain a single criterion that would allow developers to make decisions when planning investments in wave power generation projects	The impact of various factors as the impact of the maritime climate, wave energy resource and the characteristics of the wave energy converter in the prediction of the energy production	This MCA methodology is valid, as the objectives were achieved	Other factors, such as development policies, limited investment opportunities, environmental impacts, etc., should be incorporated
[18]	Three stage methodology and an MCA	Selection of the most suitable WEC [2] system for the areas that have been previously identified as suitable for this type of installation	Firstly, the WEC technology is assessed, followed by the characterization of the location resulting with the combination of both to define the suitability of a WEC for a certain location	A Site/WEC matching area was defined for the NZ [3] case study	This approach does not consider neither economic nor energy usage related factors for the assessment of the projects. It is a good start but with still long way ahead
[19]	MCA	Identification of the most suitable locations to deploy WECs	A combination of suitability values (Weighs given to different factors affecting the assessment of locations for the deployment of WECs) are assessed	The suitability values are obtained for six factors and its combination with the locations are assessed	It gives a partial view of the scope, not considering other relevant parameters. Further extension of the methodology should be required
[20]	Spatial Planning	Identification of the most suitable locations to accommodate the WECs	Assessment of several key factors to make compatible the WECs exploitation with the marine spatial planning	Establishment of a Suitability Index for the selection of suitable location for WECs and obtaining the wave resource map of the suitable areas of the coast of the Basque Country.	Methodology and results are useful for the developers. There is no certainty about the performance of the methodology, as it has been evaluated from a theoretical point of view.

Table 1. *Cont.*

Source	Methodology	Objectives	Approach	Results	Authors' Remarks
[21]	MCA	Set pairing relations between WECs and selected spots for their deployment	From the standard deviation of the wave resource in some selected spots with smooth resource variability a relation between it and the WEC is set.	Promising pairing relations were achieved	It did not take into consideration other economic or performance layers for the location-device pairing
[22]	MCA	Estimation of LCOE [4] for several water currents and wave energy converters	By setting several reference models, the LCOE was estimated for every single of them and then for several arrays of different sizes to estimate the cost reductions by using synergies	Promising LCOE was obtained in the case of the point absorber	It did not take into consideration the full picture of the problem giving more significance to pure economics rather than physical ones
[23]	MCA	Identification of locations where optimal amount of wave energy is available	Using MCA and ANN [5] to define an indicator for suitable energy locations	Several criteria were ranked by using the suitability indicator and applied to two locations	It neglects very important criteria as economic and logistic, however the methodology is promising
[24]	Delphi methodology	Evaluation of the viability of wave energy facilities in function of the available resource	By using the available historical data several parameters were identified and experts consulted to rank the importance of them	Several locations were assessed and ranked according to the parameters identified	It does not consider the economic factors and the logistics are only partially considered
[25]	MCA	Technology Performance Level Assessment for Wave Energy Converters	Through a specialised tool, and by giving scores from 1 to 9 to several questions related to 7 areas of expertise a score is given to every submitted project	TPL [6] scores are obtained for the submitted projects. Obtained TPLs guide on the next steps to take	Useful mainly for developers as it gives them an idea about the level of development of their products.
[26]	MCA	Assessment of wave energy potential and its spatial and temporal variability in certain locations	Using simulation tools, the resource fundamentals are assessed	A map with the most suitable wave energy areas is issued in the study area	It does not consider neither the influence of the WEC in the exploitation of the resource nor the performance of it
[27]	MCA model using AHP [7]	Selection of the most effective system for generating power from the waves	The MCA model supported by an AHP model	Using the MCA and the AHP model the OWC [8] system appears to be the most effective in comparison with other technologies	The results are partial and focused on a specific and expected result. There is no evidence that in general conditions the results were the same
[28]	MCA	Assessment of the TPL attributes and rank them through consultation to industry stakeholders	A TPL score is searched by asking relevant stakeholders to rank the attributes linked to the TPL definition	Several TPL scores were obtained for 7 different categories of capabilities of the WECs	It does not give a full picture of the project as it "only" assessed the TPL, while other factors such environmental, logistics, resource availability, energy usage, would or would not be including in the TPL attributes
[29]	MCA	Assessment of the economic criteria and their relative importance for the development of the wave and tidal energy technologies based on the experts' judgment.	The Delphi methodology was used to rank several economic factors associated to the feasibility of wave and tidal energy projects	Through the consultation to experts, selling the energy and tax incentives related factors were ranked with the highest grade of consensus and importance	This research only evaluates economic related factors, neglecting other factors that could affect to the overall project feasibility
[30]	MCA	Assessment of the feasibility to wave energy projects by using LCOE and Risk	By defining the indicator RR [9] several case studies are used to test the model	After crossing the RR for the different case studies the result is a development strategy for every case	The methodology is fairly comprehensive, although it does not clearly take into account the effect of the destination of electricity. It covers many of the aspects necessary for project assessment

[1] Multi criteria analysis, [2] Wave Energy Converter, [3] New Zealand, [4] Levelized Cost of Energy, [5] Artificial Neural Network, [6] Technology Preparedness Level, [7] Analytic Hierarchy Process, [8] Oscillating Water Column, [9] Risk/Reward ratio.

Regarding the possible use of WEC devices in ports, there are already some examples of prototypes that would meet the structural requirements of ports. Among such systems, we can cite the oscillating water column systems (e.g., Oceanlinx prototype, Australia [31]) or overtopping devices (e.g., WaveDragon, Denmark [32]). Such devices can be installed on existing infrastructures, such as breakwaters or sea walls. A multi-criteria methodology will be presented below to try to categorise the main variables to be considered for the materialisation of this type of project.

2.2. Methodology Used in This Research

As it has been seen in the literature review, the key criteria are still in the selection and definition phase. The definition of the key criteria for the selection of the optimal technology is conditioned by the actors observing the problem (academia, researchers, and business developers) and their involvement in this type of projects.

It is worth noting that another criterion to be considered, which almost none of the studies consulted consider, is the end use of the energy produced, since it is not the same whether the end use is to sell it to the energy grid or to cover certain specific own consumption needs. In each of these scenarios, the economic conditions are totally different, so the identification of the key criteria in the port area requires the use of a methodology that gathers the opinion of experts in the development of devices for the exploitation of wave energy from the initial concept phase to the final phase of their implementation.

2.2.1. Description of the Problem

In the situation which arises, and which gives rise to the present research, there is no detailed and contrasted information that would allow the adoption of concrete criteria regarding the viability of this type of projects, however, the collective subjective judgements of experts could be valuable.

2.2.2. Approach to the Problem

Through the consultation of experts identified as occupying key positions in the different stages of the process, it will be possible to obtain their opinions on the level of importance of a series of criteria that are generally accepted by the community in relation to the viability of wave energy extraction projects.

The aim of this consultation is to obtain the most reliable consensus opinion from the group of experts consulted, who individually submit themselves to a series of questionnaires, which are interspersed with the opinions of the group and which, based on an open exploration, after successive responses, produce an opinion representative of the group.

For this purpose, a survey is proposed to the experts, asking them to rate from 1 (irrelevant) to 5 (the highest importance) the level of relevance of several parameters in the study: the assessment of the feasibility of a project for a wave power generation plant.

In view of the problem posed and the participation of experts in the field being the way to obtain a relevant consensus to solve it and to be of help in the approach to the viability of future wave energy extraction projects, it is proposed to use the Delphi methodology to determine a sufficiently broad consensus based on the opinions of accredited experts in the field.

2.2.3. Application of Delphi Methodology

The name of the Delphi methodology has its origin in the Delphi Oracle. This method was initially created in the early 1950s at the RAND Corporation in the USA by Olaf Helmer and Theodore J. Gordon with the aim of making predictions about the occurrence of a nuclear catastrophe.

Since then, the Delphi method has been used to make high quality forecasts and predictions based on the intuitive judgment of a group of experts to obtain a consensus of informed opinions to address the problem.

The Delphi methodology is an information-gathering technique that allows the opinion of a group of experts to be obtained through repeated consultations. It consists of a technique for obtaining information, based on the consultation of experts in an area, with the aim of reaching the most reliable consensus opinion of the group consulted [33].

This methodology is useful in situations where the following assumptions occur:

- There is no concrete and contrasted information that allows the adoption of concrete criteria in relation to the feasibility of this type of project, however, the collective subjective judgements of experts could be valuable.
- The potential participants needed to work on this case may be experts from different backgrounds and without direct contact with each other, for example, technology developers, researchers, or academics.
- To carry out the research, it is necessary to have a larger number of participants than can be accommodated in a room.
- Money and time make frequent group meetings impractical due to the high number of responses required.
- Group meetings can often be a problem due to personality or strong differences of opinion, whereas anonymous communication could avoid this problem.

Like all methodologies, the Delphi method has advantages and disadvantages, among the former are:

- It allows information to be obtained on points of view on broad or specific topics.
- The horizon of analysis can be very varied.
- It allows the participation of more experts than could be gathered in one room.
- It helps to systematically and objectively explore problems that require qualified responses from many experts.
- It reduces the negative effects of physical meetings.

However, among the disadvantages of this method, it is worth mentioning:

- The high cost, sometimes.
- High execution time from the beginning until the results are obtained.
- They require high participation to give statistical validity to the results.
- Difficulty in the selection of the questions in the questionnaire.
- Errors in the selection of experts.
- Possible desertion of experts, due to the long running time or availability of experts.

To implement the Delphi methodology in our case, the following sequence will be followed:

1. Phase 1: Definition.
2. Phase 2: Formation of the group of experts.
3. Phase 3: Execution of the consultation rounds.
4. Phase 4: Results. This phase will be presented in Section 4, which deals with the results.

Once these four phases have been completed, the result will be a final report including the results obtained in the consultation that will allow the appropriate decisions to be taken in relation to the problem that was initially posed, and which should fulfil the objectives set at the beginning. Each of the above phases will be further elaborated next.

Phase 1: Definition

Starting from the defined research problem, the objective of the consultation was formulated, the dimensions to be explored of the consultation and the possible sources of information were identified.

Definition of the problem: Categorisation of the most suitable criteria for the choice of a WEC technology.

- The final goal of the questionnaire was to obtain from the research experience of experts in the study of the behaviour of different WEC technologies, a ranking of how various parameters affect the choice of a viable technology type for wave energy production at a certain location.
- As already mentioned above, a survey of 10 blocks of questions were proposed to the experts, asking them to rate from 1 (irrelevant) to 5 (the highest importance) the level

of relevance of several parameters in the study: the assessment of the feasibility of a project for a wave power generation plant.

Phase 2: Formation of the Group of Experts

In this section, the profile of the participating experts and their location was defined, the protocol for selecting the group—who have representative information, time, and interest—was drawn up, and the potential members were contacted, chosen, invited and their commitment to collaborate obtained. The size usually ranges from six to 30 depending on the problem, although it is not a determining factor. Quality must always take precedence over quantity.

Requests for participation in the survey related to the research using the Delphi methodology were sent to 35 experts from different fields related to marine energies and specifically those related to the extraction of energy from the gravitational movement of waves.

As for the sample chosen, experts in the field of wave energy, researchers, academics, and technology developers were selected, each of the selected groups of experts was characterized as follows:

- **Academics**, individuals associated with higher levels of education. The variety of meanings of the concept of academics allows it to be used not only for those who carry out research or work as such, but also for individuals pursuing studies at the higher level. Therefore, there is a differentiation between researcher and academic, as the latter is oriented towards the dissemination of knowledge in regulated institutions.
- **Researchers**, considered as those who carry out or participate in research, that is, who carry out a project oriented towards the search for knowledge and the clarification of facts and relationships. Researchers are essentially engaged in scientific research.
- **Business/technology developers** are individuals who provide their professional services in companies that, based on the knowledge of both researchers and academics, try to give it a commercial return by applying the practical part of the theoretical knowledge of the previous groups.

All the information about the group of experts and their location will be found in Appendix A.

Phase 3: Execution of the Consultation Rounds

The initial questionnaire was drawn up, the information was analysed, and the next round of feedback was prepared and drawn up again to produce consensus/dissensus that responded to the objectives of the study. The responses were categorized and ranked according to the degree of agreement. The result was the starting point for subsequent opinions.

Initially, two areas of interest were differentiated for the selection of criteria affecting the feasibility of a wave energy harvesting installation. Based on these two areas, and at a lower level, 10 blocks of questions were established with the aim of comprehensively covering all facets that could affect the use of wave energy by a given WEC system. In turn, each of these 10 blocks had sub-blocks of questions on specific criteria, with the final questionnaire consisting of 50 multi-choice questions in which experts could answer between 1 (irrelevant) and 5 (highest importance).

The structure of the questionnaire and the description of the criteria is included in Appendix B. The first round of questionnaires was sent to 35 experts, however only 27 valid answers were received. Once the responses to the first round had been received, and the results obtained had been managed, a second round of questions was sent to the experts, in which they were informed of the results of the first round. The intention of providing this information was to try to achieve more consensus on the answers where there was more disagreement.

In this second round, the questionnaires were sent to 27 expert and only 22 valid answers were registered.

3. Results

Once the two rounds of consultations have been completed, the level of consensus of the responses obtained should be obtained as well as the level of importance given by the experts to each of the criteria, blocks, and areas.

An initial analysis of the results of the first round confirms that all the criteria established in the survey are of great importance for the evaluation of a wave energy installation in ports, as the average score for all the criteria was 3.95 out of 5, with the highest score being "Q33: Influence of the accessibility to the device for carrying out maintenance tasks" with 4.63 out of 5 and the lowest score being "Q13: Influence of the Seabed slope", with 3.04 points out of 5.

Table 2 shows the results obtained in each of the global areas as follows.

Table 2. Results obtained both from the two areas of research (values out of 5) and from the blocks that comprise them after round one.

Area/Block	Average Value	Standard Deviation
Conditions associated with the physical environment and seabed	**3.79**	**0.39**
Influence of the average and extreme wave regime on the choice of technology	3.89	0.30
Influence of the nature of the seabed and the location where the device is intended to be located	3.48	0.56
Conditions associated with the energy harvesting technology	**4.01**	**0.36**
available resource and its variability	3.80	0.34
influence of the power generation capacity	3.89	0.43
influence of the system efficiency	3.76	0.25
influence of the energy evacuation system	3.88	0.14
environmental factors	3.91	0.49
influence of logistics	4.33	0.39
associated economic concepts	4.13	0.30
social factors in the environment	4.14	0.19

This initially indicates that criteria related to energy production and economic performance have a higher level of preference in importance among the questioned experts.

Going into more detail on the results of the first round, it is confirmed that most of the blocks related to the Area 1 had lower scores than those from the Area 2. However, a second round of consultations was carried out to further refine the expert consensus on the different criteria, and the results of the first round of consultations were sent together with the questionnaire.

After the second round, the same trend of the results was obtained, although some changes in the convergence, measured by the standard deviation, of the experts' answers were detected. Table 3 shows the results obtained after the second round of consultation.

The results will be presented in more detail below.

According to the evaluation made by the 22 respondent experts to each criterion named from Q1 to Q50, two statistical elements being the *DI* (degree of importance) (Equation (1)) and the DC (degree of consensus) index were calculated to screen the criteria based on the plotted IG (importance graph) [27] (see Figure 1).

$$DI = (100 \times L1) + (75 \times L2) + (50 \times L3) + (25 \times L4) + (1 \times L5) \quad (1)$$

In this equation [27], $L1$ to $L5$ are the numbers of "highest importance" to "irrelevant" responses, respectively (Table 4). DC index was measured through the classification of the Likert scale responses into three main categories, as presented in Table 5. The highest percentage of experts who evaluated a parameter in one of the mentioned categories is selected to represent the DC index.

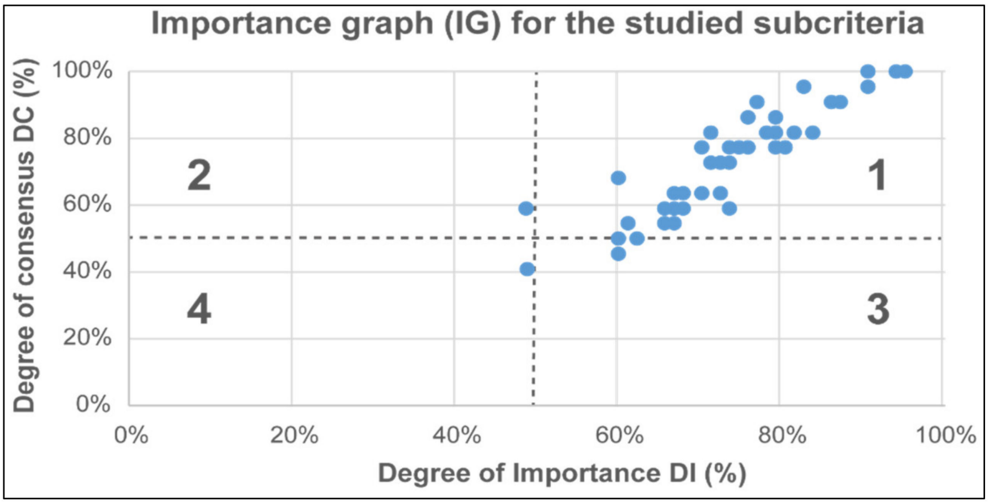

Figure 1. Dispersion graph showing the DI/DC relationship of all criteria analysed (Q1 to Q50). Area 1: DI > 50% and DC > 50%, Area 2: DI < 50% and DC > 50%, Area 3: DI > 50% and DC < 50%, Area 4: DI < 50% and DC < 50%.

Table 3. Results obtained both from the two areas of research (values out of 5) and from the blocks that comprise them after round two.

Area/Block	Average Value	Standard Deviation
Conditions associated with the physical environment and seabed	**3.73**	**0.36**
Influence of the average and extreme wave regime on the choice of technology	3.83	0.30
influence of the nature of the seabed and the location where the device is intended to be located	3.40	0.41
Conditions associated with the energy harvesting technology	**4.00**	**0.40**
available resource and its variability	3.80	0.25
influence of the power generation capacity	4.03	0.53
influence of the system efficiency	3.99	0.25
influence of the energy evacuation system	3.61	0.22
environmental factors	3.88	0.62
influence of logistics	4.37	0.52
associated economic concepts	4.03	0.35
social factors in the environment	4.06	0.17

Table 4. Likert scale weights.

Highest Importance	Important	Moderate	Not Important	Irrelevant
5	4	3	2	1

Table 5. Consensus categories.

Category	(A)	(B)	(C)
Rating	Highest importance and important	Moderate	Not important and irrelevant

Using the Equation (1) and the values from Tables 4 and 5, Table 6 shows the values obtained for the degrees of importance and consensus:

Table 6. Degree of importance (DI) and degree of consensus (DC) for all blocks evaluated.

Criteria	Overall		
	DI	Rank	DC
Influence of the average and extreme wave regime on the choice of technology	70.80%	7	68.18%
Influence of the nature of the seabed and the location where the device is intended to be located	59.85%	10	46.97%
Influence of the available resource and its variability	70.17%	8	63.64%
Influence of the power generation capacity	75.76%	4	74.24%
Influence of the system efficiency	74.77%	5	71.28%
Influence of the energy evacuation system	65.17%	9	62.12%
Influence of environmental factors	71.90%	6	70.45%
Influence of logistics	84.32%	1	87.27%
Influence of associated economic concepts	75.80%	3	73.18%
Influence of social factors in the environment	76.52%	2	77.27%

Further to Table 7 outcomes, it is worth highlighting the difference between the values of DI and DC between the academics and the researchers by one side and the business developers by the other side.

Table 7. Degree of importance (DI) and degree of consensus (DC) for every expert category.

Criteria	Academia		Researchers		Business Developers	
	DI	DC	DI	DC	DI	DC
Influence of the average and extreme wave regime on the choice of technology	69.00%	68.00%	67.29%	62.50%	81.00%	82.00%
Influence of the nature of the seabed and the location where the device is intended to be located	60.00%	53.33%	58.33%	44.44%	65.00%	60.00%
Influence of the available resource and its variability	71.25%	85.00%	65.33%	50.00%	80.00%	75.00%
Influence of the power generation capacity	71.67%	66.67%	77.08%	77.78%	76.67%	73.33%
Influence of the system efficiency	72.00%	76.00%	73.75%	65.00%	80.00%	84.00%
influence of the energy evacuation system	70.00%	73.33%	62.53%	55.56%	66.67%	66.67%
Influence of environmental factors	63.75%	60.00%	70.83%	70.35%	83.75%	80.00%
influence of logistics	81.00%	88.00%	85.00%	86.67%	86.00%	88.00%
Influence of associated economic concepts	74.02%	76.00%	72.92%	68.33%	84.50%	82.00%
Influence of social factors in the environment	75.00%	73.33%	72.92%	69.44%	86.67%	100.00%

When evaluating the answers given by the business developers, values of DI and DC equal or over 80% have been obtained for three blocks out of 10, these blocks being those related to "influence of climate extreme events in the choice of technology", "influence of the system efficiency" and "influence of social factors", all these blocks purely related to industrial issues, hence it is more likely that experts close to the industry are more concerned about them. Moreover, if we look much deeper in the results of the surveys, values of DI and DC equal or over 90% have been obtained for 11 criteria out of 50 whereas the values for academics were seven out of 50 and those for the researchers were only three out of 50 (see Tables 8–10)

Table 8. Criteria meeting DI $\geq$ 90% and DC $\geq$ 90% values.

Criterion	Block	Average Value	DI	DC
Q18: total energy generated (annual)—AEP	4	4.64	91.00%	100.00%
Q33: Accessibility to the device to carry out installation and maintenance tasks	8	4.64	91.00%	95.00%
Q36: Safety of the device in the event of extreme weather conditions	8	4.82	94.00%	100.00%
Q37: Durability of the components of the device	8	4.77	95.00%	100.00%

Table 9. Criteria meeting DI $\geq$ 90% and DC $\geq$ 90% values. Academia.

Criterion	Block	Average Value	DI	DC
Q2: Numerical modelling data	1	4.6	90.00%	100.00%
Q18: total energy generated (annual)—AEP	4	4.6	90.00%	100.00%
Q22: Capacity factor, Cf	5	4.6	90.00%	100.00%
Q33: Accessibility to the device to carry out installation and maintenance tasks	8	4.6	90.00%	100.00%
Q36: Safety of the device in the event of extreme weather conditions	8	4.8	95.00%	100.00%
Q37: Durability of the components of the device	8	4.6	90.00%	100.00%
Q38: Capital Costs—CAPEX	9	4.8	95.00%	100.00%

Table 10. Criteria meeting DI $\geq$ 90% and DC $\geq$ 90% values. Researchers.

Criterion	Block	Average Value	DI	DC
Q33: Accessibility to the device to carry out installation and maintenance tasks	8	4.58	90.00%	92.00%
Q36: Safety of the device in the event of extreme weather conditions	8	4.75	94.00%	100.00%
Q37: Durability of the components of the device	8	4.83	96.00%	100.00%

4. Discussion

Table 3 has given us information on the average values obtained for every area and block and the standard deviation. Considering these data and in relation to the dispersion of the responses received. Using the Empirical Rule, which said that almost all (99.7%) of the data would be within 3 standard deviations, 95% of the data would be within 2 standard deviations and 68% of the data would be within 1 standard deviation, if the distribution is a bell-shaped [34], and applying it to the obtained results:

Area 1: Conditions associated with the physical environment and seabed

- 69.2% of the values are distributed within one standard deviation of the mean,
- 92.3% within two standard deviations of the mean,
- 100% within 3 standard deviations of the mean.

Area 2: Conditions associated with the energy harvesting technology

- 73% of the values are distributed within one standard deviation of the mean,
- 91.9% within two standard deviations of the mean,
- 100% within 3 standard deviations of the mean.

The conditions required by the empirical law are not fully met, since 95% of the data are not within two standard deviations, probably due to the small sample size for an analysis of the data with this methodology. Therefore, these results show some volatility or uncertainty in the values obtained from the expert surveys, and do not give clear information on the level of consensus in the responses. Therefore, we will use the values of the degree of importance and consensus for the evaluation of the results obtained.

From the results shown in Table 6 it can be deduced that the logistics are the most important criteria to be considered when evaluating the feasibility of wave energy facilities (DI = 84.32% and DC = 87.27%), as they have shown the highest degrees of importance and consensus according to the experts' opinion. In relation to the number of questions included in the questionnaire, corresponds to 10% of the total, which means that there is a high degree of consensus and importance on only 10% of the questions among all the experts consulted.

The results obtained are consistent as, due to the relatively incipient state of the technology, it is important to use lessons learned from other more advanced sectors such as the oil and gas or offshore wind industries. In these sectors, logistical criteria are extremely important for the materialisation of projects.

In addition to the above, only the criteria related to economic (DC = 73.18%), social (DC = 77.27%), environmental (DC = 70.45%), system efficiency (DC = 71.28%) and energy production capacity factors (DC = 74.24%) reach high consensus values in the rating of these as being of great importance, although less so than that of the factors associated with logistics. This group corresponds to 50% of the questions asked, which together with the previous 10% results in 60% of the criteria for which there is a high consensus on their high importance in the evaluation of projects related to wave energy extraction.

Other criteria, such as those related to the nature of the location of the device, or the evacuation system of the generated energy remain at a discrete level of importance as well as consensus. These criteria correspond to 12% of the total number of criteria consulted with the experts.

First, the positions given to the blocks, including the criteria consulted to the experts according to their answers, will be discussed.

4.1. Influence of the Average and Extreme Wave Regime on the Choice of Technology

This block obtained the 7th place in terms of importance from the answers given by all experts. This means that although it is a matter worth to consider, it was not essential for the development of wave energy facilities.

By detailing the responses of each group of experts, academics gave it the 8th place, while researchers and developers gave it the 7th and 5th places respectively. it seemed that the developers gave more importance to these criteria as it influences other criteria such as survivability, availability of the resource and the maintenance and operational costs of the device.

4.2. Influence of the Nature of the Seabed and the Location Where the Device Is Intended to Be Located

This block obtained the 10th place in terms of importance from the answers given by all experts. This means that although it is a matter worth considering, it was not essential for the development of wave energy facilities.

By detailing the responses of each group of experts, all agreed to rank it 10th in importance out of all the blocks assessed.

4.3. Influence of the Available Resource and Its Variability

This block was ranked 8th in terms of importance from the answers given by all experts. By detailing the responses of each group of experts, academics gave it the 6th place, while researchers and developers gave it the 8th and 6th place respectively.

These results are surprising, because in the case of the researchers, only the criteria relating to the evacuation of energy and those relating to the nature of the seabed are considered less important, when it is known that to obtain a reliable and constant resource, in addition to having a reasonable amount of energy extractable from the resource, the variability of the resource should be as low as possible.

4.4. Influence of the Power Generation Capacity

This block of criteria was ranked in 4th place considering the responses of all experts. Particularly for each group of experts, academics ranked it in 5th place, researchers in 2nd place and developers in 8th place.

It is striking that this block of criteria is ranked 8th by one group of experts and 2nd by another. The reason could be that researchers work more theoretically on the technology of the device, while developers focus more on the exploitation of the device. For researchers it is important to maximise production capacity at the theoretical level while developers enter a more advanced state of TPL (Technology Performance Level) where they consider this contingency already solved.

4.5. Influence of the System Efficiency

This block deserves a similar treatment as for block 4. The ranking in importance for all experts was at 5th position, while in case of each group of experts it was at 4th, 3rd and 6th position respectively (academia, researchers, developers).

The efficiency of the wave energy extraction system is studied at a pre-commercialisation stage of project development and is linked to the definition of the type of technology to be applied. The efficiency of the device in generating energy is also related to the energy generation capacity, therefore the importance given by the experts to these criteria, both at global and disaggregated level, are consistent with those given to the criteria in block 4.

4.6. Influence of the Energy Evacuation System

The overall rank for this block was 9th. Similar results were obtained for expert researchers and developers, while academics were given 7th place in importance.

This result is rather surprising, as it relegates the type of PTO (Power Take-off) used, the distance to the energy discharge grid, and most importantly, to the authors' knowledge, the intended use of the energy to a residual role within the criteria to be evaluated.

It is necessary, at this point, to highlight the fact that almost no author in the literature reviewed gives importance to the use of the energy generated, since according to the results obtained from the consultation this factor is strongly related to economic factors, namely CAPEX (Capital Expenditures). However, according to the results of the study, the value of the degree of importance was 61%, and there is not a high degree of consensus on this point.

Specifically, the figures for evaluating the performance of a generation system are not the same when they are prepared by a business/technology developer who intends to sell energy to the market in a competitive framework as when they are run by a public entity to cover a specific supply need for social, structural or image reasons or to act as a technology driver, since in the latter case the profitability variables can be much more relaxed, even allowing there to be no profitability at all in the project. This is the case of public administrations or, in the case dealt with in this article, a Port Authority that manages a port and whose electricity grid it owns, supplying energy to the port's concessionary companies.

In these situations, a port's reasons for implementing wave energy (or other renewable energy sources) in its facilities are strategic, image and even corporate social responsibility reasons, so the profitability criteria of the installation may differ from those of projects promoted by private operators seeking to sell the energy to the grid.

4.7. Influence of Environmental Factors

The ranking given to this block, 6th out of 10, indicates that the environmental factors are important, although they are not the most important of all those assessed. In fact, the disparity in the evaluation of the different groups of experts confirms this, going from 9th place in the case of academics to 6th place in the case of researchers and finally to 4th place in the case of developers. These partial results could indicate a particular tendency on the part of the industry to comply with the increasingly demanding regulations on environmental protection and compatibility of wave energy facilities with other maritime uses.

4.8. Influence of Logistics

This block was the best ranked according to the experts' opinions. Only in the case of developers did it not reach the first place in importance, but it nevertheless came in second place.

Logistical criteria must indeed be considered among the most important in wave energy projects, as they directly influence the costs of installation, operation, maintenance, and decommissioning. A good choice of logistics associated with a wave energy installation can be the difference between a good project and a ruinous project, even if the conditions of resource availability and production capacity are optimal, bad logistical decisions can ruin a project.

In the research that is the subject of this article, there is also the fact that there is great agreement among the experts in giving maximum importance to these variables, as a degree of consensus of over 85% was obtained in all cases.

4.9. Influence of Associated Economic Concepts

Traditionally, the costs associated with projects together with the expected profitability of the projects play a key role in estimating project viability. However, because of the present research, this block came in 3rd place among the 10 blocks analysed. Looking at the responses by type of group, both in the group of academics and developers, this block came in 3rd place, while researchers gave it 4th place in importance.

The hierarchy given to this block is slightly surprising, because although its importance could be hidden behind the importance of the logistical criteria block, given that it directly affects the cost of the project, it is also true that the price at which wave energy is obtained should be competitive to displace traditional fossil fuels in the energy mix.

However, if we analyse the questions asked in this block, we can see that none of them is among the most important for the experts (see Table 8). Only in the case of academics and developers the questions in block 9 are among those given the greatest importance and with the greatest consensus of responses (Tables 9 and 11). These different assessments by the groups of experts are due to their location in the project development stage, as some are closer to the conceptual part and others to the exploitation part. Later, we will see that the criteria that maximise the economic performance of the installation as well as minimise the energy cost may not be the most important criteria in the case of port installations.

Table 11. Criteria meeting DI $\geq$ 90% and DC $\geq$ 90% values. Business/technology developers.

Criterion	Block	Average Value	DI	DC
Q1: Instrumental data	1	4.6	90.00%	100.00%
Q17: Average power available	3	4.6	90.00%	100.00%
Q18: total energy generated (annual)—AEP	4	5	100.00%	100.00%
Q25: Energy availability	5	4.6	90.00%	100.00%
Q32: Alignment with the Sustainable Development Goals.	7	4.8	95.00%	100.00%
Q33: Accessibility to the device to carry out installation and maintenance tasks	8	4.8	95.00%	100.00%
Q36: Safety of the device in the event of extreme weather conditions	8	5	100.00%	100.00%
Q37: Durability of the components of the device	8	4.8	95.00%	100.00%
Q39: Operation and Maintenance Costs	9	5	100.00%	100.00%
Q40: Estimated annual production per unit of CAPEX	9	4.8	95.00%	100.00%
Q41: Levelized cost of energy—LCOE	9	5	100.00%	100.00%

4.10. Influence of Social Factors in the Environment

Social factors and the environment have been ranked in 2nd place both in DI and DC. Initially, it would seem that economic and logistical criteria, which in the end influence economic criteria, would have to be considered the most important and with the greatest consensus among experts, however, the concept of sustainable projects is gradually becoming part of the strategy of companies.

It should be recalled that the criteria consulted within this block refer to social acceptance of the project, improvement of the corporate image and job creation. In this respect, policies such as the Green Deal condition the obtaining of subsidies to a high degree of implementation in the projects of initiatives related to the subject matter of this block, so it can be understood that the experts consider this type of criteria to be important to be able to undertake investments with institutional support.

Figure 2 shows the highest values of importance and consensus for the evaluated criteria.

Where it is seen that the highest importance and consensus are met for the logistics related criteria, more specifically those criteria related to the durability of the device, safety in the event of inclement weather, accessibility of the device for maintenance and the expected energy output.

This result means that what experts agreed to be essential in the evaluation of wave energy projects was to maximise energy production and minimise operational, repair and maintenance costs.

Second, the results obtained from each group of experts consulted, shown in Table 7, will be evaluated. In the case of academia, the criterion given the greatest importance and with the greatest consensus is logistics, and this result is repeated in the case of researchers. However, in the case of technology developers, social factors are the most valued and with the greatest consensus. This result may come as a surprise, but not that surprising given that companies are becoming increasingly sustainable due to stricter local and national funding policies and regulations regarding the development of sustainable projects.

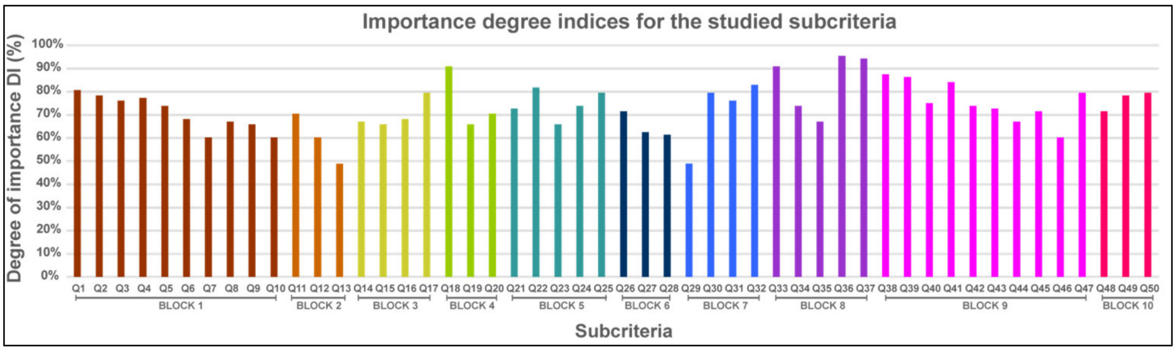

Figure 2. Bar chart showing the degree of importance (DI) of all criteria analysed (Q1 to Q50) by the experts consulted. Own elaboration.

At the other extreme, the criteria least valued by academics, researchers and technology developers are those related to the nature of the place of installation of WEC devices, although the level of consensus is not high.

In view of the above and confirming the first statements made at the beginning of this article, we see that there is no consensus on the importance of the different variables for the evaluation of wave energy extraction projects. In fact, the review of the existing literature has already revealed the disparity of existing criteria, which have been partially evaluated by the authors.

Figures 3–5 below evaluate the results obtained for every single criterion at the level of each group of experts.

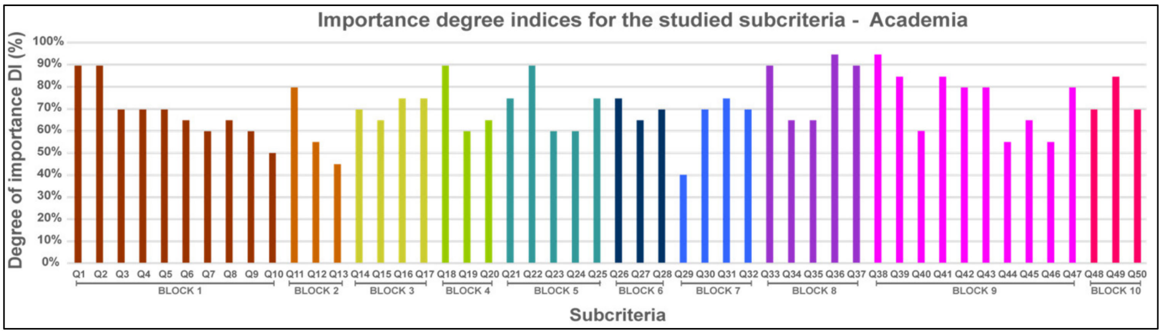

Figure 3. Bar chart showing the degree of importance (DI) of all criteria analysed (Q1 to Q50) by academia experts only. Own elaboration.

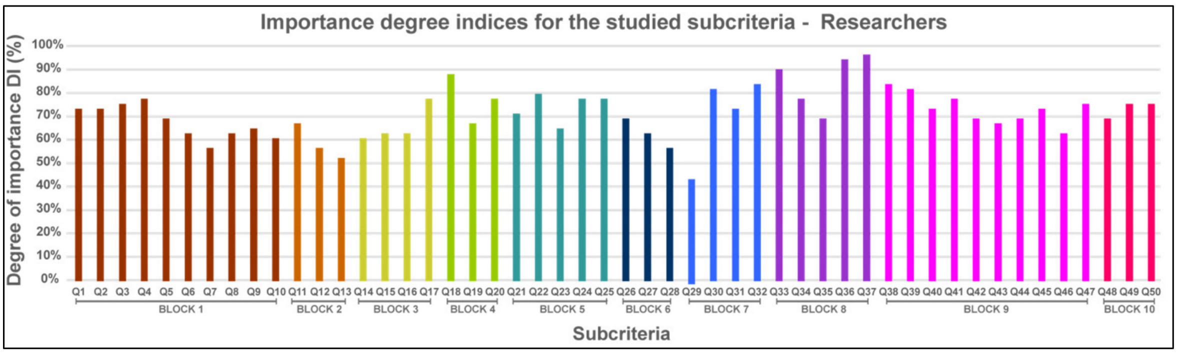

Figure 4. Bar chart showing the degree of importance (DI) of all criteria analysed (Q1 to Q50) by the research experts only. Own elaboration.

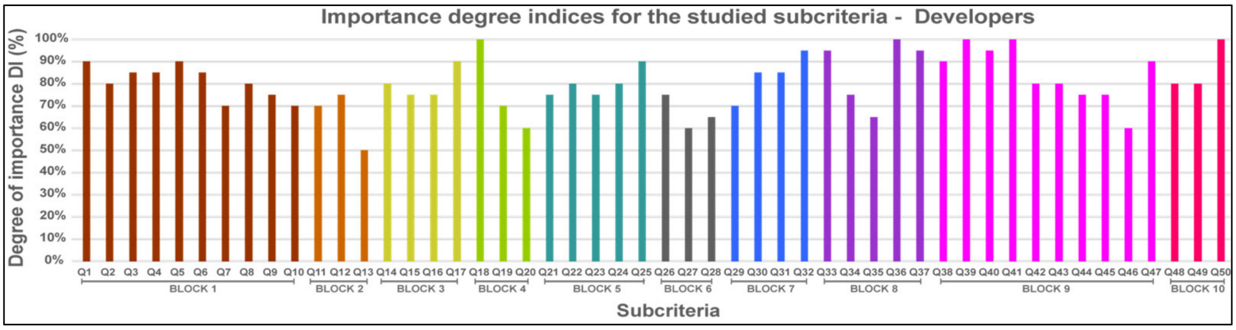

Figure 5. Bar chart showing the degree of importance (DI) of all criteria analysed (Q1 to Q50) by the business/technology developers' experts only. Own elaboration.

The same pattern applies when considering the answers given by every single group of experts, being the logistics block the most important and with the highest consensus. These results are shown in Tables 9–11 below.

It is deduced that academia gives importance to several criteria which build the overall conceptual design of the wave energy facility, however particular importance is shown in logistics related criteria. Attention is drawn to the fact that there is absolute consensus in the responses of the experts in this group on the criteria considered most important.

From the above results, it is seen that researchers give the most importance to the logistic related criteria.

As a result of the above, business developers give more importance to criteria related to logistics and economics, also resource availability and sustainable imaging related criteria are considered important. As in the case of the group of researchers, there is absolute consensus in the group of developers on the selection of the most important criteria among those considered in the survey.

One point that should be highlighted, in line with the objective of this article, is how these results influence the devices installed to supply energy in ports on their way to become energy self-sufficiency and zero emissions ports.

In the list of criteria established and consulted with experts, there are only a small number of them that refer specifically to onshore or near-shore facilities, most of which are included in block 8 of the criteria related to logistics. Therefore, when applying the methodology of this research to the case of ports, we will have to take this block very much into account, as they are the ones that cause the least uncertainty to the projects in these cases.

Remote areas, such as ports or islands, are highly dependent on energy generated elsewhere. This dependency can lead to shortages at critical times, which in the case of ports cannot be accepted as it would create a critical problem in the supply chain. It is therefore a necessity for ports to explore all possibilities available to them to secure the electricity supply that will allow them to continue to operate even in times of high energy demands. Due to space limitations in the ports, as the land reclaimed from the sea is very expensive and must therefore be used to make it profitable by carrying out pure maritime-logistical operations and not to produce energy, which could be produced in other locations. This is the key to ports and, being exposed to the effects of the maritime climate, they can use their protective docks to house wave power generation systems to ensure energy supply.

However, considering WEC technologies in a global scope and the results obtained in relation to the criteria that must be evaluated to study the viability of a WEC facility, the installation of these systems in ports offers a series of advantages that can make projects that are not viable from a standard point of view viable from a port point of view.

These advantages are several: on the one hand, logistics lose their weight, since it is not necessary to establish weather windows or use expensive vessels and highly qualified personnel for maintenance operations, nor is the availability of a sufficient resource essential to achieve a competitive energy value, since the infrastructures best oriented to the most abundant and constant resource will be chosen, nor would the PTO system to be implemented be so important, since being on land, the options could be expanded, in addition, the survival of the device would be greater since in case of extreme events it could be placed in safe mode without the need for complex logistics operations, and finally, the econometric criteria of viability would not be the same as in the typical off-shore case, since its profitability is not sought as a main priority but the energy autonomy of the port.

In continuation of the above, and considering that among all the criteria evaluated, those related to logistics are considered the most important and with the highest level of consensus, we believe that, in the specific case of port facilities, greater weight should be given to these criteria. Likewise, when determining the area where the wave energy device will be deployed, there are certain criteria among those evaluated that are no longer important or are less important in the evaluation of this type of project.

Continuing with the results obtained in the survey, there are criteria related to the nature of the deployment site of the device, since, being integrated in the port infrastructure, neither the depth, nor the material or the slope of the seabed are important. Therefore, for a further evaluation of port projects, criteria included in block 2 could be disregarded. In fact, already in the answers given by the experts, the criteria included in block 2 were considered the least important.

Finally, the criteria that fall in areas 2, 3 and 4 of the IG graphs, (Figure 1) are the least important and at the same time with the lowest consensus reached in the expert consultation. These criteria are related to landscape impact and the climate and nature of the location and mainly belong to blocks 1 and 2, both included in the Area 1.

Table 12 shows the lowest values of importance and consensus for the evaluated criteria.

Table 12. Criteria meeting DI $\leq$ 60% and DC $\leq$ 60% values.

Criterion	Block	Average Value	DI	DC
Q7: Direction of swell	1	3.41	60.00%	45.00%
Q10: Duration of events above a value of Tm	1	3.41	60.00%	50.00%
Q12: Material of the seabed	2	3.41	60.00%	45.00%
Q13: Slope of the seabed	2	3.00	49.00%	59.00%
Q29: Landscape impact	7	2.96	49.00%	41.00%

Again, we find that criteria that do not obtain a high degree of importance from the experts, in the case of port installations, are not important either, as the nature of the location is not important when considering an installation attached to the exposed breakwaters of the ports.

Occasionally, ports are forced to self-supply with energy in order to become energy independent, thus guaranteeing the supply for the port operations. In this case, the cost of energy criterium is not among the most relevant ones.

Considering the case of ports and based on the results obtained in [35] it is evident that according to the experts' opinions the logistic factors and due to their direct influence on CAPEX and OPEX, the economic factors are the most important in the evaluation of wave energy projects, and in their application to the case study they influence the following cost concepts:

- WEC (structure and prime mover), estimated at 38% of the CAPEX
- Balance of the plant, estimated at 33% of the CAPEX
- Installation and commissioning, estimated at 13% of the CAPEX
- Decommissioning, estimated at 10% of the CAPEX
- Operation and Maintenance expenditures, estimated at 94% of OPEX (up to 9% of CAPEX). For offshore wind in a plant with synergies we could reach 3%, therefore, being optimistic we could reach the same level in wave installations in ports)

Logistical criteria would play a more important role in the evaluation of the viability of the projects, since a decrease in the CAPEX and, therefore, in the OPEX of the projects due to a lower cost of the logistics associated with the projects could validate the classification of the social factors within the three most important criteria to be considered.

This, together with the fact that the main reason for the execution of these projects by the port management bodies is the accessibility to clean energy for self-consumption, makes wave energy installations in ports an interesting alternative in the future for the decarbonization of ports.

5. Conclusions

This paper aims to establish the most important criteria for assessing the feasibility of wave energy generation projects. After this, the authors proposed the application of the results to the case of WEC implementation in ports. To this end, and based on the existing literature, two areas of interest have been identified, formed in turn by ten blocks containing up to 50 criteria that have previously been considered of interest in the literature reviewed and which have been submitted to the consultation of experts in the field so that they can rate the latter according to their importance.

In 60% of the criteria consulted, the experts reached an elevated level of consensus in their assessment of the degree of importance of the criteria, while in 12% the consensus reached was not so high.

It is clear that the experts agree that the most highly valued criteria are those corresponding to the blocks related to logistics, economic viability and the social impact of the projects. These results are generally applicable to all projects. However, when transferring the results obtained to the case of facilities located in ports, these criteria, although of great importance, are less so, since ports as logistics platforms facilitate these tasks, and therefore their impact on the project's economy is lower. On the other hand, and linked to the above, the economic factors do not follow the usual profit pattern of commercial projects either, as depending on the existing need for accessible renewable energy production, profitability could be a secondary objective compared to the possibility of obtaining clean energy for self-consumption. Social criteria are linked to labour-related factors and the improvement of corporate image, which is increasingly being imposed on corporations.

As a consequence of the above, the experts have been questioned about their opinion on installations at a general level, without specifying any particular technology or location. These experts have been carefully selected among those whose trajectory is somehow linked to near shore or onshore locations.

The evaluation of wave energy projects cannot be assessed in a single way, as depending on the use to which the energy is put and the nature of the promoter, it will be necessary to consider giving more weight in the final equation to some criteria over others. Ports offer infrastructure where WEC could be deployed. In this case, factors such as efficiency or resource availability could be compensated by others such as survivability, easy access for installing and maintaining operations, and energy evacuation in terms of importance for the experts.

Considering logistics, PTO selection, survivability and energy production essential criteria for the evaluation of WEC facilities, ports could give a proper answer to them, as the locations that ports offer could solve the uncertainties created by these criteria.

In addition to the advantages of installing WECs in ports, when the most important thing is to secure energy supply and achieve energy independence, the economic viability of the project must be balanced with the former, to obtain the reality of the viability of the project as a whole.

Considering the results obtained, the advantages that ports can offer to the development of wave energy projects are evident: logistic costs, and therefore CAPEX and OPEX can be significantly reduced, thus compensating possible deficiencies that could eventually occur due to lower availability of the resource.

From this point on, the path is open for further research into this type of project, not only from the technical–economic feasibility side but also from the use and social side, in order to find the answer to the problem posed in this article.

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

Appendix A

Table A1. Detailed description of the experts participated in the study.

Row	Country	Sector	Area of Expertise	Status
1	The Netherlands	University	Ocean Renewable Energies, Offshore Wind, Climate Change, Energy Economics, Energy Policy and Numerical Modelling	PhD
2	Portugal	University	Coastal structures, physical modelling, coastal management, coastal dynamics, and sea energy.	PhD
3	Portugal	University	Ocean renewable energies and coastal engineering	PhD
4	France	University	Wave farms/generators matching methodology designer	PhD
5	Greece	University	Civil Engineering	PhD
6	Spain	Research Centre	Ocean waves advances numerical modelling and Ocean wave propagation	PhD
7	United Kingdom	Research Centre	Development of Standards for Marine Renewable Energy Systems	PhD
8	The Netherlands	Research Centre	Offshore engineering focused on floating marine energy devices	PhD
9	Portugal	Research Centre	Numerical methods and tools to simulate the dynamics of wave energy converters	PhD
10	Ireland	Research Centre	Estimation and forecasting the excitation forces on wave energy devices	MsC
11	Turkey	Research Centre	Civil Engineering	PhD
12	Belgium	Research Centre	Experimental Study of Wave-Energy Converter Arrays	MsC
13	Sweden	Research Centre	Renewable energy sources and their integration with the grid	PhD
14	Italy	Research Centre	Numerical modelling and structural optimization of multifunctional maritime structures aimed to protect harbours and produce energy	PhD
15	Australia	Research Centre	Marine renewables, wave dynamics and wave energy conversion	PhD
16	Spain	Research Centre	Marine Renewable Energies Harnessing	MsC
17	Portugal	Research Centre	Floating offshore wind technologies and wind farm design	MsC
18	Israel	Industry	Nearshore WEC developers	PhD
19	Spain	Industry	Nearshore WEC developers	PhD
20	USA	Industry	Off-shore wind farms developer	PhD
21	Ireland	Industry	Subsea construction and installation globally, including project management and offshore execution projects	Business developer
22	Sweden	Industry	Engineering program and system design of WEC	Engineering Manager

Appendix B

Area 1: Conditions associated with the physical environment and seabed.

Table A2. Block 1: Influence of average climatic extremes on the choice of technology. Q1 to Q10.

Id.	Sub-Criteria	Description	Reference
Q1	Instrumental data	Availability of reliable historical instrumental data sources for the deployment area	[24]
Q2	Numerical modelling data	Availability of validated historical data sources from numerical modelling of the deployment site	[24]
Q3	Average Wave height values	Influence of the Mean value to the mean values of Hm0 s of the historical data series	[23]
Q4	Extreme Wave Height values	Influence of the extreme Hm0 values of the historical data series	[18]
Q5	Average Tp values	Influence of the Mean value to the mean values of Tp of the historical data series	[23]
Q6	Average Tm values	Influence of the mean value to the mean values of Tm of the historical data series	[23]
Q7	Direction of swell	Influence of the predominant swell direction from the historical data series	[25]
Q8	Average directional frequency values	Influence of the mean value to the directional frequency distribution of energy from the time series of the free sea surface variation	[25]
Q9	Duration of events above a value of Hm0	Influence of the persistence over a wave height threshold (duration of events above a value of Hm0)	[36]
Q10	Duration of events above a value of Tm	Influence of the persistence over a wave height-period threshold (duration of events above a value of Tm)	[36]

Table A3. Block 2: Influence of the nature of the seabed and the location where the WEC device is intended to be placed. Q11 to Q13.

Id.	Sub-Criteria	Description	Reference
Q11	Depth	Influence of the depth of the study area	[20,37]
Q12	Material of the seabed	Influence of the type of pf material of the seabed	[19,20]
Q13	Slope of the seabed	Influence of the slope of the seabed	[19]

Area 2: Conditions associated with the energy harvesting technology.

Table A4. Block 3: Influence of the available wave resource and its variability on a wave energy project. Q14 to Q17.

Id.	Sub-Criteria	Description	Reference
Q14	Monthly variability of available power	Variation in the monthly average of the wave power over several years	[2,21,24,26,38]
Q15	Seasonal variability of available power	Variation in the seasonal average of the wave power over several years	[21,26,38]
Q16	Yearly variability of available power	Variation in the yearly average of the wave power over several years	[26,38]
Q17	Average power available	Average power available at the study point (kW/m)	[19,23,38,39]

Table A5. Block 4: Influence of power generation capacity. Q18 to Q20.

Id.	Sub-Criteria	Description	Reference
Q18	AEP	total energy generated (annual)—AEP	[22]
Q19	Available power at specific times	available power at specific times	[25,26,34]
Q20	Versatility of the device	Ability of the device to harness wave energy in both high potential and low potential areas	[34,40]

Table A6. Block 5: Influence of the efficiency of the generation system. Q21 to Q25.

Id.	Sub-Criteria	Description	Reference
Q21	Width factor, Cw	Defined as the capture width ratio of a WEC	[39]
Q22	Capacity factor, Cf	The capacity factor defined as the average electrical power generated divided by the rated peak power	[39]
Q23	Load factor, IL	Load Factor defined as the ratio of total energy used over a specific period to the total possible energy available within that period	[41]
Q24	Rated power of the device	Maximum power that a WEC can produce at maximum performance	[21,39]
Q25	Energy availability	Time during which the system is producing or Ratio of available resource to the device's ability to convert it into energy	[17,25]

Table A7. Block 6: Influence of the energy disposal system. Q26 to Q28.

Id.	Sub-Criteria	Description	Reference
Q26	PTO	Specific operational principle of evacuation of the wave energy harvesting system	[42]
Q27	Distance to the grid	Distance to the centre of delivery of the generated energy	[14,19,37]
Q28	Use of the electricity produced	Direct discharge to the electricity grid or supply to a specific consumer	[43]

Table A8. Block 7: Influence of environmental factors. Q29 to Q32.

Id.	Sub-Criteria	Description	Reference
Q29	Landscape impact	Landscape impact caused by the presence and operation of marine energy generating devices	[3]
Q30	Impact on marine fauna	Possible negative influence of devices on marine fauna	[20,37]
Q31	Compatibility with other uses	Integration of wave energy generation devices into the water and land-use planning of the area where they are deployed	[20]
Q32	Alignment with the Sustainable Development Goals.	Identification of initiatives with the UN Sustainable Development Goals (SDGs)	[44]

Table A9. Block 8: Influence of logistical factors. Q33 to Q37.

Id.	Sub-Criteria	Description	Reference
Q33	Accessibility to the device to carry out installation and maintenance tasks	Easy access to the device deployment area both for connectivity and lack of weather restrictions	[25]
Q34	Proximity to a port	Distance from the deployment area to a port	[14,20,37]
Q35	Area with a high density of maritime traffic	Whether the area of deployment of the device is within the limits of an area with high density of maritime traffic	[20,27]
Q36	Safety of the device in the event of extreme weather conditions	Survivability of the device in case of extreme climate events	[42]
Q37	Durability of the components of the device	Resistance of the device's components to fatigue caused by operation under normal conditions	[27]

Table A10. Block 9: Influence of economic and cost-benefit performance factors. Q38 to Q47.

Id.	Sub-Criteria	Description	Reference
Q38	Capital Costs—CAPEX	Initial costs of setting up a project, includes projects planning and purchasing, transporting, installing, and commissioning the WEC	[25,27,28,45]
Q39	Operation and Maintenance Costs	Costs for the normal operation of the device and to perform predictive maintenance	[27]
Q40	Estimated annual production per unit of CAPEX	Is the expected energy production by unit of CAPEX	[45,46]
Q41	Levelized cost of energy—LCOE	It is the total system cost per energy output based on annual average values, lifetime of the technology, and financing assumptions	[22,29,30]
Q42	Payback period (PP)	It provides the minimum number of years needed to recover the initial investment on a project.	[29]
Q43	Net Present Value (NPV)	Indicator that evaluates the profitability of a specific project. It is the sum of all the present values of the cash-flows corresponding to the project.	[29]
Q44	Profitability Index (PI)	It is the ratio between the present value of future expected cash flows and the initial amount invested in the project.	[29,30]
Q45	Internal rate of return—IRR	It is the rate of return that makes the net present value of all cash flows from a particular investment equal to zero.	[29,30]
Q46	Discounted payback period—DPP	It is used to calculate the amount of time that it will take for a project to "break even," or to get the point where the net cash flows generated cover the initial cost of the project.	[29]
Q47	Existence of a regulatory environment favourable to the deployment of these technologies	Existence of policies in force in favour of the deployment of marine renewable energy devices	[47]

Table A11. Block 10: Influence of social factors. Q48 to Q50.

Id.	Sub-Criteria	Description	Reference
Q48	Social acceptance	Public acceptance of the development of such devices	[48]
Q49	Job creation3	Creation of jobs related to the installation and operation of devices to produce energy from marine renewable resources	[25,29]
Q50	Corporate sustainable image	Improving the company's image by including sustainability criteria in its policies and processes	[49]

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