Factors affecting LCOE of Ocean energy technologies: a study of technology and deployment attractiveness

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Abstract

Due to the emergent status of ocean energy technologies, the study of how to reduce the cost of energy to a level competitive with other renewable energy alternatives is an important aspect of sector development. In this work, a technology case study related to the Levelised cost of energy (LCOE) of two wave energy devices (multipoint absorber and attenuator) and three tidal energy devices (fixed bottom mounted, fixed surface piercing and floating) is presented. The impacts of a number of project enhancements or changes on the LCOE are investigated, and the pathway towards a reduced LCOE is presented. In addition, the differences between the state of tidal and wave prototypes are highlighted therefore reinforcing the different needs of the wave and tidal energy sectors as they progress on the path towards a reduced LCOE.

1. Introduction

Ocean energy is still in a prototype testing stage and there has have been little commercial deployment to date. One of the reasons for this lack of deployment is that the electricity production, in kWh, from the current prototypes is still expensive in comparison with other renewable energy sources such as wind energy.

There are very few scientific studies regarding the evolution and the current status of the Levelised Cost Of Energy (LCOE) for present day ocean energy technologies. According to research carried out by Carbon Trust, it was concluded that ocean energy could achieve a cost of 15 pence/kWh by 2050 [1], with a global deployment potential of 46,5 GW.

However, there are only a small number of studies that clearly show the innovation pathway needed to achieve this goal. For instance, regarding wave energy, Previsic et al. [2] investigated the current status of wave energy regarding the LCOE. They identified some key areas with cost-reduction potential for a specific type of converter. They concluded that wave energy could achieve the target of 15 cents/kWh in the near future. With regards to tidal energy Li et al. [3] studied the economic ability of a tidal farm. They found that the best-case energy cost for a large farm (consisting of 100 turbines) with a 20-year life in offshore British Columbia could be as low as 8 cents/KWh; which is only slightly higher than the local market price. Also, with respect the main factors affecting LCOE, they concluded that besides tidal flow velocity, the two most important control variables for energy cost are farm size and the relative distance between individual devices (i.e. turbine distribution in the farm).

There exists very little research with regards to the pathways that technology developers may need to follow in order to achieve commercialisation. The Energy Technologies Institute (ETI)/UKERC Marine Energy Technology Roadmap [4] presents 40 technology and deployment activities and prioritises them from the perspective of the ETI. While this reflects the needs of the industry, there is no route map for defining timelines for the development of each identified activity, nor prioritisation of the aspects that are considered to be a key step towards achieving a lower LCOE.

In this paper, a technology case study is presented where the influence of several aspects on the LCOE of technologies is investigated. Within the wave technologies a fixed multi-point absorber and a floating multi-body pitching device will be studied. For the tidal technologies, three options were considered: a fixed bottom mounted single rotor turbine, a fixed surface piercing foundation structure with twin turbine rotors, and a floating tidal turbine with twin rotors. The LCOE (Levelised Cost of Energy) depends predominantly on three parameters: CAPEX, OPEX and average Annual Energy Production (AEP). The technology case study will assess the impact from each factor on the overall LCOE, determining which factors have the biggest influence on overall LCOE and how research, development or deployment investment support should be targeted.

2.- Wave Energy case study

For the wave technologies a fixed multi point absorber and a floating multi-body pitching device have been selected for comparison. Data for the economic analysis, including the power matrix of both devices, has been obtained.

Data regarding the energy yield of the devices is explained in Table 1. The multipoint absorber is assumed to be deployed for this study in Hanstolm (Denmark), while the attenuator is assumed to be deployed at EMEC (UK). The annual energy production is calculated by the multiplication of the scatter plot (% of yearly occurrences of a certain sea state) and the device power matrix (energy production in kWh per sea state). The scatter plot has been obtained from a COE Tool from Julia Fernandez Chozas Consulting Engineer [5] for both cases. The power matrix has been obtained for the Multi point absorber case through conversation with the device developer. For the attenuator case, the power matrix has been taken from O'Connor et al [6], some costs of this converter have been taken from Dalton and Lewis [7]. It should be noticed that these figures are taken considering only one unit and that no learning has been applied to these costs.

	Multi point absorber	**Attenuator**
Location	Hanstolm (Denmark)	EMEC (UK)
Average depth	30 m	75 m
Average Resource	5,8 kW/m	28,5 kW/m
Estimated lifetime	20 years	20 years
Rated power of the device	1 MW	750 kW
Inicial Cost (Structural cost of the device + PTO)	11 M€	3,8 M€
Mooring system	-----	0,4 M€
Electrical connection	0,3 M€	0,5 M€
Installation	3,5 M€	1,7 M€
Total CAPEX	17 M€	8.3 M€
Annual OPEX	(0.5 %CAPEX) 0,18 M€	(3% CAPEX) 0,18 M€

Table 1: Characteristics of the selected devices

Firstly, the intention of this study is to investigate how the different variations in existing wave energy prototypes would affect the LCOE and, ultimately, what LCOE could be realistically expected for the future. For this reason several variations have been studied. For the multipoint absorber case the reference case study has been selected with the following characteristics:

- Structure made with fibre glass
- Resistive control
- Hydraulic efficiency of PTO =0,7

For the attenuator the base case is set with:

- Reactive control
- Structure made with steel
- O&M strategy without optimization
- Restrained availability (80%)

	Case number	**Characteristics**	**Energy Yield (MWh/year)**
Multipoint absorber	1M	Reference Case	340
	2M	Base case+ Reactive control	500
	3M	Case 2+ 10% improvement on PTO efficiency	1028
	4M	Case 3+ Optimum control	1144
	5M	Case 4+ Ultra High perform Concrete	1144
Attenuator	1A	Reference case	1185
	2A	Base case + concrete	1185
	3A	Case 2 + optimization of O&M strategy	1185
	4A	Case 3 + enhanced control	1539
	5A	Case 4+ Increase on availability (95%)	1729

Table 2: WEC characteristics case studies

It should be noted that in Table 2 each subsequent case takes into account the improvements specified in previous cases in order to find out the net influence of each case on the LCOE. For the calculation of the LCOE an discount rate of 15% due to the novelty of the technology has been selected. The procedure in order to do the cash-flow analysis has been performed following the methodology outlined in previous studies [8].

In Figure 1 the LCOE for both prototypes is shown. For the multipoint absorber, the LCOE reference case is relatively high (5 Euros/kWh) because the control strategy that is applied is not efficient and the prototype is made from glass fibre reinforced plastic (which is relatively expensive). For the second case the control strategy is changed to a reactive control (2 constants, damping and stiffness control strategy), instead of resistive (1 constant control strategy), and, as can be seen in **¡Error! No se encuentra el origen de la referencia.**, the power production sees an increase of almost a 50% (therefore the LCOE is reduced by approximately 50%). It also needs to be highlighted that, for the multipoint absorber case, the improvement of 10% on the hydraulic efficiency of the PTO leads to a LCOE reduction of 200%.

Also, in both cases the LCOE reduction is very significant when cheaper materials are applied to the main hull of the converter. For the multipoint absorber case, if ultra high performance concrete is applied, it could lead to a LCOE decrease of 60 %. For the attenuator case, similar material improvements and cost reductions lead to a LCOE decrease of approximately 30%.

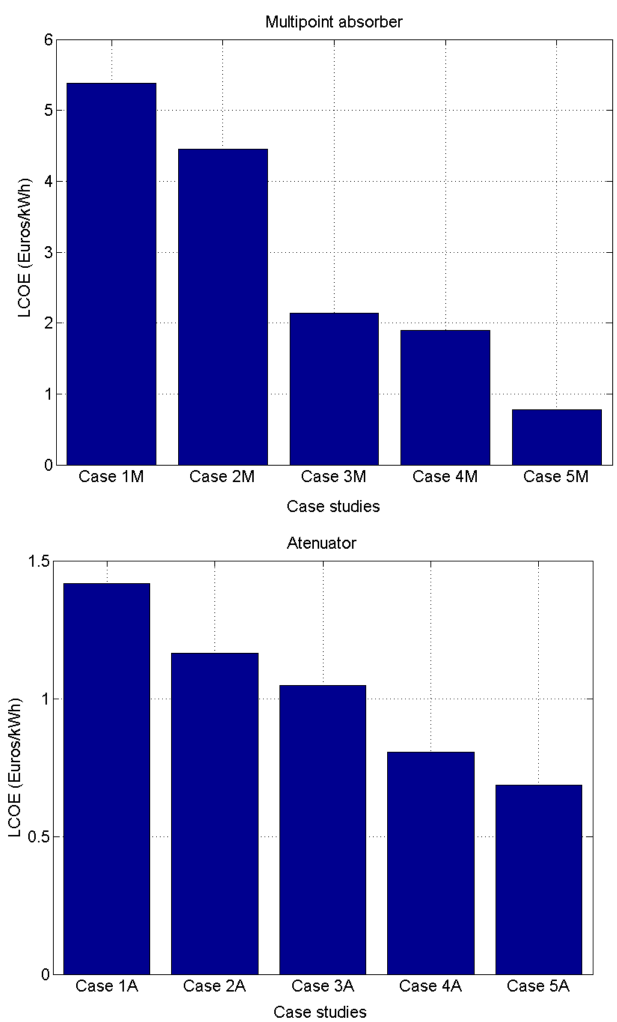

Figure 1: LCOE for the different cases

For the attenuator case, the improvement with a highest impact on LCOE is the optimization of the control strategy of the converter. It is concluded that both converters need to improve their power capture in order to enhance their power production and facilitate an advance towards commercialization.

However, in terms of comparing the two devices, this initial LCOE comparison is unfair, as the deployment locations for both devices are very different (Hanstolm has a resource of just 5,4 kW/m, whereas EMEC has a resource of 28,5 kW/m). In order to address this, as a continuation from the previous case study, six locations exhibiting favourable resource climates for wave energy development have been selected, in order to make a fair comparison for the devices. The selected locations are specified in Table 3.

Locations	Average resource (kW/m)	Availability (%) for multipoint absorber case (Hs<4 m)	Availability (%) for attenuator case (Hs<6m)
EMEC (UK)	28,5	92	94
BIMEP (Spain)	20,5	99	100
Humbold Bay (USA)	26,1	95	98
SEM REV (France)	15,7	95	99
Nova Scotia (Canada)	16,3	99	100
Chile	30	82	92

Table 3: Selected locations for study

The data for EMEC, BIMEP, Humbold Bay and SEM REV have been obtained from COE Tool from Julia Fernandez Chozas [5]. The data for Nova Scotia has been obtained from a buoy located at the coordinates (43,71; 59,85) named “wel429”, located on a site with depth of 37 m. For the location in Chile, as there wasn't open source buoy data available, the data was selected from a Global reanalysis database used previously in studies by de Andres et al. [9] and validated within existing literature [10] at the coordinates -73,5; 26.

For these comparisons at a national level, the cases 5M and 5A are selected. The CAPEX and OPEX costs are constant for all the locations (although it is known that the materials cost and labour cost can vary from country to country). It should be highlighted that no feed in tariff has been applied on this study in order to make a fair comparison among the economic performance among the different locations. The feed in tariff is considered to be in direct correlation to political, and, as such, it is isolated from this case study.

Figure 2 shows the LCOE in €/kWh for the two technologies within each of the aforementioned locations. It should be noted that for all the cases except EMEC, the multipoint absorber has a lower LCOE than the attenuator. The highest differences are found on Nova Scotia and SEM-REV locations. The multipoint absorber is designed for relatively mild climates and for low energy periods. On the other hand, the attenuator is designed for rougher climates and higher energy periods. As a result, both converters have different markets and their prospective target markets should not collide or interfere.

From a power performance point of view it should be highlighted that Table 3 outlines the location with highest resource as Chile and the location with the lowest resource was SEM REV (France). However, on the LCOE chart the location with the lowest LCOE is Humbold Bay in USA. This is due to the fact that Chile, despite its great resource, has a lower availability and therefore net power yield over the period of one year. In addition, the Nova Scotia case should be highlighted: The resource is low (16,3 kW/m) compared to the other locations, however, for the multipoint absorber case, the LCOE is the third lowest. This fact gives evidence to support the vision that locations with low resource can still be successful for wave energy development, providing the converter is matched for these particular met-ocean conditions.

Figure 2 also leads to the idea of market targeting for wave energy converters. As the design approach and the working principle is different between the studied technologies, the performance of the converters is very different at each of the geographic locations considered within this study. Further studies of wave energy development with specific converter types are needed in order to gauge the attractiveness of different converter designs for specific wave climates.

3.-Tidal technologies

For the tidal energy technology case study, three technology variations were selected for comparison. Due to the general design consensus of tidal energy converters to horizontal axis turbine designs, the technology variation considers foundation and mooring alternatives: a fixed bottom mounted structure with single turbine, a fixed surface piercing structure with twin turbines, and a moored floating structure with twin turbines.

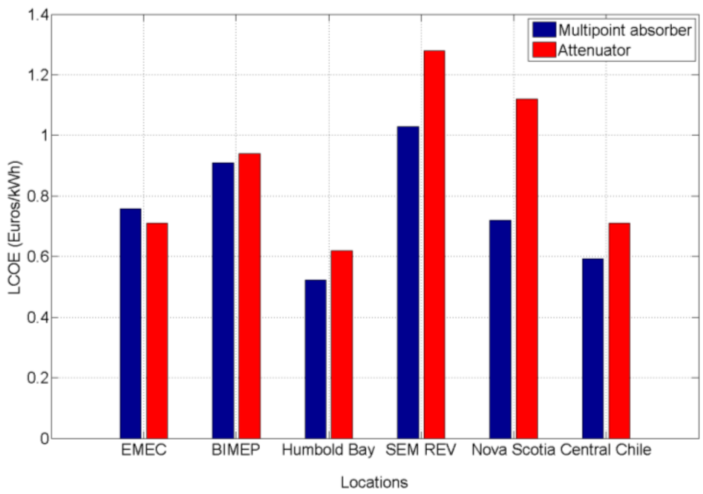

Figure 2: Cost of Energy on the different selected locations

For the purposes of this paper, it has been assumed that each rotor consists of a 1MW powertrain, with identical performance characteristics for each rotor, regardless of foundation type used. Therefore the fixed bottom mounted device is assumed to have a 1MW rated capacity, while the fixed surface piercing and the moored floating foundation options are assumed to have 2MW rated capacities (due to the twin rotors in these designs). The two fixed technologies are assumed to operate lower in the water column than the floating technology. As a result of velocity shear, the velocity profile within a tidal channel generally follows an exponential profile; 75% of the energy in a tidal stream is located in the upper 50% of the water column [11]. The floating turbine technology is assumed to have access to faster flowing water closer to the surface, thus giving the floating turbine enhanced AEP characteristics in comparison to the fixed turbine variants.

Utilising information acquired during the Strategic Initiative for Ocean energy (SI Ocean) project [11], cost estimations and approximate cost breakdowns for current generation tidal energy technologies have been combined with the Carbon Trust's Cost Estimation Methodology tool [13] in order to assess the LCOE resulting from these devices. It must be noted that these cost estimates are for current generation technologies (i.e. the devices that will be used within the initial pre-commercial array projects), and therefore there has been no assumed cost reduction due to learning effects.

In order to be able to compare technologies on a level playing field, consideration must be given to existing cost structures, as the current costs of tidal technologies will play a significant role in the route to project development and deployment. There is little benefit in using assumed future costs if the current costs of tidal energy projects are preventing early arrays from reaching Final Investment Decision (FID).

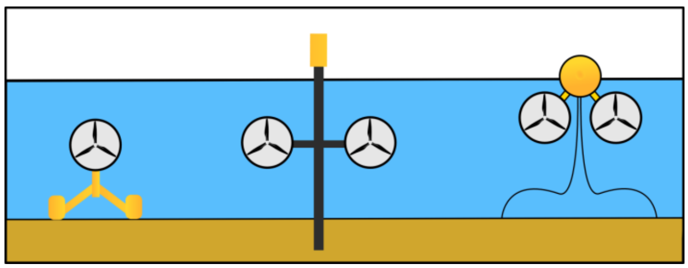

Figure 3: Tidal Energy Converter Technology Variations: Fixed Bottom Mounted, Fixed Surface Piercing, Floating

The base case scenarios for each foundation type are based on information available in the public domain, with validation through the SI Ocean project for cost breakdown percentages by cost centre [12] in order to provide a representation of costs with generic turbine Power-Take-Off (PTO) and electrical conditioning components. The installation and O&M costs are foundation specific. A basic summary of the input values is shown in Table 4 below. Certain information is confidential, and has not been replicated within this report, but an indicator of the relative cost values has been provided.

Technology Type	Fixed Bottom Mounted	Fixed Surface Piercing	Floating
Device Rated Power (MW)	1	2	2
Annual Electricity Production per device (GWh/yr)	Approx. 2,6	Approx. 5,2	Approx 5,8
CAPEX Costs (€million/MW)	8,6	5,9	3,75
Installation Cost	High	High	Low
OPEX Costs	High	Low	Low
Availability	85%	85%	85%
Design Life (years)	25	25	20

Table 4: Tidal technology assumptions

3.1 Base Case Assumptions:

The device rotors in question are assumed to have identical performance characteristics. The fixed bottom mounted device is considered to be single rotor, with the other foundation platforms allowing for twin rotors on a single foundation.

Annual energy production is assumed to vary according to the height that the rotors are placed within the water column. Using a reference ADCP dataset, consideration was made for the approximate hub height: For the bottom mounted designs hub height has been set at a value of 25m above the sea bed; for the floating designs hub height has been set at a value of 35m above the sea bed (taken as an approximation below the mean sea level for simplicity, however in reality it is recognised that the height above the sea bed will vary constantly with a floating turbine design). Annual Energy Production (AEP) calculation was based on a generic power curve. ADCP data recorded over a 31 day time period at a 1 minute sample interval was used as the input data, and then harmonic analysis (further details of this process can be found in [14]) was performed in order to recreate a velocity time series for a one year period. This one year dataset of velocities was used to calculate an approximate AEP at both 25m and 35m hub heights.

CAPEX costs are linked to installation costs, and the costs associated with the technical complexity of the foundation design and necessary installation technique. This also accounts for the type of vessel required to complete the installation process. Within the CAPEX cost figures, all costs associated with turbine Power Take Off (PTO), turbine structure, control and instrumentation, and grid connection are assumed to be identical for each turbine design, regardless of foundation type. However, mooring, foundation and installation costs are assumed to vary depending on foundation or mooring type, predominantly due to the different vessel requirements and quantities of material involved.

CAPEX and OPEX costs for a sea bed mounted turbine are high, due to the need for heavy lift capabilities in order to deploy or retrieve the nacelle to/from the bottom mounted foundation. A return to base operation and maintenance (O&M) technique will be required regardless of the nature or severity of the failure.

For surface piercing bottom mounted designs, there is a similar high CAPEX cost, but there is an opportunity to carry out maintenance in-situ. As a result of the ability to lift rotors out of the water, vessel requirements for O&M are significantly reduced, favourably impacting the OPEX cost.

For floating designs, a return to base technique may be needed, although for simple fault correction it may be possible to replace components in-situ. However, given the ease of access to surface mounted platforms, and the reduced vessel requirements, the costs associated with the O&M or a return to base are significantly lower than for bottom mounted designs.

Given that there is no information publicly available on the performance and availability characteristics of tidal devices, an estimated 85% availability has been applied to the base case scenario, that represents a reasonable (and, ideally, achievable) target. The design life for the bottom mounted designs is 25 years, based on input from the SI Ocean project. The floating turbine has a 20 year design life. This is based on information obtained from publicly available data [15].

There are a number of financial inputs for which the costs remain confidential, and as such the value used for the analysis will not be discussed within this report. Information on these costs came from the SI Ocean project as a result of discussion with device developers and stakeholders within the ocean energy sector.

The baseline inputs, when entered into the appropriate cells of the Carbon Trust Cost Estimation spreadsheet tool [13] provide reference LCOE for each technology type. An assumed discount rate of 15% has been assumed, which gives the following results in Euro cents/kWh for the base case assumptions:

Fixed Bottom Mounted	Fixed Surface Piercing	Floating
91 cents/kWh	61 cents/kWh	45 cents/kWh

Table 5: Baseline LCOE for tidal using an assumed discount rate of 15%

A range of scenarios were analyzed in order to investigate the effect on the LCOE. The scenarios, and the resultant changes to the LCOE are detailed in Table 6.

Scenario	Fixed Bottom Mounted	Fixed Surface Piercing	Floating
Base Case	91	61	45
-10% CAPEX	86	58	43
+10% CAPEX	96	65	47
-50% CAPEX	65	44	34
-10% OPEX	88	60	44
+10% OPEX	93	63	46
-50% OPEX	79	56	39
-10% Availability	103	70	51
+10% Availability	81	55	40
-10% insurance	90	60	44
-50% insurance	85	56	40
Best Case	43	30	22

Table 6: Scenarios and resultant LCOE in Euro cents/kWh using an assumed 15% discount rate

Table 6 above clearly highlights that the current LCOE of tidal energy is significantly higher than the market pull support mechanisms that are available in any country at present. This explains the reason why in addition to attractive market pull support mechanisms, the early array projects also require support from capital grants or other funding sources in order to make a valid business case to progress with the array deployment. Although the LCOE, at present, appears high, each scenario represents a plausible improvement in LCOE that will help various foundation platforms reach a level closer to economic attractiveness. However, it should be noted that the only foundation/mooring solution that offers an LCOE reduction to level reaching near-competitiveness with offshore wind (currently ~19,4c/kWh) [16] is the floating foundation. This suggests that radical innovation will need to take place within other foundation designs in order to allow adequate cost reduction to take place.

The scenarios were designed to represent a sensitivity analysis, based on the focus of effort on one key area from the following: CAPEX, OPEX, or AEP. As LCOE calculations are based primarily on these variables, it seemed prudent to assess the relative impact of changes to each variable on the overall LCOE.

- A 10% reduction in CAPEX resulted in a 6%, 6%, and 5% reduction in LCOE for Fixed Bottom Mounted, Fixed Surface Piercing, and Floating technologies respectively.
- A 10% reduction in OPEX resulted in a 3%, 2%, and 2% reduction in LCOE for Fixed Bottom Mounted, Fixed Surface Piercing, and Floating technologies respectively.
- A 10% increase in availability resulted in an 11% reduction in LCOE in all cases.

This sensitivity suggested that modest changes to the AEP resulted in significant contributions to LCOE decrease. Turbine reliability and availability are therefore paramount to achieving a favourable and attractive LCOE. Availability will be impacted by both turbine reliability, and also the weather conditions during which an installation or a retrieval operation is planned to be carried out. The current velocity and the weather, specifically wind speed, significant wave height and period, will affect lifting operations and vessel movements. This will have a knock on effect to turbine intervention. The speed at which a failed turbine can be retrieved and replaced will prove to be a decisive factor in whether a technology can truly achieve a competitive LCOE.

In order to assess more significant cost reductions in both CAPEX and OPEX, reductions of 50% in both cases were also investigated.

- A 50% reduction in CAPEX resulted in a 28%, 28%, and 23% reduction in LCOE for Fixed Bottom Mounted, Fixed Surface Piercing, and Floating technologies respectively.
- A 50% reduction in OPEX resulted in a 13%, 9%, and 12% reduction in LCOE for Fixed Bottom Mounted, Fixed Surface Piercing, and Floating technologies respectively.

Very high insurance costs are currently required for this new technology, are these costs have been cited by various technology developers as a significant constraint on the ability of tidal technologies to become cost competitive with other, more mature, renewable energy technologies. While it is recognised that insurance costs are likely to decrease significantly with increasing turbine reliability and performance proving (and also the involvement of large Original Equipment Manufacturers (OEMs) such as Siemens and Alstom), the sensitivity analysis carried out here investigated the impact to the LCOE based on a 10% insurance reduction and a 50% insurance reduction.

- A 10% reduction in insurance costs resulted in a 1%, 2%, and 2% reduction in LCOE for Fixed Bottom Mounted, Fixed Surface Piercing, and Floating technologies respectively.
- A 50% reduction in insurance costs resulted in a 6%, 9%, and 11% reduction in LCOE for Fixed Bottom Mounted, Fixed Surface Piercing, and Floating technologies respectively.

In all of the above scenarios, the technology still fails to reach cost competitiveness with offshore wind, and so a combination of scenarios will need to be achieved in order to unlock the large scale deployments that the industry seeks. A best case scenario, with a 50% reduction in CAPEX, 50% reduction in OPEX, 50% reduction in insurance costs, and a 10% increase in availability, was therefore investigated to yield the resulting changes to LCOE.

- A best case scenario resulted in a 52%, 52%, and 51% reduction in LCOE for Fixed Bottom Mounted, Fixed Surface Piercing, and Floating technologies respectively.

A comparison of the LCOE achieved in the base case scenario and the best case scenario for all foundation and mooring types is shown in Figure 4.

It should be noted that the fixed bottom mounted technologies with a single rotor perform significantly less attractively than twin rotor technology. Even in a best case scenario, a single 1MW rotor will effectively result in an LCOE 43% higher than that of twin rotors mounted on a surface piercing bottom mounted foundation. It is therefore clear that single rotor turbines at MW scale offer limited opportunity to achieve significant levels of cost reduction, making cost-competitiveness with technologies such as offshore wind unlikely with existing systems and cost structures. Multiple rotor structures allow enhanced performance in terms of LCOE, due to the increased swept area allowing increased AEP from a given foundation platform.

However, in all LCOE scenarios, the bottom mounted structures are significantly outperformed by the floating structure. Due to the significant changes to vessel requirements, and the ability to connect and disconnect devices using only modest workboat sized vessels, the floating technology has, on average, an LCOE of 51% less than the fixed bottom mounted turbine, and 27% less than the fixed surface piercing turbines.

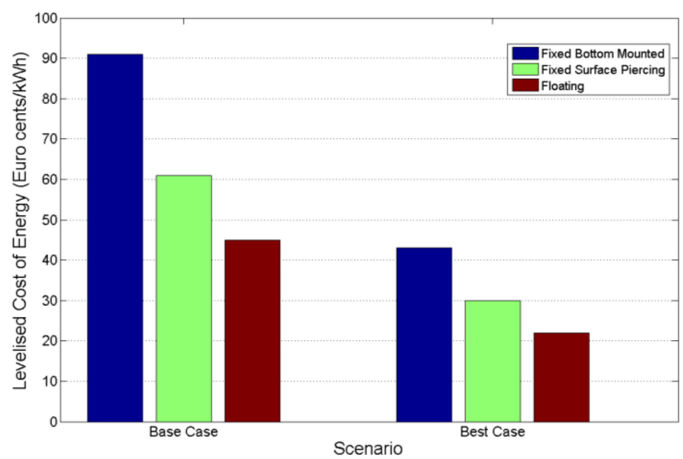

Figure 4: Tidal - default and best scenario

A range of scenarios are required in order to achieve cost competitive power generation, and the type of foundation or mooring will significantly impact the early array economic case. While significant CAPEX and OPEX cost reductions are essential, modest availability (and AEP) improvements are capable of a more drastic alteration in the LCOE compared to modest CAPEX and OPEX reductions. The relationship between foundation type and device accessibility in the event of a component failure must therefore be given due attention, in addition to the reliability improvements of components and sub-components. Speed and efficiency of component replacement is essential to achieving high availability in the early devices, where initial "bedding-in" failures are more likely to occur.

4.-Conclusions

Ocean energy development and deployment has not yet reached a commercial stage. It is clear that the LCOE for these wave and tidal technologies need to decrease significantly in order to be competitive with the other renewable sources such as offshore wind. However, within the ocean energy sector, there is no clear path towards commercialisation. In this paper the current and future LCOE of some wave and tidal prototypes has been investigated.

It should be noted that important differences exist between the wave and tidal ies. The first difference relates to the base cases used in the LCOE analyses within this paper, where tidal energy is already ahead of wave energy in terms of cost reduction. For the wave technology case study, the default case leads to an LCOE of 5 Euros/kWh and 1.7 Euros/kWh (for multipoint absorber and attenuator respectively), while the tidal technologies base case lead to a LCOE of 0,91 Euros/kWh, 0,61 Euros/kWh and 0,45 Euros/kWh (fixed bottom mounted, fixed surface piercing and floating respectively). It should also be highlighted that for the different technology improvements for the wave energy converters studied, the improvements could lead to a decrease in the LCOE (from current cost levels) of more than 85 %. However, in the case of tidal energy converters, this reduction was around 51-52% (from current cost levels) in the best case scenario investigated.

Wave energy needs to achieve greater levels of cost reduction in order to reach cost competitiveness with other forms of renewable energy, but the opportunities for cost reduction are clear.

Improvements in capital costs, maintenance costs, and availability are needed in order for tidal energy to achieve a more attractive LCOE. The most significant cost savings could in fact be achieved through the selection of moored foundation platforms, which unlock significant CAPEX and OPEX savings in addition to unlocking access to the higher velocity flows in the upper water column. In the near term, this work has shown that only floating tidal turbines are capable of cost reductions to below 0,20 Euro/kWh.

A clear focus for wave and tidal energy converter technology developers must be on achieving and demonstrating reliable long term device performance. Without significant levels of availability, the LCOE quickly increases, and any unplanned interventions could make projects teetering on the edge of economic viability lose any credibility in achieving significant cost reduction.

Although the available locations for wave energy development are much broader than for tidal, the variability in the wave conditions is much higher across the global resource. As has been demonstrated in the wave technology section within this paper, the different technology types are site still very site specific, and the performance of each converter type is variable from one location to another. Site specific met-ocean studies to influence market targeting for individual devices is seen as essential, due to the lack of design convergence within the wave energy sector. Wave energy technologies need to focus the R&D efforts mainly on improving their control strategies, enhancing the hydraulic efficiency of their PTO and building their prototypes with lower cost materials in order to unlock significant LCOE reductions.

It should be noted that on that piece of work the LCOE was selected as the main indicator in order to analyze how close the technologies are from commercialization. However, LCOE is nowadays an indicator based on several assumptions regarding the cost and projections of the predicted power output of the devices. Further work will be performed in order to reduce this uncertainty and develop an appropriate metrics to properly measure the commercial ability of a certain technology.

5.- Acknlowledgements

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