Manuscript Number: EGY-D-18-01213R1

Title: Delphi-based Prioritization of Economic Criteria for Development of Wave and Tidal Energy Technologies

Article Type: Full length article

Keywords: Wave and tidal energies, Economic criteria, Delphi methodology

Corresponding Author: Dr. Mohammadreza Kamali,

Corresponding Author's Institution: University of aveiro

First Author: Akram Jahanshahi, PhD student

Order of Authors: Akram Jahanshahi, PhD student; Mohammadreza Kamali; Mohammadreza Khalaj, PhD student; Zahra Khodaparast, PhD student

Abstract: Harness of wave and tidal energies can play an important role in the future energy portfolios to ensure the energy security and to reach the low-carbon energy development plans. However, despite the existence of adequate resources of these energies through the world, they have not been well exploited yet. This study has focused on the assessment of the economic criteria and their relative importance for the development of the wave and tidal energy technologies based on the experts' judgment. To this end, the expert elicitation process was performed using Delphi methodology. 5 main criteria and 29 sub-criteria were initially identified through a comprehensive literature review. During two rounds of Delphi questionnaires, the degree of importance and the degree of consensus values were identified for each individual parameter. According to the results achieved, selling the energy produced and tax incentives were rated as the most important factors with the highest degrees of consensus. While quotas and tenders were not identified by the experts participated in the survey with high importance on the development of wave and tidal energies although with low degrees of consensus.

Subject: Paper to be submitted Energy

8 August 2018

Dear Editor,

I am re-submitting here with a manuscript entitled: “Delphi-based Prioritization of Economic Criteria for Development of Wave and Tidal Energy Technologies” for publication in Energy. We would like to appreciate the reviewers for their favorable opinion and their comments which have contributed to more added value to the paper. We hope now our paper can be fully accepted for publication.

In the following we present our point-by-point responses to each of the comments of the reviewers.

Yours sincerely,

Corresponding author

Mohammad Reza Kamali

Editor comments:

- Authors should follow the instructions for writing the research highlights

Response:

The research highlights were revised according to the instructions.

- The highlights should include the main outputs/results of the study.

Response:

The research highlights were revised according to include the main results of the study.

- Please include a more detailed description of the Delphi process (e.g. description experts included - country, area of expertise, work sector...; description of the implementation procedure- online? Phone; personal interviews?; others)

Response:

An annex was added to describe the information of the experts participated in the study. The criteria for selection of the experts and the method used were clarified in the methodology section.

- Improve introduction with related literature demonstrating the scientific gap addressed in this study;

Response:

The introduction was improved with the related studies from the literature. Please see page 4, line 9 - page 5, line 4.

- Analyse the results comparatively to other studies from the literature.

Response:

In fact, the authors could not find any similar study in the literature for prioritization of the economic criteria of marine renewable technologies. However, in the discussion part, the main related studies were comprehensively cited and discussed. Please see the discussion part of the paper.

- Clearly demonstrate in the conclusions how the specific results of this study can be used by decision makers and other stakeholders.

Response:

The discussion was revised to demonstrate how the results of this study can be used by the involved parties.

Reviewers' comments:

Reviewer #1: It is a topic of interest to the researchers in the related areas, but the paper needs some significant improvement. My detailed comments are as follows:

1.It is noted that your manuscript needs careful editing by someone with expertise in technical English editing paying particular attention to English grammar, spelling, and sentence structure so that the goals and results of the study are clear to the reader.

Response:

The English of the paper was carefully revised in order to improve the grammar, spelling and sentence structure.

2. The knowledge gap needs to be clearly addressed in Introduction. Literature survey is not sufficient. You should carry out a thorough literature survey of papers published in the last three/four years.

Response:

A literature review was added to the introduction of the paper to clarify the knowledge gap. It was tried to include the most recent published papers in the field to improve the literature survey. Please see page 4, line 9 - page 5, line 4.

3. Also, there are few explanations of the rationale for the study design. Try to set the problem discussed in this paper more clearly.

Response:

It was tried to add more explanations for the rationale of this study in the introduction part. Please see page 4, line 9 – page 4, line 19.

4. The section of Results is too simple. Furthermore, an explanation of why the authors did these various discussions should be provided. Based on the above, I suggest the paper could be published after major changes.

Response:

More results were included to the results section. Please see page 8 line 10 to page 10 line 5. The discussion provided in the paper is to compare the results of these study with the other published papers in the field and to clarify how the results can be used by the involved parties. Now, it has been more clarified in conclusion and introduction parts.

Reviewer #2: Development of wave and tidal energy can significantly contribute to the efforts in overcoming climate change and other environmental challenges we face in the energy sector. In this regard, the authors' effort in analyzing the priority economic criteria in such development is appreciated.

However, the final objective of a paper of this nature should have been to examine the barriers to development and deployment of these technologies. Prioritizing economic criteria and addressing those priority areas are only part of one element. In this regard, it would have been better if the scope of the study were expanded to encompass other aspects of development of these technologies. In my view, other external factors such as low energy density (leading to structures spanning larger areas of the coast having their own economic value) and engineering challenges are the ones which really inhibit growth of deployment of these technologies worldwide unlike most of the other established technologies such as wind and solar. It would have been better if these aspects were covered in the survey with a more in-depth analysis followed by conclusion. The authors are encouraged to expand the study to examine most of the possible challenges to development and deployment of these technologies.

Response:

The comments from the reviewer is highly appreciated. The scope of this study is to identify, to screen, to prioritize and to discuss how the economic factors can influence the development of marine renewable energies. Any of such economic criteria can be interpreted where applicable. For instance, requirement for structures spanning larger areas may influence the initial investments for such technologies. In the discussion part, it has been tried to address such issues and to provide recommendation to increase the economic benefits from such technologies. It is evident that other studies for the evaluation of the importance of technical and environmental criteria are highly welcome but in our points of view it would be very difficult to consider all this aspects in one paper which may prevent an in-depth discussion for each of these criteria. However, the comments of the reviewer encouraged us to expand our studies to other areas. Hopefully, in the near future, the results will be submitted in separated papers for consideration in Energy journal. It should be noted that the necessity of considering other factors are now emphasized in the paper according to the comments from the reviewer. Please see page 3, line 10 - page 4, line 6.

Highlights

- 29 economic criteria for W&T energy technologies development were screened.
- Operational costs and revenue were identified the most important economic criteria.
- Recommendations for W&T technologies development were provided and discussed.

1 **Delphi-based Prioritization of Economic Criteria**
2 **for Development of Wave and Tidal Energy**
3 **Technologies**

4 Akram Jahanshahi^a, Mohammad Reza Kamali^{b,*}, Mohammadreza Khalaj^c,
5 Zahra Khodaparast^d

6 ^a. Department of Economics, Management, Industrial Engineering and Tourism, Department of
7 Mechanical Engineering, University of Aveiro, 3810-193 Aveiro, Portugal. jahanshahi@ua.pt

8 ^b. Department of Environment and Planning, Center for Environmental and Marine Studies,
9 CESAM, Aveiro Institute of Materials, CICECO, University of Aveiro, 3810-193 Aveiro, Portugal.
10 kamali@ua.pt

11 ^c. Department of Environment and Planning, University of Aveiro, 3810-193 Aveiro, Portugal.
12 khalaj@ua.pt

13 ^d. Department of Biology, Center for Environmental and Marine Studies, CESAM, University of
14 Aveiro, 3810-193 Aveiro, Portugal. khodaparast@ua.pt

16 **Abstract**

17 Harness of wave and tidal energies can play an important role in the
18 future energy portfolios to ensure the energy security and to reach the low-
19 carbon energy development plans. However, despite the existence of adequate
20 resources of these energies through the world, they have not been well exploited
21 yet. This study has focused on the assessment of the economic criteria and their
22 relative importance for the development of the wave and tidal energy
23 technologies based on the experts' judgment. To this end, the expert elicitation
24 process was performed using the Delphi methodology. 5 main criteria and 29

* Corresponding author E-Mail: Kamali@ua.pt

sub-criteria were initially identified through a comprehensive literature review. During two rounds of Delphi questionnaires, the degree of importance and the degree of consensus values were identified for each individual parameter. According to the results achieved, selling the energy produced and tax incentives were rated as the most important factors with the highest degrees of consensus. While quotas and tenders were not identified by the experts participated in the survey with high importance on the development of wave and tidal energies although with low degrees of consensus.

Keywords:

Wave and tidal energies, Economic criteria, Delphi methodology.

1. Introduction

The ongoing demand of energy has been a critical challenge for human societies all around the world [1]. In this sense, there is an obvious relationship between the economic growth and energy demand, especially for developing countries [2]. Currently, a large portion of the world's energy need is met by the liquid and gaseous fossil fuels (i.e., petroleum and natural gas) [3]. This is because of their widespread availability and the convenience of use. Hence, fossil fuels are still the driving force behind the technological progresses in many countries through the world. However, the evacuation of fossil fuels and the disastrous environmental effects of excessive consumption have forced communities to reconsider and to limit the use of fossil fuels as a source of energy. Increasing the demand for energy and the rising energy price in one hand, and the environmental consequences on the other hand, have made it inevitable to develop and to facilitate the use of urgent alternative energy resources. With this motivation, development of a sustainable and clean source

of energy has attracted a huge attention from academic, social and political communities. Due to this fact that more than 70% of the surface of the earth is covered by the seas and oceans, exploitation of energy from marine water movements can be considered as a good solution to address the mentioned global issues. This form of energy can be harnessed for electricity generation for various applications such as transport, domestic uses and industrial activities.

Wave and tidal (W&T) energies are the most extractable sources of ocean energy technologies [4]. So, there has been a tendency for the rapid development of these technologies worldwide. For instance, in the EU it has been aimed to extract 100 GW of combined W&T energies by 2050 [5]. In this regard, identification of both driving parameters and development barriers of these energy technologies may be helpful to accelerate taking advantage of these technologies. Since W&T energy technologies are still at an early stage of development [6], economically, technically and environmentally reliability, feasibility, and survivability of the devices need to be studied [7,8]. According to Uihlein & Magagna, (2016)[6] about 68% of funded researches by EU in the marine energy is related to technology development sector. Environmental consequences have also crucial roles in the development of such novel technologies. Manufacturing, operation, maintenance and decommissioning of marine energy devices as all other renewable sources of energy will have some environmental impacts. Impact on the benthic community [6,9], species-specific response to habitat change [6], the entanglement and collision risk of marine mammals, turtles, larger fish and seabirds [6] along with the impact of noise [6,8,10], vibration [6], electromagnetic fields [6,8,10], competition for space [6], beach morphodynamics [11,12], marine archaeology [12] and visual impacts [9] are among the possible environmental impacts of such energies.

1 Nonetheless, the environmental impacts such as pollution, visual pollution and
2 noise of the current marine energy devices are smaller than other forms of
3 renewable energies. The structure of the rotors is also such that the blades have
4 the least effect on marine habitats [8]. In spite of the determinative roles of
5 economic parameters in the development of marine energy technologies, fewer
6 studies have addressed to these parameters.

7 Due to the importance of economic consideration for the rapid
8 development of these technologies, it would be vital to screen and prioritize the
9 main influencing economic criteria. To the best of the authors' knowledge,
10 economic incentives and barriers to the development of marine energy
11 technologies have not been discussed systematically in the literature.
12 Identifying the relative importance of each criterion, in addition to contribute to
13 the pace of the development may enhance the economic benefits. In the
14 economic studies in marine energy, each of the different economic criteria has
15 been studied individually, for instance, making an estimate of the current and
16 future costs of marine energy and cost-benefit analyses [6]. Considering all
17 criteria would be necessary in order to establish sustainable policies. Multi-
18 criteria decision analysis (MCDA) could help to weight different economic
19 factors based on the importance on the development of marine technologies.
20 There are a few studies in the literature which have used multi-criteria analysis
21 in the energy sector. For instance, Borges and Antunes (2003)[13] applied a
22 Fuzzy multiple objective decision support model instead of input-output model
23 for energy economy planning. In another study, San Cristóbal (2011)[14] used
24 MCDA for selection of renewable energy project in Spain. According to the
25 results, biomass plant option is the best choice, and wind and solar power are
26 the second and third alternatives [14]. Hartmann et al. (2017)[15] applied

MCDA to revise the Hungarian Renewable Energy Utilization Action Plan. The results indicate that bioenergy will occupy the most fraction of Hungarian renewable portfolio by 2020. In association with economic assessment of marine energy, authors did not find relevant study in the literature. To this end, this paper aimed to identify and prioritize the mentioned criteria and sub-criteria, and to identify their relative importance for the development of the W&T energy technologies according to the expert elicitation process.

2. Materials and methods

According to the literature, the main economic criteria and sub-criteria which may have important effects on the development of W&T renewable energies were categorized in five main groups. The identified criteria were then screened and weighted using the Delphi methodology.

Screening process of the criteria and sub-criteria and the weighting process were performed using Delphi methodology [16,17]. To this end, a total 21 experts from academic, industrial and governmental organizations from various countries (see appendix) participated in the survey. Careful selection of the participants was performed in order to minimize the bias and also to ensure the incorporation of different panelist's perspectives. Characteristics such as having an extensive knowledge in the field, the ability to simplify the complicated problems and the ability to communicate with expertise were considered to select the participants [18]. Participants were requested to assign weights to the proposed criteria in order to reflect the importance of each parameter, based on a five-point Likert scale, as shown in Table 1.

Table 1.

Likert scale weights.

Very important	Important	Moderate	Not important	Negligible
9	7	5	3	1

According to the points given by the experts to each criterion, two statistical elements including the degree of importance (DI) (Eq.1) and the degree of consensus (DC) index were calculated in order to screen the criteria based on the plotted importance graph (IG).

$$DI = (100 * L_1) + (75 * L_2) + (50 * L_3) + (25 * L_4) + (1 * L_5) - (100 * N) \quad \text{Eq.1}$$

In this equation, L_1 to L_5 are the numbers of “very important” to “negligible” responses, respectively (Table 1). Also, N in this equation refers to the number of “not necessary” responses. DC index was measured through the classification of the Likert scale responses into three main categories, as presented in Table 2. The highest percentage of experts who evaluated a parameter in one of the mentioned categories is selected to represent the DC index.

Table 2.

Consensus categories.

Category	(A)	(B)	(C)
Members	Very important and important	Moderate	Not important and negligible

3. Results

3.1 Identification of main criteria and the sub-criteria

According to the literature, the main economic criteria and sub-criteria with the important effects on the development of W&T renewable energies were identified and grouped in five main categories, namely, incentives (C1), profitability factors (C2), pre-operation costs (C3), operational costs and revenue (C4) and externalities (C5).

Incentives are here referred to those policy-based tools accomplished by the governments to encourage the potential investors to invest in marine renewable energy or to expand their existing activity in this area. Ownership right (C11) [10,19–21], feed-in tariffs (C12) [6,19,30,31,22–29] , quotas (C13) [22,23,27,30,32], tenders (C14) [22,23,30], tax incentives (C15) [22,23,31–34] and public financial supports (C16) [4,26,30,35,36] are the sub-criteria identified for the incentives in this survey which seem to have important roles in pushing the investments on the W&T energy technology (Table 3).

Profitability is another main economic criterion which can determine the potential of a marine energy facility to compete against other sources of energy. This factor can be also of high importance to attract new investments and to a company's long-term survivability. Cost competitiveness against other renewable energies (C21) [36–38], short-term return of the investments (C22) [37] direct profitability (C23) [8,25,29,34,39], cost competitiveness against conventional energy sources (C24) [4,8,34,38,40,41], combination possibility (C25) [25,38,42,43], relative profitability (C26) [8,25,34,39,44] and relative return period (C27) [8,34] are the sub-criteria of profitability we extracted from the literature as important factors in attracting investment towards the W&T energy facilities (Table 4).

Pre-operating cost (C31) [38], first devices capital cost (C32) [36], costs of licenses and permissions (C33) [9,38,45] and initial investments (C34) [29,38,46,47] were identified the main branches of this criterion (Table 5).

In the category of operational costs and revenue, parameters including operational expenditure (C41) [4,38,40,43], decommissioning costs (C42) [38,39,48–50] and selling the energy produced (C43) [19,27,34,38,40] may play the role of influencing sub-criteria (Table 6).

Externalities deal with the economic consequences of the activities experienced by unrelated third parties. The impacts of W&T renewable energies on: wholesale electricity price (C51) [25], system operation costs (C52) [25], GDP (C53) [6,24,50,51], trading carbon credits (C54) [21,38,44], energy supply security (C55) [6,23,31,38,50,52], creation of new jobs (C56) [6,10,38,50,53,54], integration potential into the economic fabric (C57) [38], the price volatility (C58) [22,55] and development of relevant net technologies (C59) [55] are here considered as crucial parameters, according to the main goals of this study (Table 7).

Table 3
Main sub-criteria of the “incentives” criterion.

Identification	Sub-Criteria	Description	Reference
C11	Ownership	The right to own the objects, the land, or the intellectual property for all parties including idea makers, investors, etc. in various stages of a marine energy facility development.	[10,19–21]
C12	Feed-in tariffs	A set of policies for offering ensured prices for the electricity produced from marine energy sources, for a certain period of time.	[6,19,30,31,22–29]
C13	Quotas	A set of quantity-based policy tools which involves electricity retailers to supply a portion of the electricity demand from marine energy sources.	[22,23,27,30,32]
C14	Tenders	The mechanisms adopted by the governmental organizations to persuade the producers to produce electricity from marine energy sources at a lower cost as the winner of a tender is whom with the lowest proposed cost.	[22,23,30]
C15	Tax incentives	A set of governmental fiscal policy instruments to encourage the investors to invest in marine energy technology.	[22,23,31–34]
C16	Public financial supports	Direct financial supports received from the government to develop marine renewable energies.	[4,26,30,35,36,56]

Table 4
Main sub-criteria of the “profitability” criterion.

Identification	Sub-Criteria	Description	Reference
----------------	--------------	-------------	-----------

C21	Cost competitiveness against other renewable energies	The relative cost of electricity producing by marine energy facilities compared with other renewable energies.	[36–38]
C22	Short-term return of the investments	Described as the expectations for the return of the investment in a relatively short period of time.	[37]
C23	Direct profitability ^a	A factor which aids the investors to investigate profitability of the investment on the project based on their expectations.	[8,25,29,34,39]
C24	Cost competitiveness ^b against conventional energy sources	The relative cost of electricity producing by marine energy facilities compared with other energy sources.	[4,8,34,38,40,41]
C25	Combination possibility	The possibility for the combination of different marine energy facilities to reduce the investment costs.	[25,38,42,43]
C26	Relative profitability ^c	The relative profitability of electricity producing by marine energy facilities compared to other energy sources.	[8,25,34,39,44]
C27	Relative return period ^d	The relative return period of the investments in marine energy facilities against other energy sources.	[8,34]

- 1 a. Measured by net present value (NPV) index. Strict positive for the value of the project according NPV is a required
2 condition for being profitable.
3 b. Measured by levelised cost of energy (LeCOE).
4 c. Measured by internal rate of return (IRR).
5 d. Measured by discounted pay-back period (DPBP).

6 Table 5

7 Main sub-criteria of the “pre-operation costs” criterion.

Identification	Sub-Criteria	Description	Reference
C31	Pre-operating cost	Defined as the costs of primary studies, environmental impact assessment (EIA), consenting procedures, management, etc.	[38]
C32	First devices capital cost	Defined as the level of deployment before the sustained cost reduction, and the learning rate (which is the average rate of cost reduction with deployment).	[36]
C33	Costs of licenses and permissions	The cost of acquiring the official permissions or permits to develop a marine energy facility.	[9,38,45]
C34	Initial investments	The installation cost required for the marine energy facilities.	[29,38,46,47]

8

9 Table 6

10 Main sub-criteria of the “operational costs and revenue” criterion.

Identification	Sub-Criteria	Description	Reference
C41	Operational expenditure	The overall costs related to the operation and maintenance activities, revision and time off, spares, public	[4,38,40,43]

		services, renting, insurance and taxes.	
C42	Decommissioning costs	The whole plant is supposed to be dismantled after a limited period of years and the decommissioning cost could be estimated as a percentage of the initial investment.	[38,39,48–50]
C43	Selling the energy produced	Defined as the total energy production multiplied in the price.	[19,27,34,38,40]

Table 7

Main sub-criteria of the “externalities” criterion.

Identification	Sub-Criteria	Description	Reference
C51	Impact on wholesale electricity price	The effect of the electricity of the marine energy facilities on the price of electricity sold as a whole.	[25]
C52	Impact on system operation costs	The effect of the operational cost of electricity produced by a marine energy facility on the overall operational cost for the production of electricity from all the resources.	[25]
C53	Effects on GDP	Defined as the effects of energy facilities on the gross domestic product.	[6,24,50,51]
C54	Trading carbon credits	The benefits from selling the surplus carbon credits achieved from the reduction of greenhouse gases by using marine energy facilities.	[21,38,44]
C55	Energy supply security	The decrease in the risks attributed to the supply cuts of conventional fuels.	[6,23,31,38,50,52]
C56	Creation of new jobs	Defined as the effect of marine energy facilities on the creation of new jobs.	[6,10,38,50,53,54]
C57	Integration into the economic fabric	The potential of a given marine energy facility to activate (or re-activate) other local businesses.	[38]
C58	The effect on price volatility	The potential effect of a marine energy facility or a set of marine energy facilities to prevent the volatility of the energy price.	[22,55]
C59	Development of relevant net technologies	The effect on the formation of local, national or international firm clusters working in different but relevant technological field.	[55]

3.2 Delphi methodology

Through conducting two rounds of Delphi, two main indexes, including DI and DC were measured to identify the importance of the economic criteria influencing in the development of W&T renewable energies. The contributors received the report of the first round, including the outputs, prior to the second round. Fig.1 shows the percentages of the Likert weights (Table 1) allocated to

the five categories of the main criteria. In all cases, the sums of the “important” and “very important” measures are greater than 50% indicating that they are all important for the development of W&T technologies. However, by looking more precisely at the weighting distribution of the results, it is evident that the operational costs and revenue obtained more scores in the two mentioned scales (63%). In addition, pre-operation costs (58%), incentives (57%), profitability (54%) and also externalities (54%) were allocated next importance among the main categories of the studied criteria.

Fig. 1.

Distribution of contributed answers on the Likert scale for main criteria.

The degree of importance values for the studied sub-criteria obtained by applying the Eq.1 is shown in Fig.2. Selling the energy produced (C43) and tax incentives (C15) achieved the highest DIs (93% and 83%, respectively). Whereas, quotas (C13) and tenders (C14) were rated less important sub-criteria (DIs = 49% and 48%, respectively), although there is no consensus among the experts about their low importance. The integration of DI values and DC values are presented in Fig.3. This figure shows the relationship between the evaluated importance degree for each sub-criterion and the calculated degrees of consensus for the sub-criterion.

1 **Fig. 2**
2 Importance degree indices for the studied sub-criteria.

3 **Fig. 3**
4 Importance graph for the studied sub-criteria.

5 In Figure 3, parameters located in quartiles 1 and 3 have the DI values
6 more than the threshold (50%) emphasizing the high importance of the
7 parameters. When a criterion is located in quartiles 2 or 4, it reveals that the
8 criterion has lower importance regarding the main goal of the study. Hence,
9 except the quotas (C13) and tenders (C14), all the studied sub-criteria have been

evaluated by the experts highly important for the development of W&T energies. Although there are no recommendations for the DC threshold of the Delphi methodology [57], a 50% consistency in the answers provided by participants has been proposed as the acceptable threshold for this index [18]. Using this threshold, only the quartiles 1 and 2 can contain the parameters with high consensus levels. So, there are no high levels of consensus for the degree of importance values of the quotas (C13), tenders (C14), combination possibility (C25), cost of licenses and permissions (C33) and selling the surplus carbon credits (C54) among the participant experts. All the remained sub-criteria are located in quartile 1 meaning that they have important effects on the development of marine renewable energies.

4. Discussion

As stated before, operational costs and revenue has been ranked the most important criterion from the experts' points of view. Pre-operation costs and investment, incentives, profitability and externalities are ordered in the next priorities, respectively. The following sections are to discuss how the sub-criteria of these main criteria can affect the development of W&T renewable energies.

4.1 Operational costs and revenue

From the studied sub-criteria of operational costs and revenue, selling the energy produced ($DI > 90\%$) from these sources was identified as the most important economic sub-criterion. This parameter has an essential effect on the attraction of the potential investors. Since marine energy is a less developed technology among the renewable energies [25] and there are a lot of uncertainties on the prices and the demand for the produced electricity,

governmental supports may be crucial to ensure long-term economic benefits of these types of renewable energies. The operational expenditures criterion which includes the cost of annual operating and maintenance tasks, insurance, rent payments, taxes, etc. is also a determinant criterion in the development of W&T energy technologies. However, there is not still a precise calculation of the operational expenditures due to the novelty of W&T energy technologies. Engineering designs to reduce decommissioning costs can also to some extent influence the economic profitability of the marine renewable energies (DI=50%). Generally, decommissioning costs are higher than required due to less attention paid to this item during the initial engineering and construction of a wave or tidal energy facility. The experiences from offshore technologies can also reinforce this idea. For instance, Stokes (2014) [58] indicated that a 50% reduction in decommissioning costs of an offshore oil and gas field can increase the net present value (NPV) by 13%.

4.2 Pre-operation costs

Among the pre-operation costs and investments, the amount of the initial investments in W&T technologies is the most important parameter (DI= 80%). Hence, the potential investors are exposed to a very high degree of risk without adequate public supports [32]. This can be considered another reason why the public supports are so important for the development of W&T technologies. Pre-operating and first device capital costs have gained the next priorities when considering the economic criteria for the development of W&T energies. In spite of the availability of adequate resources to ensure the generation of the consistent marine energy in many regions of the world [59] many types of marine energy facilities are in their infancy stages yet. For instance, tidal

current turbines as well as wave energy turbines are less developed compared with the devices like tidal barrages, probably due to the existing economic barriers [60]. Any decrease in initial costs may result in pushing the involved parties to overcome the remained technical barriers attributed to the scientific knowledge required for the design, production and test of the more mature devices [61]. The importance of the first device capital costs have also been emphasized by the recent studies. MacGillivray et al. (2014) [37] by using a single-factor learning model indicated the sensitivity of W&T energies to main factors including the first devices capital cost, the deployment level before reaching the sustained cost reduction, and the learning rate.

The cost of acquiring official licenses or permissions (DI>55%) to develop a marine energy facility is another factor that may have a moderate effect on W&T energies rapid development. The process may be complicated and costly for the developers of new advanced technologies such as marine renewable energy. Although the direct costs of licenses and permissions are estimated to be a small percentage of the initial investments on the W&T devices [39], governmental supports may be required to facilitate the related procedures to motivate the investors.

4.3 Incentives

Tax incentive as a governmental fiscal policy can also have a very high influence (DI>80%) in the attraction in investments on the development of marine energy facilities according to the opinions of our participants. For instance, reducing the financial burden, as a tax incentive policy, can potentially encourage the marine energy investors or developers to allocate the financial resources to establish new facilities or to expand the existing marine power

capacities [32]. The importance of the public supports for marine renewable energy development can be more highlighted through an insight on the difficulties involved in the early stages of development of such energies when the marine energy facilities are passing through the lab-scale to real-scale installations, which is so-called “valley of death” [35,62]. The public financial supports (also $DI > 80\%$) can also extensively aid to develop more advanced low-cost facilities through promoting the high-quality R&D activities. This way, governmental financial investments are supposed to encourage individual investments in lower-risk marine energy facilities.

Feed-in tariff, as another incentive, can offer an ensured minimum price for the electricity produced from the wave or tidal energy sources, for a certain period of time [33]. This incentive policy, that has gotten a high degree of priority in this study ($DI > 70\%$), diminishes the uncertainties about the fluctuations of the selling prices, helps investors to make positive decisions in a more secure environment and consequently, pushes the selling of generated electricity. The second tool for the reinforcement of the produced electricity selling can insure the amount of the electricity sale. A quota ($DI = 49\%$) involves the electricity retailers to supply a portion of the electricity demand from marine energy sources. However, based on the results achieved in this study, feed in tariff as a price-based policy instrument has been evaluated much more important than the quota as a quantity-based policy, to promote the deployment of marine renewable energy facilities. More significant effects of feed-in tariffs than quotes have been obtained by Kilinc-ata (2016)[22]. Also, Brer and Wstenhagen (2009)[31] through studying 60 investments from European and North American venture capital and private equity funds indicated that feed-in

tariffs are the most effective tools to promote investments on such emerging renewable energies.

The ownership can also slightly enhance or limit the tendency of the parties who want to engage in the developments. Effective mechanisms can guarantee the economic benefits for the investors and innovators in a logical period of time. Such mechanisms are required to ensure the share of the investors to dominate the future markets [19]. Tender is also among the policy instruments (although with the least degree of importance, less than 50%) that governments can adopt to encourage the development of W&T energies to generate marine energy with a lower cost. As a result, their cost competitiveness against other renewable energies will be increased.

4.4 Profitability

Cost competitiveness against other renewable energies is another significant economic sub-criterion regarding the accomplished Delphi method ($DI \sim 75\%$). In spite of the existence of enormous sea and ocean resources worldwide, the energy generated by these resources is not in commercial level yet. It is mainly due to the existing barriers which make the produced energy more expensive compared with other renewable energies [32]. It is maybe one of the most important reasons that wind and solar renewable energies have gained more attention by scientific communities, social bodies, governments and other parties. However, it seems that technical solutions can considerably decrease the cost of the energy produced compared with other sources of renewables. Relative profitability or the opportunity cost of the investment in the marine renewable energies, which can be measured by the internal rate of return (IRR) is also a determinant parameter ($DI > 70\%$) in decision making

between different renewable energies. IRR can be defined as the discount rate, which makes NPV of the project equal to zero as described in Eq. 2.

$$NPV = -I_0 + \sum_{i=1}^n \frac{CF_i}{(1 + IRR)^i} = 0 \quad \text{Eq.2}$$

In this equation, I_0 is the initial investment and CF_i represents the cash-flow in each year. By comparing the IRR of the marine energy projects with other renewable energy technologies, potential investors can make a real economic-based decision for the investment on marine renewable energies. Potential investors in renewable energies prefer to invest their financial resources in the most profitable energy technologies. Also, it may encourage the public sector more to support the energies with a higher internal rate of return. Governmental financial supporting policies are also needed to reduce the initial investments and predicted costs (pre-operation and operational costs) for the electricity produced and to increase the reliability of the future yields for the investments on the marine energy capacities. The relative return period is also a significant determinant of profitability which can be measured by indicators such as the discounted pay-back period (DPBP) (Eq.3).

$$-I_0 + \sum_{i=1}^{DPBP} \frac{CF_i}{(1 + r)^i} \geq 0 \quad \text{Eq.3}$$

In this equation, I_0 is the initial investment, CF_i represents the cash-flow in each year and r is the discount rate. In the planning for making investments in marine energies like any other projects, the time period in which the investments and the annual expenditures will be paid-back has a crucial effect on the investment on marine renewable energies. Investors prefer to allocate their financial resources into a technology that has a shorter discounted pay-back period [8]. One other profitability criterion that is in the next priority of

importance is the direct profitability of marine renewable energy (DI>65%). Being a profitable project, solely, regardless of the profitability of other renewable energy projects is also an essential initial parameter considered by the investors. In this regard, NPV could be a proper measure for the calculation of the direct profitability of a marine renewable energy facility (Eq.4).

$$NPV = -I_0 + \sum_{i=1}^n \frac{CF_i}{(1+r)^i} \quad \text{Eq.4}$$

Where, I_0 is the initial investment, CF_i represents the cash-flow in each year and r is the discount rate.

The investment on the marine energy project is likely profitable if the calculated NPV is positive.

The possibility of the combination of W&T energies with the surrounding renewable energy facilities such as offshore wind energy technologies is a noteworthy point which was also evaluated important (DI>60%). Such combinations can be advantageous by a significant reduction in both capital and maintenance costs [38]. Three various approaches can be used to combine these systems, regarding the location and the depth of water, including the collocated energy technologies, hybrid convertor systems and energy island systems [43]. However, the integration of W&T energies with other renewable energy technologies has been proposed very recently and there exists no such commercial combined farms currently. The enhanced profitability can be achieved from such combined systems is an attractive option which can promote the development of W&T renewable energies.

Cost competitiveness against other conventional sources of energy measured by levelised cost of energy (LeCOE) index (Eq.5) can also be considered as a determinant for the overall acceptance of the energy extracted

from marine resources (DI=60%). The levelised cost has been widely used when a precise comparison of the economic feasibility and competitiveness of the renewable energy production technologies is desired [29,36,63].

$$LeCOE = \frac{\sum_{i=0}^n \frac{C_i}{(1+r)^i}}{\sum_{i=0}^n \frac{EO_i}{(1+r)^i}} \quad \text{Eq.5}$$

In this equation, r is the discount rate, C_i and EO_i are cost and energy output, respectively. Magagna and Uihlein (2015)[4] illustrated the levelised cost of generating energy by W&T energy and also by conventional energy resources. They showed that the levelised cost of W&T energies is very high compared with other conventional energy sources. However, this obstacle can be overcome through allocating the resources to improve the technical features and supporting mechanisms. This criterion was evaluated by participants to be less important than cost competitiveness of marine energy against other renewable energies. It is probably due to the international regulations for reducing the greenhouse gas emissions and targets set by countries for using renewable energies instead of conventional sources of energy mainly fossil fuels.

The return on the initial investments is another factor with less importance (DI>55%) compared with the so far mentioned criteria. Since the initial investment in the installation of W&T energy capacities is very high, so the risk of the investments in these technologies seem to be high [32]. Therefore, return of the investments in a short period of time can be effective for the investors allocate their financial resources in this sector.

4.5 Externalities

In addition to the mentioned economic factors that can directly promote the deployment and production of electricity using marine energy facilities,

1 economic externalities can also be emphasized to encourage the policy makers
2 and potential investors. Impact on wholesale electricity prices (DI>75%) is
3 among the economic consequences of marine energy development which may
4 highly affect the cost of electricity for consumers and the overall public
5 satisfaction. Having this, all the activities and supporting policies that are able
6 to reduce the cost of electricity produced (such as tax incentives) can be highly
7 recommended in order to minimize the probable adverse economic effects
8 which can restrict their rapid development.

9 The capability for the creation of the new jobs is also a socio-economic
10 determinant factor with enormous impact (DI> 70%) on the development of
11 marine energy facilities. It seems that the W&T energies have the capabilities to
12 create a number of new job opportunities. As an example, Elliott (2010)[64]
13 stated that by development of wave energy billion and thousands of jobs can be
14 generated in the UK. It must be also stated that the development of may affect
15 the existing local jobs such as local fishing. Alexander, Potts, and Wilding
16 (2013)[65] concluded that the Scottish fishers generally hold positive or neutral
17 attitudes towards W&T energies. However, due to relatively high importance of
18 this criterion according to the results of this study, more studies are required to
19 maximize the potential of the W&T energies to create new jobs. The reliability
20 for the production of consistent and low-cost energy is also required to persuade
21 the investors on marine renewable energy. In this condition, development of
22 marine renewable energy can itself ensure the security of energy production in
23 the current energy demanding global situations. Although after the energy crises
24 and increasing the prices of fossil fuels in 1970s more rapid efforts were induced
25 for the renewable energies development, it is still a need for to be secured by
26 long-term supports (20-30 years) [66,67]. As a result, W&T energies (along with

1 other types of renewable energy sources) can lead to an increase in the diversity
2 and, consequently, to a decrease in economic and political vulnerability of
3 energy supply and price shocks.

4 Integration of W&T energies into the overall energy system, along with
5 other renewable energies (i.e. solar, wind, etc.), can also potentially control the
6 fluctuations in the system through compensation of the other renewable energy
7 sources instabilities [68,69]. Therefore, it is expected by design and
8 implementation of the W&T renewable energies with enhanced stabilities in the
9 production of energy, the total system operation certainty increases. Deane and
10 Dalton (2012)[25] used a one-year market simulation for 2020 for investigating
11 the effect of integration of 500 MW wave energy into the Ireland's electricity
12 production system by supposing that 40% of total electricity is generated by
13 wind and wave energies. They concluded that integration of wave power could
14 reduce the total costs of the energy system. However, in order to accelerate the
15 development of the marine renewable energies, there is a need for more precise
16 estimations of the share of W&T energies to increase the stability of the energy
17 system. Engineering solutions can also aid to increase the stability of such
18 energies and to reduce the total costs of the energy produced by these
19 technologies.

20 Development of marine energy can also affect the GDP through different
21 ways, such as creation of new employment opportunities, stimulated by the
22 construction, operation and maintenance expenditures, reduction of energy
23 imports, trading carbon credits, etc. The potential beneficial effects on the GDP
24 can motivate governments to increase their supports on the development of this
25 clean technology. Researches on the effect of marine energy development on the
26 total economic activities, employment and GDP have a determinant role in this

purpose. For example, Allan et al. (2008)[50] applied a regional computable general equilibrium (CGE) model to estimate the effect of the deployment of 3GW marine energy on the economic activity in Scotland. They showed the positive impacts of the development of marine renewable energies on GDP.

Another opportunity to increase the benefits from the development of marine renewable energies is selling the surplus carbon credits. According to the Kyoto protocol, Annex I, developed countries, which are responsible for the most emitted greenhouse gases into the atmosphere, are committed to reducing their emissions to a specified level known as “assigned amounts” that can be divided into the units known as carbon credits. Each credit is the allowance of emitting one metric tonne of carbon dioxide equivalent. The countries which have not used the total amounts of the permitted credits have the opportunity to sell their surplus carbon credits in private or international markets. Substituting the energies from fossil fuels with clean renewable energies would be a solution to reduce the CO₂ emissions. At the moment, there is not enough information to estimate the amount of carbon dioxide emitted from activities, i.e. manufacturing, installation, operation and disassembling W&T facilities. In this regard, life cycle assessment studies can aid to calculate the exact amount of emissions reduced by the development of W&T energy generating technologies. Such information may accelerate the development of W&T renewable energies. For instance, Li and Willman (2014)[49] indicated that by using a tidal energy facility (56 kW) in the Southern Alaska community of Elfin Cove, almost 12000 gallons of diesel, which is the common fossil fuel in this area, can be displaced annually. This amount is equal to a reduction of almost 244000 lb CO₂ and about 1400 lb CO per year, in addition to the enormous reductions in other

main environmental pollutants such as PM-10, nitrogen oxides, sulfur oxides, etc.

Another possible beneficial consequence of the development of marine energy facilities is that they can activate other related economic activities in the region. Marine energy facilities such as offshore wind energy has the potential to take ports in remote areas out of stagnation [38], therefore they can motivate policymakers to support the development of these facilities.

The potential of the W&T energies to activate the relevant net technologies can also be considered as a motivation for involved parties (DI>50%). Offshore aquaculture and hydrogen production are two main businesses which can be activated by development of W&T energy technologies [70]. However, it seems that there is a potential for W&T energies to develop more associated or relevant businesses. Such perspectives can also persuade the supporting mechanisms to push further development of such energies.

5. Conclusion

Economic criteria are counted crucial to ensure long-term stability and to motivate the research and the developments, especially in the early stages of growth of novel technologies. Over a two rounds Delphi methodology, the economic criteria influencing in the development of wave and tidal renewable energies were rated. Both the degree of importance and degree of consensus among the participated experts for each criterion was considered as the indexes to judge about the importance of the studied criteria. Selling the energy produced and tax incentives were identified as the most important parameters that can push the developments of the marine renewable energies. Also, some factors were identified with low degree of importance in this regard such as

quotas and tenders. The results of this study can be used by the all the involved parties and decision makers to decide based on the relative importance of the economic criteria studied in this manuscript. To this end, involved bodies such as governments and policymakers are encouraged to facilitate the related rules and policies and studies are welcome to provide strong scientific knowledge for the promotion of these technologies according to the criteria and their importance evaluated in this study. For instance, more focus on the energy selling mechanisms more economic incentives resulted in the development acceleration.

References

- [1] Brook BW, Bradshaw CJA. Key role for nuclear energy in global biodiversity conservation. *Conver Biol* 2014;29:702–12. doi:10.1111/cobi.12433.
- [2] Sheng Y, Shi X, Zhang D. Economic growth, regional disparities and energy demand in China. *Energy Policy* 2014;71:31–9. doi:10.1016/j.enpol.2014.04.001.
- [3] World Energy Council. World Energy Resources 2016. 2016. doi:http://www.worldenergy.org/wp-content/uploads/2013/09/Complete_WER_2013_Survey.pdf.
- [4] Magagna D, Uihlein A. Ocean energy development in Europe: Current status and future perspectives. *Int J Mar Energy* 2015;11:84–104. doi:10.1016/j.ijome.2015.05.001.
- [5] Badcock-Broe A, Flynn R, George S, Gruet R, Medic N. Wave and Tidal Energy Market Deployment Strategy for Europe. *SI Ocean* 2014:47.

- [6] Uihlein A, Magagna D. Wave and tidal current energy – A review of the current state of research beyond technology. *Renew Sustain Energy Rev* 2016;58:1070–81. doi:10.1016/j.rser.2015.12.284.
- [7] Lange M, O’Hagan AM, Devoy RRN, Le Tissier M, Cummins V. Governance barriers to sustainable energy transitions – Assessing Ireland’s capacity towards marine energy futures. *Energy Policy* 2018;113:623–32. doi:10.1016/j.enpol.2017.11.020.
- [8] Segura E, Morales R, Somolinos JA, López A. Techno-economic challenges of tidal energy conversion systems: Current status and trends. *Renew Sustain Energy Rev* 2017;77:536–50. doi:10.1016/j.rser.2017.04.054.
- [9] Margheritini L, Hansen AM, Frigaard P. A method for EIA scoping of wave energy converters-based on classification of the used technology. *Environ Impact Assess Rev* 2012;32:33–44. doi:10.1016/j.eiar.2011.02.003.
- [10] Bonar PAJ, Bryden IG, Borthwick AGL. Social and ecological impacts of marine energy development. *Renew Sustain Energy Rev* 2015;47:486–95. doi:10.1016/j.rser.2015.03.068.
- [11] Abanades J, Greaves D, Iglesias G. Wave farm impact on beach modal state. *Mar Geol* 2015;361:126–35. doi:10.1016/j.margeo.2015.01.008.
- [12] Abanades J, Greaves D, Iglesias G. Wave farm impact on the beach profile: A case study. *Coast Eng J* 2014;86:36–44. doi:10.1016/j.margeo.2015.01.008.
- [13] Borges AR, Antunes CH. A fuzzy multiple objective decision support

model for energy-economy planning. Eur J Oper Res 2003;145:304–16.
doi:10.1016/S0377-2217(02)00536-2.

[14] San Cristóbal JR. Multi-criteria decision-making in the selection of a
renewable energy project in Spain: The Vikor method. Renew Energy
2011;36:498–502. doi:10.1016/j.renene.2010.07.031.

[15] Hartmann B, Börsök E, Groma VO, Osán J, Talamon A, Török S, et al.
Multi-criteria revision of the Hungarian Renewable Energy Utilization
Action Plan – Review of the aspect of economy. Renew Sustain Energy
Rev 2017;80:1187–200. doi:10.1016/j.rser.2017.05.287.

[16] Kamali M, Alesheikh AA, Khodaparast Z, Hosseinniakani SM,
AlaviBorazjani SA. Application of Delphi-AHP and Fuzzy-GIS Approaches
for Site Selection of Large Extractive Industrial Units in Iran. J
Settlements Spat Plan 2015;6:9–17.

[17] Kassem A, Al-Haddad K, Komljenovic D, Schiffauerova A. A value tree for
identification of evaluation criteria for solar thermal power technologies
in developing countries. Sustain Energy Technol Assessments
2016;16:18–32. doi:10.1016/j.seta.2016.02.003.

[18] Amer M, Daim T. Expert judgment quantification. Res. Technol. Manag.
Electr. Ind. Methods, Tools Case Stud., Portland: Springer; 2013, p. 31–
65. doi:http://dx.doi.org/10.1007/978-1-4471-5097-8.

[19] Leete S, Xu J, Wheeler D. Investment barriers and incentives for marine
renewable energy in the UK: An analysis of investor preferences. Energy
Policy 2013;60:866–75. doi:10.1016/j.enpol.2013.05.011.

[20] Kerr S, Colton J, Johnson K, Wright G. Rights and ownership in sea

country: Implications of marine renewable energy for indigenous and local communities. *Mar Policy* 2015;52:108–15. doi:10.1016/j.marpol.2014.11.002.

[21] Houde J. Cost-benefit analysis of tidal energy generation in nova scotia: a scenario for a tidal farm with 300mw of installed capacity in the minas passage in 2020. Dalhousie Univ 2012.

[22] Kilinc-ata N. The evaluation of renewable energy policies across EU countries and US states: An econometric approach. *Energy Sustain Dev* 2016;31:83–90. doi:10.1016/j.esd.2015.12.006.

[23] Pacesila M, Gabriel S. Analysis of renewable energies in European Union. *Renew Sustain Energy Rev* 2016;56:156–70. doi:10.1016/j.rser.2015.10.152.

[24] Montoya FG, Aguilera MJ, Manzano-agugliaro F. Renewable energy production in Spain: A review. *Renew Sustain Energy Rev* 2014;33:509–31. doi:10.1016/j.rser.2014.01.091.

[25] Deane JP, Dalton G. Modelling the economic impacts of 500 MW of wave power in Ireland. *Energy Policy J* 2012;45:614–27. doi:10.1016/j.enpol.2012.03.012.

[26] Macdougall SL. Risk management through internationally staged investments in tidal energy development. *Int J Mar Energy* 2017;18:78–87. doi:10.1016/j.ijome.2017.03.002.

[27] Romano T, Mennel T, Scatasta S. Comparing feed-in tariffs and renewable obligation certificates: the case of repowering wind farms. *Econ e Polit Ind* 2017;44:291–314. doi:10.1007/s40812-017-0071-z.

- [28] Bricker JD, Esteban M, Takagi H, Roeber V. Economic feasibility of tidal stream and wave power in. *Renew Energy* 2017;114:32–45. doi:10.1016/j.renene.2016.06.049.
- [29] de Andres A, Maillet J, Todalshaug JH, Möller P, Bould D, Jeffrey H. Techno-economic related metrics for a wave energy converters feasibility assessment. *Sustain* 2016;8:1–19. doi:10.3390/su8111109.
- [30] Butler L, Neuhoﬀ K. Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. *Renew Energy* 2008;33:1854–67. doi:10.1016/j.renene.2007.10.008.
- [31] Bürer MJ, Wüstenhagen R. Which renewable energy policy is a venture capitalist’s best friend? Empirical evidence from a survey of international cleantech investors. *Energy Policy* 2009;37:4997–5006. doi:10.1016/j.enpol.2009.06.071.
- [32] Chang Y-C, Wang N. Legal system for the development of marine renewable energy in China. *Renew Sustain Energy Rev* 2017;75:192–6. doi:10.1016/j.rser.2016.10.063.
- [33] Ringel M. Fostering the use of renewable energies in the European Union: the race between feed-in tariffs and green certificates. *Renew Energy* 2006;31:1–17. doi:10.1016/j.renene.2005.03.015.
- [34] Teillant B, Costello R, Weber J, Ringwood J. Productivity and economic assessment of wave energy projects through operational simulations. *Renew Energy* 2012;48:220–30. doi:10.1016/j.renene.2012.05.001.
- [35] Corsatea TD. Increasing synergies between institutions and technology developers: Lessons from marine energy. *Energy Policy* 2014;74:682–96.

doi:10.1016/j.enpol.2014.07.006.

[36] Allan G, Gilmartin M, McGregor P, Swales K. Levelised costs of Wave and Tidal energy in the UK: Cost competitiveness and the importance of “banded” renewables obligation certificates. *Energy Policy* 2011;39:23–39. doi:10.1016/j.enpol.2010.08.029.

[37] MacGillivray A, Jeffrey H, Winskel M, Bryden I. Innovation and cost reduction for marine renewable energy: A learning investment sensitivity analysis. *Technol Forecast Soc Change* 2014;87:108–24. doi:10.1016/j.techfore.2013.11.005.

[38] Astariz S, Iglesias G. The economics of wave energy: A review. *Renew Sustain Energy Rev* 2015;45:397–408. doi:10.1016/j.rser.2015.01.061.

[39] Dalton GJ, Alcorn R, Lewis T. Case study feasibility analysis of the Pelamis wave energy convertor in Ireland, Portugal and North America. *Renew Energy* 2010;35:443–55. doi:10.1016/j.renene.2009.07.003.

[40] Vazquez A, Iglesias G. Capital costs in tidal stream energy projects e A spatial approach. *Energy* 2016;107:215–26. doi:10.1016/j.energy.2016.03.123.

[41] Astariz S, Iglesias G. The collocation feasibility index e A method for selecting sites for co-located wave and wind farms. *Renew Energy* 2017;103:811–24. doi:10.1016/j.renene.2016.11.014.

[42] Kalogeri C, Galanis G, Spyrou C, Diamantis D, Baladima F, Koukoula M, et al. Assessing the European offshore wind and wave energy resource for combined exploitation. *Renew Energy* 2017;101:244–64. doi:10.1016/j.renene.2016.08.010.

- 1 [43] Pérez-Collazo C, Greaves D, Iglesias G. A review of combined wave and
2 offshore wind energy. *Renew Sustain Energy Rev* 2015;42:141–53.
3 doi:10.1016/j.rser.2014.09.032.
- 4 [44] Koo B. Examining the impacts of Feed-in-Tariff and the Clean
5 Development Mechanism on Korea's renewable energy projects through
6 comparative investment analysis. *Energy Policy* 2017;104:144–54.
7 doi:10.1016/j.enpol.2017.01.017.
- 8 [45] Zubiate L, Villate JL, Torre-Enciso Y, Soerensen HC, Holmes B,
9 Panagiotopoulos M, et al. Methodology for site selection for wave energy
10 projects. *Proceeding 8th Eur Wave Tidal Energy Conf (EWTECo8)*
11 2005:1089–95.
- 12 [46] Magagna D, Nijs W, Sgobbi A, Sim G. Assessing the impacts of technology
13 improvements on the deployment of marine energy in Europe with an
14 energy system. *Renew Energy J* 2016;89:515–25.
15 doi:10.1016/j.renene.2015.11.076.
- 16 [47] Portilla J, Sosa J, Cavaleri L. Wave energy resources: Wave climate and
17 exploitation. *Renew Energy* 2013;57:594–605.
18 doi:10.1016/j.renene.2013.02.032.
- 19 [48] Morandeau M, Walker RT, Argall R, Nicholls-lee RF. Optimisation of
20 marine energy installation operations. *Int J Mar Energy* 2013;3–4:14–26.
21 doi:10.1016/j.ijome.2013.11.002.
- 22 [49] Li Y, Willman L. Feasibility analysis of offshore renewables penetrating
23 local energy systems in remote oceanic areas - A case study of emissions
24 from an electricity system with tidal power in Southern Alaska. *Appl*
25 *Energy* 2014;117:42–53. doi:10.1016/j.apenergy.2013.09.032.

- 1 [50] Allan GJ, Bryden I, McGregor PG, Stallard T, Kim Swales J, Turner K, et
2 al. Concurrent and legacy economic and environmental impacts from
3 establishing a marine energy sector in Scotland. *Energy Policy*
4 2008;36:2734–53. doi:10.1016/j.enpol.2008.02.020.
- 5 [51] Carmen S, Varela-v P. Estimation of the potential effects of offshore wind
6 on the Spanish economy. *Renew Energy J* 2017;111:815–24.
7 doi:10.1016/j.renene.2017.05.002.
- 8 [52] Foteinis S, Tsoutsos T. Strategies to improve sustainability and o ff set the
9 initial high capital expenditure of wave energy converters (WECs).
10 *Renew Sustain Energy Rev* 2017;70:775–85.
11 doi:10.1016/j.rser.2016.11.258.
- 12 [53] Zhang Y, Lin Z, Liu Q. Marine renewable energy in China: Current status
13 and perspectives. *Water Sci Eng* 2014;7:288–305.
14 doi:10.3882/j.issn.1674-2370.2014.03.005.
- 15 [54] Gilmartin M, Allan G. Regional Employment Impacts of Marine Energy in
16 the Scottish Economy: A General Equilibrium Approach. *Reg Stud*
17 2015;49:337–55. doi:10.1080/00343404.2014.933797.
- 18 [55] Allan GJ, Lecca P, McGregor PG, Swales JK. The economic impacts of
19 marine energy developments: A case study from Scotland. *Mar Policy*
20 2014;43:122–31. doi:10.1016/j.marpol.2013.05.003.
- 21 [56] Falcao FO. Modelling of Wave Energy Conversion. *Inst Super Técnico,*
22 *Univ Técnica Lisboa* 2014:1–38.
- 23 [57] Phillips AC, Lewis LK, McEvoy MP, Galipeau J, Glasziou P, Hammick M,
24 et al. A systematic review of how studies describe educational

- interventions for evidence-based practice: Stage 1 of the development of a reporting guideline. *BMC Med Educ* 2014;14:1–11. doi:10.1186/1472-6920-14-152.
- [58] Stokes AW. Decommissioning Costs Can Be Reduced. *Offshore Technol. Conf.*, Houston, Texas: Offshore Technology Conference; 2014. doi:https://doi.org/10.4043/25247-MS.
- [59] IEA (International Energy Agency). Offshore installation worldwide. 2014.
- [60] Zhao G, Yang R, Liu Y, Zhao P. Hydrodynamic performance of a vertical-axis tidal-current turbine with different preset angles of attack. *J Hydrodyn Ser B* 2013;25:280–7. doi:10.1016/S1001-6058(13)60364-9.
- [61] Chen L, Lam W-H. Methods for predicting seabed scour around marine current turbine. *Renew Sustain Energy Rev* 2014;29:683–92. doi:10.1016/j.rser.2013.08.105.
- [62] Corsatea TD, Magagna D. Overview of European innovation activities in marine energy technology. 2014. doi:10.2790/29334.
- [63] Girard A, Gago EJ, Ordoñez J, Muneer T. Spain's energy outlook: A review of PV potential and energy export. *Renew Energy* 2016;86:73–115. doi:10.1016/j.renene.2015.08.074.
- [64] Elliott D. Securing UK marine energy. *Renew Energy Focus* 2010;11:24–6. doi:10.1016/S1755-0084(10)70063-6.
- [65] Alexander K a., Potts T, Wilding T a. Marine renewable energy and Scottish west coast fishers: Exploring impacts, opportunities and potential mitigation. *Ocean Coast Manag* 2013;75:1–10.

doi:10.1016/j.ocecoaman.2013.01.005.

[66] Holburn G, Lui K, Morand C. Policy risk and private investment in wind power: survey evidence from Ontario. *Can Public Policy* 2010;36:465–486.

[67] Komendantova N, Patt A, Barras L, Battaglini A. Perception of risks in renewable energy projects: The case of concentrated solar power in North Africa. *Energy Policy* 2012;40:103–9. doi:10.1016/j.enpol.2009.12.008.

[68] Ayat B. Wave power atlas of Eastern Mediterranean and Aegean Seas. *Energy* 2013;54:251–62. doi:10.1016/j.energy.2013.02.060.

[69] Alonzo B, Ringkjøb HK, Jourdier B, Drobinski P, Plougonven R, Tankov P. Modelling the variability of the wind energy resource on monthly and seasonal timescales. *Renew Energy* 2017;113:1434–46. doi:10.1016/j.renene.2017.07.019.

[70] Løvdal N, Neumann F. Internationalization as a strategy to overcome industry barriers—An assessment of the marine energy industry. *Energy Policy* 2011;39:1093–100. doi:10.1016/j.enpol.2010.11.028.

1 **Delphi-based Prioritization of Economic Criteria**
2 **for Development of Wave and Tidal Energy**
3 **Technologies**

4 Akram Jahanshahi^a, Mohammad Reza Kamali^{b,*}, Mohammadreza Khalaj^c,
5 Zahra Khodaparast^d

6 ^a. Department of Economics, Management, Industrial Engineering and Tourism, Department of
7 Mechanical Engineering, University of Aveiro, 3810-193 Aveiro, Portugal. jahanshahi@ua.pt

8 ^b. Department of Environment and Planning, Center for Environmental and Marine Studies,
9 CESAM, Aveiro Institute of Materials, CICECO, University of Aveiro, 3810-193 Aveiro, Portugal.
10 kamali@ua.pt

11 ^c. Department of Environment and Planning, University of Aveiro, 3810-193 Aveiro, Portugal.
12 khalaj@ua.pt

13 ^d. Department of Biology, Center for Environmental and Marine Studies, CESAM, University of
14 Aveiro, 3810-193 Aveiro, Portugal. khodaparast@ua.pt

16 **Abstract**

17 Harness of wave and tidal energies can play an important role in the
18 future energy portfolios to ensure the energy security and to reach the low-
19 carbon energy development plans. However, despite the existence of adequate
20 resources of these energies through the world, they have not been well exploited
21 yet. This study has focused on the assessment of the economic criteria and their
22 relative importance for the development of the wave and tidal energy
23 technologies based on the experts' judgment. To this end, the expert elicitation
24 process was performed using the Delphi methodology. 5 main criteria and 29

* Corresponding author E-Mail: Kamali@ua.pt

sub-criteria were initially identified through a comprehensive literature review. During two rounds of Delphi questionnaires, the degree of importance and the degree of consensus values were identified for each individual parameter. According to the results achieved, selling the energy produced and tax incentives were rated as the most important factors with the highest degrees of consensus. While quotas and tenders were not identified by the experts participated in the survey with high importance on the development of wave and tidal energies although with low degrees of consensus.

Keywords:

Wave and tidal energies, Economic criteria, Delphi methodology.

1. Introduction

The ongoing demand of energy has been a critical challenge for human societies all around the world [1]. In this sense, there is an obvious relationship between the economic growth and energy demand, especially for developing countries [2]. Currently, a large portion of the world's energy need is met by the liquid and gaseous fossil fuels (i.e., petroleum and natural gas) [3]. This is because of their widespread availability and the convenience of use. Hence, fossil fuels are still the driving force behind the technological progresses in many countries through the world. However, the evacuation of fossil fuels and the disastrous environmental effects of excessive consumption have forced communities to reconsider and to limit the use of fossil fuels as a source of energy. Increasing the demand for energy and the rising energy price in one hand, and the environmental consequences on the other hand, have made it inevitable to develop and to facilitate the use of urgent alternative energy resources. With this motivation, development of a sustainable and clean source

of energy has attracted a huge attention from academic, social and political communities. Due to this fact that more than 70% of the surface of the earth is covered by the seas and oceans, exploitation of energy from marine water movements can be considered as a good solution to address the mentioned global issues. This form of energy can be harnessed for electricity generation for various applications such as transport, domestic uses and industrial activities.

Wave and tidal (W&T) energies are the most extractable sources of ocean energy technologies [4]. So, there has been a tendency for the rapid development of these technologies worldwide. For instance, in the EU it has been aimed to extract 100 GW of combined W&T energies by 2050 [5]. In this regard, identification of both driving parameters and development barriers of these energy technologies may be helpful to accelerate taking advantage of these technologies. Since W&T energy technologies are still at an early stage of development [6], economically, technically and environmentally reliability, feasibility, and survivability of the devices need to be studied [7,8]. According to Uihlein & Magagna, (2016)[6] about 68% of funded researches by EU in the marine energy is related to technology development sector. Environmental consequences have also crucial roles in the development of such novel technologies. Manufacturing, operation, maintenance and decommissioning of marine energy devices as all other renewable sources of energy will have some environmental impacts. Impact on the benthic community [6,9], species-specific response to habitat change [6], the entanglement and collision risk of marine mammals, turtles, larger fish and seabirds [6] along with the impact of noise [6,8,10], vibration [6], electromagnetic fields [6,8,10], competition for space [6], beach morphodynamics [11,12], marine archaeology [12] and visual impacts [9] are among the possible environmental impacts of such energies.

1 Nonetheless, the environmental impacts such as pollution, visual pollution and
2 noise of the current marine energy devices are smaller than other forms of
3 renewable energies. The structure of the rotors is also such that the blades have
4 the least effect on marine habitats [8]. In spite of the determinative roles of
5 economic parameters in the development of marine energy technologies, fewer
6 studies have addressed to these parameters.

7 Due to the importance of economic consideration for the rapid
8 development of these technologies, it would be vital to screen and prioritize the
9 main influencing economic criteria. To the best of the authors' knowledge,
10 economic incentives and barriers to the development of marine energy
11 technologies have not been discussed systematically in the literature.
12 Identifying the relative importance of each criterion, in addition to contribute to
13 the pace of the development may enhance the economic benefits. In the
14 economic studies in marine energy, each of the different economic criteria has
15 been studied individually, for instance, making an estimate of the current and
16 future costs of marine energy and cost-benefit analyses [6]. Considering all
17 criteria would be necessary in order to establish sustainable policies. Multi-
18 criteria decision analysis (MCDA) could help to weight different economic
19 factors based on the importance on the development of marine technologies.
20 There are a few studies in the literature which have used multi-criteria analysis
21 in the energy sector. For instance, Borges and Antunes (2003)[13] applied a
22 Fuzzy multiple objective decision support model instead of input-output model
23 for energy economy planning. In another study, San Cristóbal (2011)[14] used
24 MCDA for selection of renewable energy project in Spain. According to the
25 results, biomass plant option is the best choice, and wind and solar power are
26 the second and third alternatives [14]. Hartmann et al. (2017)[15] applied

MCDA to revise the Hungarian Renewable Energy Utilization Action Plan. The results indicate that bioenergy will occupy the most fraction of Hungarian renewable portfolio by 2020. In association with economic assessment of marine energy, authors did not find relevant study in the literature. To this end, this paper aimed to identify and prioritize the mentioned criteria and sub-criteria, and to identify their relative importance for the development of the W&T energy technologies according to the expert elicitation process.

2. Materials and methods

According to the literature, the main economic criteria and sub-criteria which may have important effects on the development of W&T renewable energies were categorized in five main groups. The identified criteria were then screened and weighted using the Delphi methodology.

Screening process of the criteria and sub-criteria and the weighting process were performed using Delphi methodology [16,17]. To this end, a total 21 experts from academic, industrial and governmental organizations from various countries (see appendix) participated in the survey. Careful selection of the participants was performed in order to minimize the bias and also to ensure the incorporation of different panelist's perspectives. Characteristics such as having an extensive knowledge in the field, the ability to simplify the complicated problems and the ability to communicate with expertise were considered to select the participants [18]. Participants were requested to assign weights to the proposed criteria in order to reflect the importance of each parameter, based on a five-point Likert scale, as shown in Table 1.

Table 1.

Likert scale weights.

Very important	Important	Moderate	Not important	Negligible
9	7	5	3	1

According to the points given by the experts to each criterion, two statistical elements including the degree of importance (DI) (Eq.1) and the degree of consensus (DC) index were calculated in order to screen the criteria based on the plotted importance graph (IG).

$$DI = (100 * L_1) + (75 * L_2) + (50 * L_3) + (25 * L_4) + (1 * L_5) - (100 * N) \quad \text{Eq.1}$$

In this equation, L_1 to L_5 are the numbers of “very important” to “negligible” responses, respectively (Table 1). Also, N in this equation refers to the number of “not necessary” responses. DC index was measured through the classification of the Likert scale responses into three main categories, as presented in Table 2. The highest percentage of experts who evaluated a parameter in one of the mentioned categories is selected to represent the DC index.

Table 2.

Consensus categories.

Category	(A)	(B)	(C)
Members	Very important and important	Moderate	Not important and negligible

3. Results

3.1 Identification of main criteria and the sub-criteria

According to the literature, the main economic criteria and sub-criteria with the important effects on the development of W&T renewable energies were identified and grouped in five main categories, namely, incentives (C1), profitability factors (C2), pre-operation costs (C3), operational costs and revenue (C4) and externalities (C5).

Incentives are here referred to those policy-based tools accomplished by the governments to encourage the potential investors to invest in marine renewable energy or to expand their existing activity in this area. Ownership right (C11) [10,19–21], feed-in tariffs (C12) [6,19,30,31,22–29] , quotas (C13) [22,23,27,30,32], tenders (C14) [22,23,30], tax incentives (C15) [22,23,31–34] and public financial supports (C16) [4,26,30,35,36] are the sub-criteria identified for the incentives in this survey which seem to have important roles in pushing the investments on the W&T energy technology (Table 3).

Profitability is another main economic criterion which can determine the potential of a marine energy facility to compete against other sources of energy. This factor can be also of high importance to attract new investments and to a company's long-term survivability. Cost competitiveness against other renewable energies (C21) [36–38], short-term return of the investments (C22) [37] direct profitability (C23) [8,25,29,34,39], cost competitiveness against conventional energy sources (C24) [4,8,34,38,40,41], combination possibility (C25) [25,38,42,43], relative profitability (C26) [8,25,34,39,44] and relative return period (C27) [8,34] are the sub-criteria of profitability we extracted from the literature as important factors in attracting investment towards the W&T energy facilities (Table 4).

Pre-operating cost (C31) [38], first devices capital cost (C32) [36], costs of licenses and permissions (C33) [9,38,45] and initial investments (C34) [29,38,46,47] were identified the main branches of this criterion (Table 5).

In the category of operational costs and revenue, parameters including operational expenditure (C41) [4,38,40,43], decommissioning costs (C42) [38,39,48–50] and selling the energy produced (C43) [19,27,34,38,40] may play the role of influencing sub-criteria (Table 6).

Externalities deal with the economic consequences of the activities experienced by unrelated third parties. The impacts of W&T renewable energies on: wholesale electricity price (C51) [25], system operation costs (C52) [25], GDP (C53) [6,24,50,51], trading carbon credits (C54) [21,38,44], energy supply security (C55) [6,23,31,38,50,52], creation of new jobs (C56) [6,10,38,50,53,54], integration potential into the economic fabric (C57) [38], the price volatility (C58) [22,55] and development of relevant net technologies (C59) [55] are here considered as crucial parameters, according to the main goals of this study (Table 7).

Table 3

Main sub-criteria of the “incentives” criterion.

Identification	Sub-Criteria	Description	Reference
C11	Ownership	The right to own the objects, the land, or the intellectual property for all parties including idea makers, investors, etc. in various stages of a marine energy facility development.	[10,19–21]
C12	Feed-in tariffs	A set of policies for offering ensured prices for the electricity produced from marine energy sources, for a certain period of time.	[6,19,30,31,22–29]
C13	Quotas	A set of quantity-based policy tools which involves electricity retailers to supply a portion of the electricity demand from marine energy sources.	[22,23,27,30,32]
C14	Tenders	The mechanisms adopted by the governmental organizations to persuade the producers to produce electricity from marine energy sources at a lower cost as the winner of a tender is whom with the lowest proposed cost.	[22,23,30]
C15	Tax incentives	A set of governmental fiscal policy instruments to encourage the investors to invest in marine energy technology.	[22,23,31–34]
C16	Public financial supports	Direct financial supports received from the government to develop marine renewable energies.	[4,26,30,35,36,56]

Table 4

Main sub-criteria of the “profitability” criterion.

Identification	Sub-Criteria	Description	Reference
----------------	--------------	-------------	-----------

C21	Cost competitiveness against other renewable energies	The relative cost of electricity producing by marine energy facilities compared with other renewable energies.	[36–38]
C22	Short-term return of the investments	Described as the expectations for the return of the investment in a relatively short period of time.	[37]
C23	Direct profitability ^a	A factor which aids the investors to investigate profitability of the investment on the project based on their expectations.	[8,25,29,34,39]
C24	Cost competitiveness ^b against conventional energy sources	The relative cost of electricity producing by marine energy facilities compared with other energy sources.	[4,8,34,38,40,41]
C25	Combination possibility	The possibility for the combination of different marine energy facilities to reduce the investment costs.	[25,38,42,43]
C26	Relative profitability ^c	The relative profitability of electricity producing by marine energy facilities compared to other energy sources.	[8,25,34,39,44]
C27	Relative return period ^d	The relative return period of the investments in marine energy facilities against other energy sources.	[8,34]

- 1 a. Measured by net present value (NPV) index. Strict positive for the value of the project according NPV is a required
2 condition for being profitable.
3 b. Measured by levelised cost of energy (LeCOE).
4 c. Measured by internal rate of return (IRR).
5 d. Measured by discounted pay-back period (DPBP).

6 **Table 5**

7 Main sub-criteria of the “pre-operation costs” criterion.

Identification	Sub-Criteria	Description	Reference
C31	Pre-operating cost	Defined as the costs of primary studies, environmental impact assessment (EIA), consenting procedures, management, etc.	[38]
C32	First devices capital cost	Defined as the level of deployment before the sustained cost reduction, and the learning rate (which is the average rate of cost reduction with deployment).	[36]
C33	Costs of licenses and permissions	The cost of acquiring the official permissions or permits to develop a marine energy facility.	[9,38,45]
C34	Initial investments	The installation cost required for the marine energy facilities.	[29,38,46,47]

8

9 **Table 6**

10 Main sub-criteria of the “operational costs and revenue” criterion.

Identification	Sub-Criteria	Description	Reference
C41	Operational expenditure	The overall costs related to the operation and maintenance activities, revision and time off, spares, public	[4,38,40,43]

		services, renting, insurance and taxes.	
C42	Decommissioning costs	The whole plant is supposed to be dismantled after a limited period of years and the decommissioning cost could be estimated as a percentage of the initial investment.	[38,39,48–50]
C43	Selling the energy produced	Defined as the total energy production multiplied in the price.	[19,27,34,38,40]

1

2 **Table 7**

3 Main sub-criteria of the “externalities” criterion.

Identification	Sub-Criteria	Description	Reference
C51	Impact on wholesale electricity price	The effect of the electricity of the marine energy facilities on the price of electricity sold as a whole.	[25]
C52	Impact on system operation costs	The effect of the operational cost of electricity produced by a marine energy facility on the overall operational cost for the production of electricity from all the resources.	[25]
C53	Effects on GDP	Defined as the effects of energy facilities on the gross domestic product.	[6,24,50,51]
C54	Trading carbon credits	The benefits from selling the surplus carbon credits achieved from the reduction of greenhouse gases by using marine energy facilities.	[21,38,44]
C55	Energy supply security	The decrease in the risks attributed to the supply cuts of conventional fuels.	[6,23,31,38,50,52]
C56	Creation of new jobs	Defined as the effect of marine energy facilities on the creation of new jobs.	[6,10,38,50,53,54]
C57	Integration into the economic fabric	The potential of a given marine energy facility to activate (or re-activate) other local businesses.	[38]
C58	The effect on price volatility	The potential effect of a marine energy facility or a set of marine energy facilities to prevent the volatility of the energy price.	[22,55]
C59	Development of relevant technologies	The effect on the formation of local, national or international firm clusters working in different but relevant technological field.	[55]

4

5 **3.2 Delphi methodology**

6 Through conducting two rounds of Delphi, two main indexes, including

7 DI and DC were measured to identify the importance of the economic criteria

8 influencing in the development of W&T renewable energies. The contributors

9 received the report of the first round, including the outputs, prior to the second

10 round. Fig.1 shows the percentages of the Likert weights (Table 1) allocated to

the five categories of the main criteria. In all cases, the sums of the “important” and “very important” measures are greater than 50% indicating that they are all important for the development of W&T technologies. However, by looking more precisely at the weighting distribution of the results, it is evident that the operational costs and revenue obtained more scores in the two mentioned scales (63%). In addition, pre-operation costs (58%), incentives (57%), profitability (54%) and also externalities (54%) were allocated next importance among the main categories of the studied criteria.

Fig. 1.

Distribution of contributed answers on the Likert scale for main criteria.

The degree of importance values for the studied sub-criteria obtained by applying the Eq.1 is shown in Fig.2. Selling the energy produced (C43) and tax incentives (C15) achieved the highest DIs (93% and 83%, respectively). Whereas, quotas (C13) and tenders (C14) were rated less important sub-criteria (DIs = 49% and 48%, respectively), although there is no consensus among the experts about their low importance. The integration of DI values and DC values are presented in Fig.3. This figure shows the relationship between the evaluated importance degree for each sub-criterion and the calculated degrees of consensus for the sub-criterion.

1 **Fig. 2**
2 Importance degree indices for the studied sub-criteria.

3 **Fig. 3**
4 Importance graph for the studied sub-criteria.

5 In Figure 3, parameters located in quartiles 1 and 3 have the DI values
6 more than the threshold (50%) emphasizing the high importance of the
7 parameters. When a criterion is located in quartiles 2 or 4, it reveals that the
8 criterion has lower importance regarding the main goal of the study. Hence,
9 except the quotas (C13) and tenders (C14), all the studied sub-criteria have been

evaluated by the experts highly important for the development of W&T energies. Although there are no recommendations for the DC threshold of the Delphi methodology [57], a 50% consistency in the answers provided by participants has been proposed as the acceptable threshold for this index [18]. Using this threshold, only the quartiles 1 and 2 can contain the parameters with high consensus levels. So, there are no high levels of consensus for the degree of importance values of the quotas (C13), tenders (C14), combination possibility (C25), cost of licenses and permissions (C33) and selling the surplus carbon credits (C54) among the participant experts. All the remained sub-criteria are located in quartile 1 meaning that they have important effects on the development of marine renewable energies.

4. Discussion

As stated before, operational costs and revenue has been ranked the most important criterion from the experts' points of view. Pre-operation costs and investment, incentives, profitability and externalities are ordered in the next priorities, respectively. The following sections are to discuss how the sub-criteria of these main criteria can affect the development of W&T renewable energies.

4.1 Operational costs and revenue

From the studied sub-criteria of operational costs and revenue, selling the energy produced ($DI > 90\%$) from these sources was identified as the most important economic sub-criterion. This parameter has an essential effect on the attraction of the potential investors. Since marine energy is a less developed technology among the renewable energies [25] and there are a lot of uncertainties on the prices and the demand for the produced electricity,

governmental supports may be crucial to ensure long-term economic benefits of these types of renewable energies. The operational expenditures criterion which includes the cost of annual operating and maintenance tasks, insurance, rent payments, taxes, etc. is also a determinant criterion in the development of W&T energy technologies. However, there is not still a precise calculation of the operational expenditures due to the novelty of W&T energy technologies. Engineering designs to reduce decommissioning costs can also to some extent influence the economic profitability of the marine renewable energies (DI=50%). Generally, decommissioning costs are higher than required due to less attention paid to this item during the initial engineering and construction of a wave or tidal energy facility. The experiences from offshore technologies can also reinforce this idea. For instance, Stokes (2014) [58] indicated that a 50% reduction in decommissioning costs of an offshore oil and gas field can increase the net present value (NPV) by 13%.

4.2 Pre-operation costs

Among the pre-operation costs and investments, the amount of the initial investments in W&T technologies is the most important parameter (DI= 80%). Hence, the potential investors are exposed to a very high degree of risk without adequate public supports [32]. This can be considered another reason why the public supports are so important for the development of W&T technologies. Pre-operating and first device capital costs have gained the next priorities when considering the economic criteria for the development of W&T energies. In spite of the availability of adequate resources to ensure the generation of the consistent marine energy in many regions of the world [59] many types of marine energy facilities are in their infancy stages yet. For instance, tidal

current turbines as well as wave energy turbines are less developed compared with the devices like tidal barrages, probably due to the existing economic barriers [60]. Any decrease in initial costs may result in pushing the involved parties to overcome the remained technical barriers attributed to the scientific knowledge required for the design, production and test of the more mature devices [61]. The importance of the first device capital costs have also been emphasized by the recent studies. MacGillivray et al. (2014) [37] by using a single-factor learning model indicated the sensitivity of W&T energies to main factors including the first devices capital cost, the deployment level before reaching the sustained cost reduction, and the learning rate.

The cost of acquiring official licenses or permissions (DI>55%) to develop a marine energy facility is another factor that may have a moderate effect on W&T energies rapid development. The process may be complicated and costly for the developers of new advanced technologies such as marine renewable energy. Although the direct costs of licenses and permissions are estimated to be a small percentage of the initial investments on the W&T devices [39], governmental supports may be required to facilitate the related procedures to motivate the investors.

4.3 Incentives

Tax incentive as a governmental fiscal policy can also have a very high influence (DI>80%) in the attraction in investments on the development of marine energy facilities according to the opinions of our participants. For instance, reducing the financial burden, as a tax incentive policy, can potentially encourage the marine energy investors or developers to allocate the financial resources to establish new facilities or to expand the existing marine power

capacities [32]. The importance of the public supports for marine renewable energy development can be more highlighted through an insight on the difficulties involved in the early stages of development of such energies when the marine energy facilities are passing through the lab-scale to real-scale installations, which is so-called “valley of death” [35,62]. The public financial supports (also $DI > 80\%$) can also extensively aid to develop more advanced low-cost facilities through promoting the high-quality R&D activities. This way, governmental financial investments are supposed to encourage individual investments in lower-risk marine energy facilities.

Feed-in tariff, as another incentive, can offer an ensured minimum price for the electricity produced from the wave or tidal energy sources, for a certain period of time [33]. This incentive policy, that has gotten a high degree of priority in this study ($DI > 70\%$), diminishes the uncertainties about the fluctuations of the selling prices, helps investors to make positive decisions in a more secure environment and consequently, pushes the selling of generated electricity. The second tool for the reinforcement of the produced electricity selling can insure the amount of the electricity sale. A quota ($DI = 49\%$) involves the electricity retailers to supply a portion of the electricity demand from marine energy sources. However, based on the results achieved in this study, feed in tariff as a price-based policy instrument has been evaluated much more important than the quota as a quantity-based policy, to promote the deployment of marine renewable energy facilities. More significant effects of feed-in tariffs than quotes have been obtained by Kilinc-ata (2016)[22]. Also, Brer and Wstenhagen (2009)[31] through studying 60 investments from European and North American venture capital and private equity funds indicated that feed-in

tariffs are the most effective tools to promote investments on such emerging renewable energies.

The ownership can also slightly enhance or limit the tendency of the parties who want to engage in the developments. Effective mechanisms can guarantee the economic benefits for the investors and innovators in a logical period of time. Such mechanisms are required to ensure the share of the investors to dominate the future markets [19]. Tender is also among the policy instruments (although with the least degree of importance, less than 50%) that governments can adopt to encourage the development of W&T energies to generate marine energy with a lower cost. As a result, their cost competitiveness against other renewable energies will be increased.

4.4 Profitability

Cost competitiveness against other renewable energies is another significant economic sub-criterion regarding the accomplished Delphi method (DI= $\sim$ 75%). In spite of the existence of enormous sea and ocean resources worldwide, the energy generated by these resources is not in commercial level yet. It is mainly due to the existing barriers which make the produced energy more expensive compared with other renewable energies [32]. It is maybe one of the most important reasons that wind and solar renewable energies have gained more attention by scientific communities, social bodies, governments and other parties. However, it seems that technical solutions can considerably decrease the cost of the energy produced compared with other sources of renewables. Relative profitability or the opportunity cost of the investment in the marine renewable energies, which can be measured by the internal rate of return (IRR) is also a determinant parameter (DI>70%) in decision making

between different renewable energies. IRR can be defined as the discount rate, which makes NPV of the project equal to zero as described in Eq. 2.

$$NPV = -I_0 + \sum_{i=1}^n \frac{CF_i}{(1 + IRR)^i} = 0 \quad \text{Eq.2}$$

In this equation, I_0 is the initial investment and CF_i represents the cash-flow in each year. By comparing the IRR of the marine energy projects with other renewable energy technologies, potential investors can make a real economic-based decision for the investment on marine renewable energies. Potential investors in renewable energies prefer to invest their financial resources in the most profitable energy technologies. Also, it may encourage the public sector more to support the energies with a higher internal rate of return. Governmental financial supporting policies are also needed to reduce the initial investments and predicted costs (pre-operation and operational costs) for the electricity produced and to increase the reliability of the future yields for the investments on the marine energy capacities. The relative return period is also a significant determinant of profitability which can be measured by indicators such as the discounted pay-back period (DPBP) (Eq.3).

$$-I_0 + \sum_{i=1}^{DPBP} \frac{CF_i}{(1 + r)^i} \geq 0 \quad \text{Eq.3}$$

In this equation, I_0 is the initial investment, CF_i represents the cash-flow in each year and r is the discount rate. In the planning for making investments in marine energies like any other projects, the time period in which the investments and the annual expenditures will be paid-back has a crucial effect on the investment on marine renewable energies. Investors prefer to allocate their financial resources into a technology that has a shorter discounted pay-back period [8]. One other profitability criterion that is in the next priority of

importance is the direct profitability of marine renewable energy (DI>65%). Being a profitable project, solely, regardless of the profitability of other renewable energy projects is also an essential initial parameter considered by the investors. In this regard, NPV could be a proper measure for the calculation of the direct profitability of a marine renewable energy facility (Eq.4).

$$NPV = -I_0 + \sum_{i=1}^n \frac{CF_i}{(1+r)^i} \quad \text{Eq.4}$$

Where, I_0 is the initial investment, CF_i represents the cash-flow in each year and r is the discount rate.

The investment on the marine energy project is likely profitable if the calculated NPV is positive.

The possibility of the combination of W&T energies with the surrounding renewable energy facilities such as offshore wind energy technologies is a noteworthy point which was also evaluated important (DI>60%). Such combinations can be advantageous by a significant reduction in both capital and maintenance costs [38]. Three various approaches can be used to combine these systems, regarding the location and the depth of water, including the collocated energy technologies, hybrid convertor systems and energy island systems [43]. However, the integration of W&T energies with other renewable energy technologies has been proposed very recently and there exists no such commercial combined farms currently. The enhanced profitability can be achieved from such combined systems is an attractive option which can promote the development of W&T renewable energies.

Cost competitiveness against other conventional sources of energy measured by levelised cost of energy (LeCOE) index (Eq.5) can also be considered as a determinant for the overall acceptance of the energy extracted

from marine resources (DI=60%). The levelised cost has been widely used when a precise comparison of the economic feasibility and competitiveness of the renewable energy production technologies is desired [29,36,63].

$$LeCOE = \frac{\sum_{i=0}^n \frac{C_i}{(1+r)^i}}{\sum_{i=0}^n \frac{EO_i}{(1+r)^i}} \quad \text{Eq.5}$$

In this equation, r is the discount rate, C_i and EO_i are cost and energy output, respectively. Magagna and Uihlein (2015)[4] illustrated the levelised cost of generating energy by W&T energy and also by conventional energy resources. They showed that the levelised cost of W&T energies is very high compared with other conventional energy sources. However, this obstacle can be overcome through allocating the resources to improve the technical features and supporting mechanisms. This criterion was evaluated by participants to be less important than cost competitiveness of marine energy against other renewable energies. It is probably due to the international regulations for reducing the greenhouse gas emissions and targets set by countries for using renewable energies instead of conventional sources of energy mainly fossil fuels.

The return on the initial investments is another factor with less importance (DI>55%) compared with the so far mentioned criteria. Since the initial investment in the installation of W&T energy capacities is very high, so the risk of the investments in these technologies seem to be high [32]. Therefore, return of the investments in a short period of time can be effective for the investors allocate their financial resources in this sector.

4.5 Externalities

In addition to the mentioned economic factors that can directly promote the deployment and production of electricity using marine energy facilities,

1 economic externalities can also be emphasized to encourage the policy makers
2 and potential investors. Impact on wholesale electricity prices (DI>75%) is
3 among the economic consequences of marine energy development which may
4 highly affect the cost of electricity for consumers and the overall public
5 satisfaction. Having this, all the activities and supporting policies that are able
6 to reduce the cost of electricity produced (such as tax incentives) can be highly
7 recommended in order to minimize the probable adverse economic effects
8 which can restrict their rapid development.

9 The capability for the creation of the new jobs is also a socio-economic
10 determinant factor with enormous impact (DI> 70%) on the development of
11 marine energy facilities. It seems that the W&T energies have the capabilities to
12 create a number of new job opportunities. As an example, Elliott (2010)[64]
13 stated that by development of wave energy billion and thousands of jobs can be
14 generated in the UK. It must be also stated that the development of may affect
15 the existing local jobs such as local fishing. Alexander, Potts, and Wilding
16 (2013)[65] concluded that the Scottish fishers generally hold positive or neutral
17 attitudes towards W&T energies. However, due to relatively high importance of
18 this criterion according to the results of this study, more studies are required to
19 maximize the potential of the W&T energies to create new jobs. The reliability
20 for the production of consistent and low-cost energy is also required to persuade
21 the investors on marine renewable energy. In this condition, development of
22 marine renewable energy can itself ensure the security of energy production in
23 the current energy demanding global situations. Although after the energy crises
24 and increasing the prices of fossil fuels in 1970s more rapid efforts were induced
25 for the renewable energies development, it is still a need for to be secured by
26 long-term supports (20-30 years) [66,67]. As a result, W&T energies (along with

1 other types of renewable energy sources) can lead to an increase in the diversity
2 and, consequently, to a decrease in economic and political vulnerability of
3 energy supply and price shocks.

4 Integration of W&T energies into the overall energy system, along with
5 other renewable energies (i.e. solar, wind, etc.), can also potentially control the
6 fluctuations in the system through compensation of the other renewable energy
7 sources instabilities [68,69]. Therefore, it is expected by design and
8 implementation of the W&T renewable energies with enhanced stabilities in the
9 production of energy, the total system operation certainty increases. Deane and
10 Dalton (2012)[25] used a one-year market simulation for 2020 for investigating
11 the effect of integration of 500 MW wave energy into the Ireland's electricity
12 production system by supposing that 40% of total electricity is generated by
13 wind and wave energies. They concluded that integration of wave power could
14 reduce the total costs of the energy system. However, in order to accelerate the
15 development of the marine renewable energies, there is a need for more precise
16 estimations of the share of W&T energies to increase the stability of the energy
17 system. Engineering solutions can also aid to increase the stability of such
18 energies and to reduce the total costs of the energy produced by these
19 technologies.

20 Development of marine energy can also affect the GDP through different
21 ways, such as creation of new employment opportunities, stimulated by the
22 construction, operation and maintenance expenditures, reduction of energy
23 imports, trading carbon credits, etc. The potential beneficial effects on the GDP
24 can motivate governments to increase their supports on the development of this
25 clean technology. Researches on the effect of marine energy development on the
26 total economic activities, employment and GDP have a determinant role in this

1 purpose. For example, Allan et al. (2008)[50] applied a regional computable
2 general equilibrium (CGE) model to estimate the effect of the deployment of
3 3GW marine energy on the economic activity in Scotland. They showed the
4 positive impacts of the development of marine renewable energies on GDP.

5 Another opportunity to increase the benefits from the development of
6 marine renewable energies is selling the surplus carbon credits. According to
7 the Kyoto protocol, Annex I, developed countries, which are responsible for the
8 most emitted greenhouse gases into the atmosphere, are committed to reducing
9 their emissions to a specified level known as “assigned amounts” that can be
10 divided into the units known as carbon credits. Each credit is the allowance of
11 emitting one metric tonne of carbon dioxide equivalent. The countries which
12 have not used the total amounts of the permitted credits have the opportunity to
13 sell their surplus carbon credits in private or international markets. Substituting
14 the energies from fossil fuels with clean renewable energies would be a solution
15 to reduce the CO₂ emissions. At the moment, there is not enough information to
16 estimate the amount of carbon dioxide emitted from activities, i.e.
17 manufacturing, installation, operation and disassembling W&T facilities. In this
18 regard, life cycle assessment studies can aid to calculate the exact amount of
19 emissions reduced by the development of W&T energy generating technologies.
20 Such information may accelerate the development of W&T renewable energies.
21 For instance, Li and Willman (2014)[49] indicated that by using a tidal energy
22 facility (56 kW) in the Southern Alaska community of Elfin Cove, almost 12000
23 gallons of diesel, which is the common fossil fuel in this area, can be displaced
24 annually. This amount is equal to a reduction of almost 244000 lb CO₂ and
25 about 1400 lb CO per year, in addition to the enormous reductions in other

main environmental pollutants such as PM-10, nitrogen oxides, sulfur oxides, etc.

Another possible beneficial consequence of the development of marine energy facilities is that they can activate other related economic activities in the region. Marine energy facilities such as offshore wind energy has the potential to take ports in remote areas out of stagnation [38], therefore they can motivate policymakers to support the development of these facilities.

The potential of the W&T energies to activate the relevant net technologies can also be considered as a motivation for involved parties (DI>50%). Offshore aquaculture and hydrogen production are two main businesses which can be activated by development of W&T energy technologies [70]. However, it seems that there is a potential for W&T energies to develop more associated or relevant businesses. Such perspectives can also persuade the supporting mechanisms to push further development of such energies.

5. Conclusion

Economic criteria are counted crucial to ensure long-term stability and to motivate the research and the developments, especially in the early stages of growth of novel technologies. Over a two rounds Delphi methodology, the economic criteria influencing in the development of wave and tidal renewable energies were rated. Both the degree of importance and degree of consensus among the participated experts for each criterion was considered as the indexes to judge about the importance of the studied criteria. Selling the energy produced and tax incentives were identified as the most important parameters that can push the developments of the marine renewable energies. Also, some factors were identified with low degree of importance in this regard such as

quotas and tenders. The results of this study can be used by the all the involved parties and decision makers to decide based on the relative importance of the economic criteria studied in this manuscript. To this end, involved bodies such as governments and policymakers are encouraged to facilitate the related rules and policies and studies are welcome to provide strong scientific knowledge for the promotion of these technologies according to the criteria and their importance evaluated in this study. For instance, more focus on the energy selling mechanisms more economic incentives resulted in the development acceleration.

References

- [1] Brook BW, Bradshaw CJA. Key role for nuclear energy in global biodiversity conservation. *Conserv Biol* 2014;29:702–12. doi:10.1111/cobi.12433.
- [2] Sheng Y, Shi X, Zhang D. Economic growth, regional disparities and energy demand in China. *Energy Policy* 2014;71:31–9. doi:10.1016/j.enpol.2014.04.001.
- [3] World Energy Council. World Energy Resources 2016. 2016. doi:http://www.worldenergy.org/wp-content/uploads/2013/09/Complete_WER_2013_Survey.pdf.
- [4] Magagna D, Uihlein A. Ocean energy development in Europe: Current status and future perspectives. *Int J Mar Energy* 2015;11:84–104. doi:10.1016/j.ijome.2015.05.001.
- [5] Badcock-Broe A, Flynn R, George S, Gruet R, Medic N. Wave and Tidal Energy Market Deployment Strategy for Europe. *SI Ocean* 2014:47.

- [6] Uihlein A, Magagna D. Wave and tidal current energy – A review of the current state of research beyond technology. *Renew Sustain Energy Rev* 2016;58:1070–81. doi:10.1016/j.rser.2015.12.284.
- [7] Lange M, O’Hagan AM, Devoy RRN, Le Tissier M, Cummins V. Governance barriers to sustainable energy transitions – Assessing Ireland’s capacity towards marine energy futures. *Energy Policy* 2018;113:623–32. doi:10.1016/j.enpol.2017.11.020.
- [8] Segura E, Morales R, Somolinos JA, López A. Techno-economic challenges of tidal energy conversion systems: Current status and trends. *Renew Sustain Energy Rev* 2017;77:536–50. doi:10.1016/j.rser.2017.04.054.
- [9] Margheritini L, Hansen AM, Frigaard P. A method for EIA scoping of wave energy converters-based on classification of the used technology. *Environ Impact Assess Rev* 2012;32:33–44. doi:10.1016/j.eiar.2011.02.003.
- [10] Bonar PAJ, Bryden IG, Borthwick AGL. Social and ecological impacts of marine energy development. *Renew Sustain Energy Rev* 2015;47:486–95. doi:10.1016/j.rser.2015.03.068.
- [11] Abanades J, Greaves D, Iglesias G. Wave farm impact on beach modal state. *Mar Geol* 2015;361:126–35. doi:10.1016/j.margeo.2015.01.008.
- [12] Abanades J, Greaves D, Iglesias G. Wave farm impact on the beach profile: A case study. *Coast Eng J* 2014;86:36–44. doi:10.1016/j.margeo.2015.01.008.
- [13] Borges AR, Antunes CH. A fuzzy multiple objective decision support

model for energy-economy planning. Eur J Oper Res 2003;145:304–16.
doi:10.1016/S0377-2217(02)00536-2.

[14] San Cristóbal JR. Multi-criteria decision-making in the selection of a
renewable energy project in Spain: The Vikor method. Renew Energy
2011;36:498–502. doi:10.1016/j.renene.2010.07.031.

[15] Hartmann B, Börsök E, Groma VO, Osán J, Talamon A, Török S, et al.
Multi-criteria revision of the Hungarian Renewable Energy Utilization
Action Plan – Review of the aspect of economy. Renew Sustain Energy
Rev 2017;80:1187–200. doi:10.1016/j.rser.2017.05.287.

[16] Kamali M, Alesheikh AA, Khodaparast Z, Hosseinniakani SM,
AlaviBorazjani SA. Application of Delphi-AHP and Fuzzy-GIS Approaches
for Site Selection of Large Extractive Industrial Units in Iran. J
Settlements Spat Plan 2015;6:9–17.

[17] Kassem A, Al-Haddad K, Komljenovic D, Schiffauerova A. A value tree for
identification of evaluation criteria for solar thermal power technologies
in developing countries. Sustain Energy Technol Assessments
2016;16:18–32. doi:10.1016/j.seta.2016.02.003.

[18] Amer M, Daim T. Expert judgment quantification. Res. Technol. Manag.
Electr. Ind. Methods, Tools Case Stud., Portland: Springer; 2013, p. 31–
65. doi:http://dx.doi.org/10.1007/978-1-4471-5097-8.

[19] Leete S, Xu J, Wheeler D. Investment barriers and incentives for marine
renewable energy in the UK: An analysis of investor preferences. Energy
Policy 2013;60:866–75. doi:10.1016/j.enpol.2013.05.011.

[20] Kerr S, Colton J, Johnson K, Wright G. Rights and ownership in sea

country: Implications of marine renewable energy for indigenous and local communities. *Mar Policy* 2015;52:108–15. doi:10.1016/j.marpol.2014.11.002.

[21] Houde J. Cost-benefit analysis of tidal energy generation in nova scotia: a scenario for a tidal farm with 300mw of installed capacity in the minas passage in 2020. Dalhousie Univ 2012.

[22] Kilinc-ata N. The evaluation of renewable energy policies across EU countries and US states: An econometric approach. *Energy Sustain Dev* 2016;31:83–90. doi:10.1016/j.esd.2015.12.006.

[23] Pacesila M, Gabriel S. Analysis of renewable energies in European Union. *Renew Sustain Energy Rev* 2016;56:156–70. doi:10.1016/j.rser.2015.10.152.

[24] Montoya FG, Aguilera MJ, Manzano-agugliaro F. Renewable energy production in Spain: A review. *Renew Sustain Energy Rev* 2014;33:509–31. doi:10.1016/j.rser.2014.01.091.

[25] Deane JP, Dalton G. Modelling the economic impacts of 500 MW of wave power in Ireland. *Energy Policy J* 2012;45:614–27. doi:10.1016/j.enpol.2012.03.012.

[26] Macdougall SL. Risk management through internationally staged investments in tidal energy development. *Int J Mar Energy* 2017;18:78–87. doi:10.1016/j.ijome.2017.03.002.

[27] Romano T, Mennel T, Scatista S. Comparing feed-in tariffs and renewable obligation certificates: the case of repowering wind farms. *Econ e Polit Ind* 2017;44:291–314. doi:10.1007/s40812-017-0071-z.

- [28] Bricker JD, Esteban M, Takagi H, Roeber V. Economic feasibility of tidal stream and wave power in. *Renew Energy* 2017;114:32–45. doi:10.1016/j.renene.2016.06.049.
- [29] de Andres A, Maillet J, Todalshaug JH, Möller P, Bould D, Jeffrey H. Techno-economic related metrics for a wave energy converters feasibility assessment. *Sustain* 2016;8:1–19. doi:10.3390/su8111109.
- [30] Butler L, Neuhoﬀ K. Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. *Renew Energy* 2008;33:1854–67. doi:10.1016/j.renene.2007.10.008.
- [31] Bürer MJ, Wüstenhagen R. Which renewable energy policy is a venture capitalist’s best friend? Empirical evidence from a survey of international cleantech investors. *Energy Policy* 2009;37:4997–5006. doi:10.1016/j.enpol.2009.06.071.
- [32] Chang Y-C, Wang N. Legal system for the development of marine renewable energy in China. *Renew Sustain Energy Rev* 2017;75:192–6. doi:10.1016/j.rser.2016.10.063.
- [33] Ringel M. Fostering the use of renewable energies in the European Union: the race between feed-in tariffs and green certificates. *Renew Energy* 2006;31:1–17. doi:10.1016/j.renene.2005.03.015.
- [34] Teillant B, Costello R, Weber J, Ringwood J. Productivity and economic assessment of wave energy projects through operational simulations. *Renew Energy* 2012;48:220–30. doi:10.1016/j.renene.2012.05.001.
- [35] Corsatea TD. Increasing synergies between institutions and technology developers: Lessons from marine energy. *Energy Policy* 2014;74:682–96.

doi:10.1016/j.enpol.2014.07.006.

[36] Allan G, Gilmartin M, McGregor P, Swales K. Levelised costs of Wave and Tidal energy in the UK: Cost competitiveness and the importance of “banded” renewables obligation certificates. *Energy Policy* 2011;39:23–39. doi:10.1016/j.enpol.2010.08.029.

[37] MacGillivray A, Jeffrey H, Winskel M, Bryden I. Innovation and cost reduction for marine renewable energy: A learning investment sensitivity analysis. *Technol Forecast Soc Change* 2014;87:108–24. doi:10.1016/j.techfore.2013.11.005.

[38] Astariz S, Iglesias G. The economics of wave energy: A review. *Renew Sustain Energy Rev* 2015;45:397–408. doi:10.1016/j.rser.2015.01.061.

[39] Dalton GJ, Alcorn R, Lewis T. Case study feasibility analysis of the Pelamis wave energy convertor in Ireland, Portugal and North America. *Renew Energy* 2010;35:443–55. doi:10.1016/j.renene.2009.07.003.

[40] Vazquez A, Iglesias G. Capital costs in tidal stream energy projects e A spatial approach. *Energy* 2016;107:215–26. doi:10.1016/j.energy.2016.03.123.

[41] Astariz S, Iglesias G. The collocation feasibility index e A method for selecting sites for co-located wave and wind farms. *Renew Energy* 2017;103:811–24. doi:10.1016/j.renene.2016.11.014.

[42] Kalogeri C, Galanis G, Spyrou C, Diamantis D, Baladima F, Koukoula M, et al. Assessing the European offshore wind and wave energy resource for combined exploitation. *Renew Energy* 2017;101:244–64. doi:10.1016/j.renene.2016.08.010.

- [43] Pérez-Collazo C, Greaves D, Iglesias G. A review of combined wave and offshore wind energy. *Renew Sustain Energy Rev* 2015;42:141–53. doi:10.1016/j.rser.2014.09.032.
- [44] Koo B. Examining the impacts of Feed-in-Tariff and the Clean Development Mechanism on Korea's renewable energy projects through comparative investment analysis. *Energy Policy* 2017;104:144–54. doi:10.1016/j.enpol.2017.01.017.
- [45] Zubiate L, Villate JL, Torre-Enciso Y, Soerensen HC, Holmes B, Panagiotopoulos M, et al. Methodology for site selection for wave energy projects. *Proceeding 8th Eur Wave Tidal Energy Conf (EWTECo8)* 2005:1089–95.
- [46] Magagna D, Nijs W, Sgobbi A, Sim G. Assessing the impacts of technology improvements on the deployment of marine energy in Europe with an energy system. *Renew Energy J* 2016;89:515–25. doi:10.1016/j.renene.2015.11.076.
- [47] Portilla J, Sosa J, Cavaleri L. Wave energy resources: Wave climate and exploitation. *Renew Energy* 2013;57:594–605. doi:10.1016/j.renene.2013.02.032.
- [48] Morandeau M, Walker RT, Argall R, Nicholls-lee RF. Optimisation of marine energy installation operations. *Int J Mar Energy* 2013;3–4:14–26. doi:10.1016/j.ijome.2013.11.002.
- [49] Li Y, Willman L. Feasibility analysis of offshore renewables penetrating local energy systems in remote oceanic areas - A case study of emissions from an electricity system with tidal power in Southern Alaska. *Appl Energy* 2014;117:42–53. doi:10.1016/j.apenergy.2013.09.032.

- 1 [50] Allan GJ, Bryden I, McGregor PG, Stallard T, Kim Swales J, Turner K, et
2 al. Concurrent and legacy economic and environmental impacts from
3 establishing a marine energy sector in Scotland. *Energy Policy*
4 2008;36:2734–53. doi:10.1016/j.enpol.2008.02.020.
- 5 [51] Carmen S, Varela-v P. Estimation of the potential effects of offshore wind
6 on the Spanish economy. *Renew Energy J* 2017;111:815–24.
7 doi:10.1016/j.renene.2017.05.002.
- 8 [52] Foteinis S, Tsoutsos T. Strategies to improve sustainability and o ff set the
9 initial high capital expenditure of wave energy converters (WECs).
10 *Renew Sustain Energy Rev* 2017;70:775–85.
11 doi:10.1016/j.rser.2016.11.258.
- 12 [53] Zhang Y, Lin Z, Liu Q. Marine renewable energy in China: Current status
13 and perspectives. *Water Sci Eng* 2014;7:288–305.
14 doi:10.3882/j.issn.1674-2370.2014.03.005.
- 15 [54] Gilmartin M, Allan G. Regional Employment Impacts of Marine Energy in
16 the Scottish Economy: A General Equilibrium Approach. *Reg Stud*
17 2015;49:337–55. doi:10.1080/00343404.2014.933797.
- 18 [55] Allan GJ, Lecca P, McGregor PG, Swales JK. The economic impacts of
19 marine energy developments: A case study from Scotland. *Mar Policy*
20 2014;43:122–31. doi:10.1016/j.marpol.2013.05.003.
- 21 [56] Falcao FO. Modelling of Wave Energy Conversion. *Inst Super Técnico,*
22 *Univ Técnica Lisboa* 2014:1–38.
- 23 [57] Phillips AC, Lewis LK, McEvoy MP, Galipeau J, Glasziou P, Hammick M,
24 et al. A systematic review of how studies describe educational

- interventions for evidence-based practice: Stage 1 of the development of a reporting guideline. *BMC Med Educ* 2014;14:1–11. doi:10.1186/1472-6920-14-152.
- [58] Stokes AW. Decommissioning Costs Can Be Reduced. *Offshore Technol. Conf.*, Houston, Texas: Offshore Technology Conference; 2014. doi:https://doi.org/10.4043/25247-MS.
- [59] IEA (International Energy Agency). Offshore installation worldwide. 2014.
- [60] Zhao G, Yang R, Liu Y, Zhao P. Hydrodynamic performance of a vertical-axis tidal-current turbine with different preset angles of attack. *J Hydrodyn Ser B* 2013;25:280–7. doi:10.1016/S1001-6058(13)60364-9.
- [61] Chen L, Lam W-H. Methods for predicting seabed scour around marine current turbine. *Renew Sustain Energy Rev* 2014;29:683–92. doi:10.1016/j.rser.2013.08.105.
- [62] Corsatea TD, Magagna D. Overview of European innovation activities in marine energy technology. 2014. doi:10.2790/29334.
- [63] Girard A, Gago EJ, Ordoñez J, Muneer T. Spain's energy outlook: A review of PV potential and energy export. *Renew Energy* 2016;86:73–115. doi:10.1016/j.renene.2015.08.074.
- [64] Elliott D. Securing UK marine energy. *Renew Energy Focus* 2010;11:24–6. doi:10.1016/S1755-0084(10)70063-6.
- [65] Alexander K a., Potts T, Wilding T a. Marine renewable energy and Scottish west coast fishers: Exploring impacts, opportunities and potential mitigation. *Ocean Coast Manag* 2013;75:1–10.

doi:10.1016/j.ocecoaman.2013.01.005.

[66] Holburn G, Lui K, Morand C. Policy risk and private investment in wind power: survey evidence from Ontario. *Can Public Policy* 2010;36:465–486.

[67] Komendantova N, Patt A, Barras L, Battaglini A. Perception of risks in renewable energy projects: The case of concentrated solar power in North Africa. *Energy Policy* 2012;40:103–9. doi:10.1016/j.enpol.2009.12.008.

[68] Ayat B. Wave power atlas of Eastern Mediterranean and Aegean Seas. *Energy* 2013;54:251–62. doi:10.1016/j.energy.2013.02.060.

[69] Alonzo B, Ringkjøb HK, Jourdier B, Drobinski P, Plougonven R, Tankov P. Modelling the variability of the wind energy resource on monthly and seasonal timescales. *Renew Energy* 2017;113:1434–46. doi:10.1016/j.renene.2017.07.019.

[70] Løvdal N, Neumann F. Internationalization as a strategy to overcome industry barriers—An assessment of the marine energy industry. *Energy Policy* 2011;39:1093–100. doi:10.1016/j.enpol.2010.11.028.

Figure
[Click here to download high resolution image](#)

Figure
[Click here to download high resolution image](#)

Figure

[Click here to download high resolution image](#)

Table 1.

Likert scale weights.

Very important	Important	Moderate	Not important	Negligible
9	7	5	3	1

Table 2.

Consensus categories.

Category	(A)	(B)	(C)
Members	Very important and important	Moderate	Not important and negligible

Table 3

Main sub-criteria of the “incentives” criterion.

Identification	Sub-Criteria	Description	Reference
C11	Ownership	The right to own the objects, the land, or the intellectual property for all parties including idea makers, investors, etc. in various stages of a marine energy facility development.	[10,19–21]
C12	Feed-in tariffs	A set of policies for offering ensured prices for the electricity produced from marine energy sources, for a certain period of time.	[6,19,30,31,22–29]
C13	Quotas	A set of quantity-based policy tools which involves electricity retailers to supply a portion of the electricity demand from marine energy sources.	[22,23,27,30,32]
C14	Tenders	The mechanisms adopted by the governmental organizations to persuade the producers to produce electricity from marine energy sources at a lower cost as the winner of a tender is whom with the lowest proposed cost.	[22,23,30]
C15	Tax incentives	A set of governmental fiscal policy instruments to encourage the investors to invest in marine energy technology.	[22,23,31–34]
C16	Public financial supports	Direct financial supports received from the government to develop marine renewable energies.	[4,26,30,35,36,56]

Table 4

Main sub-criteria of the “profitability” criterion.

Identification	Sub-Criteria	Description	Reference
C21	Cost competitiveness against other renewable energies	The relative cost of electricity producing by marine energy facilities compared with other renewable energies.	[36–38]
C22	Short-term return of the investments	Described as the expectations for the return of the investment in a relatively short period of time.	[37]

C23	Direct profitability ^a	A factor which aids the investors to investigate profitability of the investment on the project based on their expectations.	[8,25,29,34,39]
C24	Cost competitiveness ^b against conventional energy sources	The relative cost of electricity producing by marine energy facilities compared with other energy sources.	[4,8,34,38,40,41]
C25	Combination possibility	The possibility for the combination of different marine energy facilities to reduce the investment costs.	[25,38,42,43]
C26	Relative profitability ^c	The relative profitability of electricity producing by marine energy facilities compared to other energy sources.	[8,25,34,39,44]
C27	Relative return period ^d	The relative return period of the investments in marine energy facilities against other energy sources.	[8,34]

a. Measured by net present value (NPV) index. Strict positive for the value of the project according NPV is a required condition for being profitable.
b. Measured by levelised cost of energy (LeCOE).
c. Measured by internal rate of return (IRR).
d. Measured by discounted pay-back period (DPBP).

Table 5

Main sub-criteria of the “pre-operation costs” criterion.

Identification	Sub-Criteria	Description	Reference
C31	Pre-operating cost	Defined as the costs of primary studies, environmental impact assessment (EIA), consenting procedures, management, etc.	[38]
C32	First devices capital cost	Defined as the level of deployment before the sustained cost reduction, and the learning rate (which is the average rate of cost reduction with deployment).	[36]
C33	Costs of licenses and permissions	The cost of acquiring the official permissions or permits to develop a marine energy facility.	[9,38,45]
C34	Initial investments	The installation cost required for the marine energy facilities.	[29,38,46,47]

Table 6

Main sub-criteria of the “operational costs and revenue” criterion.

Identification	Sub-Criteria	Description	Reference
C41	Operational expenditure	The overall costs related to the operation and maintenance activities, revision and time off, spares, public services, renting, insurance and taxes.	[4,38,40,43]
C42	Decommissioning costs	The whole plant is supposed to be dismantled after a limited period of years and the decommissioning cost could be estimated as a percentage of the initial investment.	[38,39,48–50]

C43	Selling the energy produced	Defined as the total energy production multiplied in the price.	[19,27,34,38,40]
-----	-----------------------------	---	------------------

Table 7

Main sub-criteria of the “externalities” criterion.

Identification	Sub-Criteria	Description	Reference
C51	Impact on wholesale electricity price	The effect of the electricity of the marine energy facilities on the price of electricity sold as a whole.	[25]
C52	Impact on system operation costs	The effect of the operational cost of electricity produced by a marine energy facility on the overall operational cost for the production of electricity from all the resources.	[25]
C53	Effects on GDP	Defined as the effects of energy facilities on the gross domestic product.	[6,24,50,51]
C54	Trading carbon credits	The benefits from selling the surplus carbon credits achieved from the reduction of greenhouse gases by using marine energy facilities.	[21,38,44]
C55	Energy security	The decrease in the risks attributed to the supply cuts of conventional fuels.	[6,23,31,38,50,52]
C56	Creation of new jobs	Defined as the effect of marine energy facilities on the creation of new jobs.	[6,10,38,50,53,54]
C57	Integration into the economic fabric	The potential of a given marine energy facility to activate (or re-activate) other local businesses.	[38]
C58	The effect on price volatility	The potential effect of a marine energy facility or a set of marine energy facilities to prevent the volatility of the energy price.	[22,55]
C59	Development of relevant technologies	The effect on the formation of local, national or international firm clusters working in different but relevant technological field.	[55]

Appendix A. Detailed description of the experts participated in the study.

Row	Country	Sector	Area of expertise	Status
1	Portugal	University	Renewable energy economics, Analytic methods, Management systems	PhD
2	Portugal	University	Analytic methods, Management systems	PhD
3	Portugal	University	Analytic methods, Management systems	PhD
4	Portugal	University	Analytic methods, Management systems	PhD
5	Portugal	Industry	Accounting and Taxation, Credit Analyst	Master
6	Iran	University	Analytic methods, Management systems	PhD
7	Portugal	University	Analytic methods, Management systems	PhD
8	Portugal	University	Environmental Engineering, Material Engineering, Environmental economics, Analytic methods, Management systems	PhD
9	USA	Industry	Socio-technical research on tidal energy, Mechanical engineering (designing wind turbine), Marin and Environment affairs	Researcher
10	Portugal	University	Energy policy, Energy economics, Environmental economics, Social sustainability assessment of renewable energy sources	Associate Professor
11	Sweden	University	Analytic methods, Management systems	PhD
12	Iran	Government	Analytic methods, Management systems- Sustainability	PhD
13	Canada	University	Climate change economics, Energy pricing, Energy policy	Pos doc researcher
14	Portugal	University	Energy modeling to assess economic, environmental and technological impacts of low carbon pathways,	Pos doc researcher
15	Portugal	University	Analytic methods, Management systems	PhD
16	Portugal	University	Analytic methods, Management systems	PhD
17	Portugal	University	Wind energy economics, Mechanisms of carbon pricing, Low carbon development scenarios assessment	Assistant professor
18	Iran	Government	Analytic methods, Management systems	PhD
19	Iran	University	Analytic methods, Management systems	PhD
20	Portugal	University	Analytic methods, Management systems	PhD
21	Spain	University	Wind sectoral policies, Socio-economic impacts of renewable energies	Lecturer, researcher