Suitable location on the Spanish Atlantic coast for the implementation of a wave energy converter based on different parameters

Ubicación idónea en la costa atlántica española para la implantación de un convertidor de energía undimotriz basado en diferentes parámetros

ABSTRACT: At the beginning of the development of Wave Energy Converters, it is advisable to carry out a study of the waves in the areas of the possible location in order to subsequently be able to design the devices thanks to the knowledge of the waves in the area. This study should shed light on the main wave parameters such as the type of waves in the area and the frequency with which these waves occur. In this study, it will be important to know the power of the waves (per meter of wave front), the maximum slope of the waves and the different wave roses. The slope of the waves will be relevant since the study is carried out in order to later develop a converter capable of taking advantage of the slopes to generate electrical energy. The wave rose is a vital component to know in which direction to anchor the device, as is the case with other converters already developed. This study will cover different locations along the Spanish Atlantic coast, which in this particular case will be Galicia, the Basque Country, Andalusia and the Canary Islands.

Keywords: Spanish Atlantic coast, SIMAR point, Wave Energy Converter, Wave frequency, Wave slope, Wave power and Swell rose.

RESUMEN: Al inicio del desarrollo de los Wave Energy Converters conviene realizar un estudio del oleaje de las zonas del posible emplazamiento con el fin de, a posteriori, poder diseñar los dispositivos gracias al conocimiento del oleaje de la zona. Para ese estudio, se debería arrojar luz de los principales parámetros del oleaje tales como conocer la tipología de las olas que hay en la zona y la frecuencia con la que ocurren dichas olas. En este estudio será importante conocer la potencia de las olas (por metro de frente de ola), la pendiente máxima del oleaje y las diferentes rosas de oleajes. La pendiente de las olas será relevante para desarrollar un convertidor capaz de aprovechar las pendientes y así generar energía eléctrica. La rosa de oleajes es un componente vital para saber en que dirección fondear el dispositivo, como ocurre con otros convertidores ya desarrollados. Este estudio cubrirá diferentes localizaciones de la costa atlántica española que en este caso en concreto serán Galicia, País Vasco, Andalucía y las Islas Canarias.

Palabras clave: Costa atlántica española, puntos SIMAR, Convertior de energía de las olas, frecuencia de ola, pendiente de ola, potencia de ola y rosa de oleaje.

1. - INTRODUCTION

Nowadays, the depletion of conventional fossil fuel resources has led to an increase in oil and natural gas prices, thereby exacerbating the issue of energy scarcity. As a result, nations are engaging in a race to foster innovative energy ventures and attain environmentally sustainable progress.

The 2015 Paris Agreement established ambitious objectives aimed at mitigating the devastating impacts of climate change [1]. In line with this, the European Commission introduced the Green New Deal initiative, portions of which have been transformed into binding European legislation starting from 2020 [2].

The primary goal of the Green New Deal is to advance renewable energies through the implementation of innovative technologies, thereby ensuring Europe maintains a prominent position while fostering emission-free trade and services. The European Commission has made a dedicated commitment to realize the objectives of the Paris Agreement by establishing concrete targets for 2030 a 55% reduction in greenhouse gas emissions, a 32.5% share of renewables in the electricity system, and a 21.5% improvement in energy efficiency. Established renewable energy sources like hydro, wind, and solar power are at the forefront of the initial phase of the transition. Nonetheless, relying solely on these sources will not be adequate to ensure the flexibility and stability of energy supply [3].

The vast expanse of the ocean holds a tremendous amount of energy, encompassing various sources such as ocean currents, osmotic energy, ocean thermal energy, tidal energy, and wave energy. These sources have attracted significant attention and research [4-5]. Studies have compared these energy sources and highlighted the significance of wave energy, given its high energy density, widespread availability, and superior energy capacity compared to other sources [6].

The viability of harnessing ocean wave energy as a valuable and dependable energy source has gained widespread recognition. Comprehensive assessments of global [7-8] and regional [9-10] ocean wave energy resources have demonstrated their substantial potential, generating significant interest in the exploration and utilization of this renewable energy source.

The estimated average annual coastal power potential of this resource is around 2 TW, and if we take into account the wider oceans beyond the coasts, the resource could potentially be an order of magnitude greater [11]. A Greenpeace report from 2005 on renewable energy in Spain highlighted that utilizing the entire coastline could result in the production of 329 TWh/year of electricity from wave energy, which would cover approximately 118% of the projected energy demand of the Iberian Peninsula in 2050 [12].

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Europe, the United States, China, and India are leading the way in formulating strategies to integrate wave energy into their energy agendas. These countries are actively investing in research and establishing testing centres dedicated to the design and evaluation of wave energy converters (WECs) within their borders [13].
Spain is making significant progress in this field, evident through the establishment of two dedicated sites for testing various Wave Energy Converters (WECs). These sites include the Oceanic Platform of the Canary Islands (PLOCAN) [14] and the Bizkaia Maritime Energy Platform (BiMEP) [15]. PLOCAN has conducted testing on different WECs, including Wavepiston and Tveter Power [16]. Similarly, BiMEP has installed devices such as MARMOK-A-5 [17] and Penguin [18] to advance wave energy research and development.
To determine the suitability of wave characteristics for their collectors, various Wave Energy Converters (WECs) employ different methods and tools when deploying devices at different test sites. These methods often involve the analysis of swell matrices, such as the swell frequency in the area and the theoretical power that can be harnessed. Subsequently, when communicating the performance results and extractable power, wave matrices are utilized. These wave matrices use a combination of colours to indicate the most favourable waves, specifically those most suitable for a particular WEC. The matrices are presented with significant wave heights defined on one axis and different periods numbered on the other axis [19].
In this work different matrices based on the following parameters: frequency of occurrence of waves, power per meter of wavefront, slopes and swell rose were created, with the aim of defining the ideal area for the installation of Wave Energy Converters (WECs) on the Spanish Atlantic coast. First, the locations with the most suitable conditions were defined: the Basque Country, Galicia, Andalusia and the Canary Islands. Subsequently, the characteristic parameters in each of the areas were obtained. They were analysed and the most suitable location for the installation of a WEC farm in Spain was defined.

2. - MATERIAL & METHODS

In order to collect the data, different locations must be chosen. To do this, it must be taken into account that the WEC to be installed in the distant future will have to be anchored to the seabed, so the depth cannot be greater than 300 metres. This means that the Atlantic coast may not be ideal, as the depth is as much as 800 metres offshore. In order to analyse the Spanish Atlantic coast, 4 different points were considered, sufficiently separated from each other so that the data between these locations change enough so that they are not almost identical. It should be noted that it was decided to carry out the study only on various points of the Spanish Atlantic coast and not on the Mediterranean Sea because the Mediterranean has not historically experienced waves as significant as in the Atlantic. For this reason, the two test sites for wave energy extraction devices are located on the Atlantic coast, such as the aforementioned PLOCAN and BiMEP. It should be noted that, in the study carried out, different SIMAR points were analysed, which are a set of data formed by time series of variables such as wind and waves that come from numerical modelling, so they are simulated data that do not come from direct measurements of nature [20], although they are close enough to carry out this study, as the average of the data obtained shows an average efficiency of 98.72% with a standard deviation of 0.07%. Finally, it is worth mentioning that in order to have representative data, the data was taken from 1960 to the present day.
In this case, the Galician coast was considered first, approximately at the Finisterre cape in order to be able to observe which swell is in an area where the coast can hardly have any incidence on the swell. This point of the Galician coast is located at latitude 43.00ºN and longitude 9.50ºW and has a depth of 189 metres. Remaining in the north of Spain, specifically in the Cantabrian Sea, and in order to move away from the previous point, the Basque area was considered, specifically at the point with latitude 43.50ºN and longitude 2.50ºW, which has a depth of 150 metres. In the south of the Iberian Peninsula, in the Andalusian area, the aim was to analyse the wave data from the Strait of Gibraltar. To do this, it was separated sufficiently far from this geographical area so as not to interfere with maritime traffic, so the study point has the coordinates of 36.50ºN and 6.83ºW, at which point it has a depth of 298 metres. Finally, and to move away from the mainland, data were taken from the Canary coast, specifically near PLOCAN, which is a test area for WEC devices. The study point is located at a latitude of 28.00ºN and a longitude of 15.33ºW and has a depth of 278 metres.

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Fig. 1. Locations of wave data collection.

Figure 1 shows the map of the Spanish coast where the different locations have been represented with the corresponding SIMAR points, which are indicated on the map with their coordinates. This map has been obtained by marking the points in the Google Earth tool to show the points more clearly.
Initially, the SIMAR points offer frequency of occurrence of different types of waves depending on their significant height (Hs) and their inter-peak period (Tp). In these, you can select the standard deviation they will have, in these cases, to have the great majority of waves shown within the limits of the table, you will have a standard deviation of 0.5 metres in the significant height and another of 1.5 seconds in the inter-peak period.
The following four tables show the frequency of occurrence according to significant height and peak period for Galicia (Table 1), the Basque Country (Table 2), Andalusia (Table 3) and the Canary Islands (Table 4):

GALICIA SIMAR 30280400 43.00ºN 9.50ºW		Peak Period (s)											Total
		<= 1.5	3	4.5	6	7.5	9	10.5	12	13.5	15	15.0 >	
Significant Height (m)	<= 0.5	-	-	0.01	0.12	0.18	0.09	0.07	0.01	0.01	0.00	0.00	0.49
	1	-	0.00	0.22	0.85	2.49	2.86	1.54	0.49	0.19	0.07	0.03	8.72
	1.5	-	-	0.22	2.08	3.16	6.27	5.65	1.95	0.75	0.24	0.09	20.40
	2	-	-	0.01	1.52	2.79	4.01	6.42	3.79	1.66	0.41	0.15	20.76
	2.5	-	-	-	0.22	1.66	2.11	4.05	3.79	2.38	0.57	0.19	14.96
	3	-	-	-	0.01	0.55	1.24	2.39	2.90	2.41	0.74	0.20	10.44
	3.5	-	-	-	0.00	0.14	0.61	1.50	2.01	2.14	0.83	0.24	7.46
	4	-	-	-	0.00	0.03	0.34	0.84	1.40	1.65	0.86	0.24	5.35
	4.5	-	-	-	0.00	0.01	0.17	0.52	0.81	1.17	0.72	0.27	3.66
	5	-	-	-	-	0.00	0.06	0.28	0.51	0.83	0.60	0.28	2.57
	5.0 >	-	-	-	-	-	0.02	0.24	0.65	1.49	1.73	1.07	5.20
Total		-	0	0.45	4.80	10.98	17.76	23.52	18.32	14.68	6.77	2.73	100%

Table 1. Types of waves at Galicia SIMAR point between the years 1960 and 2023.

Table 1 shows that waves in Galicia are predominantly between 7.5 seconds and 13.5 seconds. Furthermore, in terms of wave height, the majority of waves are between 1.5 and 3 metres in height. It should also be noted that waves of less than 1 metre in height and shorter than 6 seconds and longer than 15 seconds between peaks hardly occur in this area of the Spanish coast.

BASQUE COUNTRY SIMAR 1070074 43.50ºN 2.50ºW		Peak Period (s)											Total
		<= 1.5	3	4.5	6	7.5	9	10.5	12	13.5	15	15.0 >	
Significant Height (m)	<= 0.5	-	0.04	0.78	0.72	1.13	2.07	1.88	0.93	0.45	0.19	0.09	8.27
	1	-	0.01	0.74	2.66	2.92	6.90	6.89	3.23	1.65	0.53	0.19	25.73
	1.5	-	-	0.04	1.07	1.74	3.84	7.77	5.04	2.77	0.80	0.24	23.32
	2	-	-	0.00	0.21	1.01	1.45	4.20	4.34	3.40	0.95	0.26	15.84
	2.5	-	-	-	0.01	0.36	0.66	1.70	2.76	2.92	1.14	0.31	9.86
	3	-	-	-	0.00	0.07	0.37	0.81	1.64	2.16	0.98	0.29	6.31
	3.5	-	-	-	-	0.01	0.17	0.46	0.84	1.52	0.84	0.26	4.11
	4	-	-	-	-	0.00	0.06	0.27	0.48	0.86	0.68	0.24	2.58
	4.5	-	-	-	-	0.00	0.01	0.14	0.28	0.46	0.45	0.20	1.54
	5	-	-	-	-	-	0.00	0.06	0.18	0.28	0.29	0.14	0.95
	5.0 >	-	-	-	-	-	0.00	0.02	0.18	0.47	0.54	0.29	1.51
Total		-	0.05	1.56	4.67	7.24	15.54	24.20	19.90	16.94	7.40	2.50	100%

Table 2. Types of waves at Basque Country SIMAR point between the years 1960 and 2023.

In the area of the Basque Country, which can be seen in Table 2, conditions are quite similar to those in Galicia (Table 1). The only difference is that there are more frequent waves at low peak periods. Even so, the most frequent waves have between 9 and 13.5 seconds of period between peaks and 1 and 2 metres of significant height. In this area of the Basque Country there are lower wave heights than in Galicia, which may affect the amount of power that can be extracted from the swell.

ANDALUSIA SIMAR 5032015 36.50ºN 6.83ºW		Peak Period (s)											Total
		<= 1.5	3	4.5	6	7.5	9	10.5	12	14	15	15.0 >	
Significant Height (m)	<= 0.5	*0*	0.12	3.77	1.93	2.43	4.73	4.98	2.24	1.25	0.41	0.10	21.96
	1	-	0.20	9.11	6.37	2.97	4.50	7.13	4.48	3.00	1.04	0.27	39.07
	1.5	-	0.00	1.80	6.91	1.96	1.37	2.59	2.95	2.64	0.82	0.26	21.30
	2	-	-	0.03	3.13	1.70	0.81	0.86	1.10	1.18	0.51	0.17	9.48
	2.5	-	-	0.00	0.49	1.28	0.67	0.45	0.42	0.52	0.22	0.10	4.15
	3	-	-	-	0.02	0.55	0.50	0.25	0.21	0.20	0.12	0.07	1.91
	3.5	-	-	-	0.00	0.12	0.38	0.19	0.13	0.13	0.07	0.03	1.05
	4	-	-	-	-	0.02	0.16	0.14	0.07	0.06	0.05	0.01	0.50
	4.5	-	-	-	-	0.00	0.05	0.10	0.05	0.03	0.04	0.01	0.27
	5	-	-	-	-	-	0.01	0.07	0.04	0.03	0.03	0.00	0.17
	5.0 >	-	-	-	-	-	0.00	0.04	0.04	0.03	0.02	0.01	0.13
Total		*0*	0.32	14.71	18.85	11.02	13.17	16.80	11.72	9.06	3.32	1.03	1.00

Table 3. Types of waves at Andalusia SIMAR point between the years 1960 and 2023.

In this area of Andalusia, Table 3, the most frequent waves have a shorter period between peaks and a lower significant height, the most repeated waves being between 4.5 and 12 seconds and from 0 to 1.5 metres respectively. Therefore, in this area the waves are even lower in height than in the Basque Country, so there is less mechanical energy in the waves in this area, an element that must be taken into account for the possible location of the WEC in the area.

CANARY ISLANDS SIMAR 4038009 28.00ºN 15.33ºW		Peak Period (s)											Total
		<= 1.5	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	15.0 >	
Significant Height (m)	<= 0.5	-	0.01	0.24	0.58	0.59	0.90	1.32	1.11	0.75	0.41	0.10	6.00
	1.00	-	0.00	1.62	4.05	4.98	3.91	3.78	3.26	2.75	1.49	0.50	26.36
	1.50	-	0.00	0.18	5.58	9.91	6.57	3.62	2.25	2.64	1.63	0.90	33.28
	2.00	-	-	-	1.01	7.72	6.09	2.31	1.26	1.34	0.93	0.75	21.41
	2.50	-	-	-	0.03	1.52	4.18	1.09	0.57	0.54	0.38	0.33	8.64
	3.00	-	-	-	0.00	0.09	1.42	0.72	0.26	0.20	0.14	0.16	2.98
	3.50	-	-	-	-	0.00	0.34	0.39	0.05	0.05	0.06	0.07	0.98
	4.00	-	-	-	-	-	0.03	0.15	0.02	0.01	0.02	0.03	0.27
	4.50	-	-	-	-	-	0.00	0.04	0.01	0.00	0.00	0.01	0.07
	5.00	-	-	-	-	-	-	0.01	0.01	0.00	-	0.00	0.02
	5.0 >	-	-	-	-	-	-	0.00	0.00	-	-	-	0.00
Total		-	0.01	2.05	11.26	24.81	23.44	13.43	8.81	8.29	5.06	2.86	1.00

Table 4. Types of waves at Canary Islands SIMAR point between the years 1960 and 2023.

In the last point, in the Canary Islands (Table 4) it can be seen that the data in the table are closer to the values of the Basque country than to either of the other two. In fact, the wave types in this area are mostly repeated between the values of 6 and 10.5 seconds in terms of peak period and between 1 and 2 metres in terms of significant height. Unlike in the Basque Country, in this area of the Canary Islands there are hardly any waves greater than 3 metres, something which in Table 2 at least occurred slightly more frequently.

Wave roses were also drawn for the 4 study areas, which are shown in figure 2:

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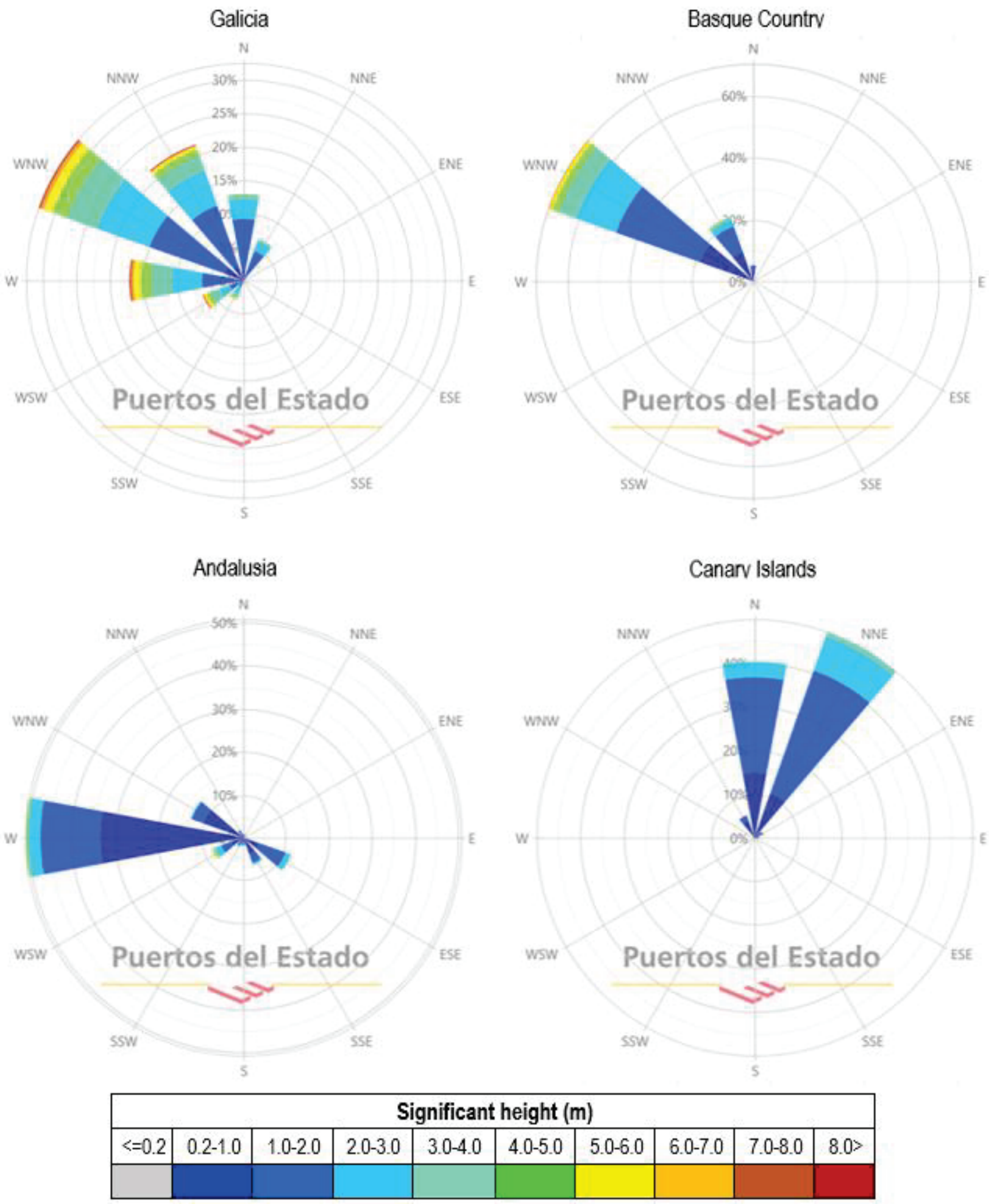

Fig. 2. Swell rose of the 4 locations between 1960 and 2023.

As for the wave roses of the 4 locations (Figure 2), there are 4 very different cases. As for the Galician area, it can be seen that the waves, although most of them come from the WNW, almost 35%, also have waves in various directions around it, decreasing in frequency as they move away from that direction. In the swell rose it can be clearly seen that Galicia is the area with the highest significant swell height. The second area with the second highest swell height is the Basque Country. The advantage of this area is that almost 70% of the waves come in a WNW direction, i.e. the vast majority of the waves. In the Canary Islands almost all the swell comes from only 2 contiguous directions (N and NNE) and in Andalusia a little more than 50% of the waves come from the W, although in these two areas the significant swell height is not as high as in the other two locations, as can also be seen in the 4 wave frequency tables above.

Once the 4 sites have been analysed and it has been decided which would be the best, a detailed study should be carried out for a full year in order to find out the specific type of waves found in the area. It would also be very interesting to be able to study the area by climatic season or even by month. It is also important to carry out this detailed study in order to know the deviation that the current swell is having with respect to that of the recent past due to climate change.

From the data obtained in the frequency of occurrence tables, the wave length (λ) for deep waters can be calculated using the following equation [21]:

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$$\lambda = \frac{gT_p^2}{2\pi} \quad (1)$$

Where g is gravity, which in the case of all the points will be assumed to be 9.81m/s^2. Then, knowing Hs and λ, the maximum slope of each of the waves, in radians, can be calculated (θ_0) thanks to the following mathematical expression:

$$\theta_0 = \pi \cdot \frac{H_s}{\lambda} \quad (2)$$

Substituting equation 1 into equation 2, the maximum wave slope, in radians, can be expressed as dependent only on Hs and Tp:

$$\theta_0 = 2\pi^2 \cdot \frac{H_s}{gT_p^2} \quad (3)$$

To display equation 3 in degrees, the following formula will be used:

$$\theta_0 = 360\pi \cdot \frac{H_s}{gT_p^2} \quad (4)$$

In addition to the wave slope, the wave power in kilowatts per metre of wave front (kW/m), (Pw) for each type of wave shall be shown by calculating this parameter using the following equation:

$$Pw = \delta \cdot \mathrm{g}^2 \cdot \mathrm{Hs}^2 \cdot \frac{\mathrm{Tp}}{32\pi} \quad (5)$$

Where δ is the density of the water, which, in this case, being seawater, will be 1.025 kg/m^3.

Another important variable to take into account in terms of wave conditions in the area is the swell rose. In addition, in the particular case of this WEC, it is even more important to know the direction of the swell in order to orient the WEC installation in that direction, as for example, in the case of the Wave Dragon [22]. As with the wave height ant period data, it is vital for the wave rose to have update data for each day.

Once the results of these calculations are known, the power that a mass falling down an inclined plane within the WEC could theoretically reach and then be transformed into electrical energy by connecting the mass to a generator could be known. Before that, the length of the inclined plane or, in other words, the beam of the boat must be known. For this, it must be taken into account that the beam of the WEC should not be greater than the half-length of the swell so that the device does not remain between the peaks of the waves and can therefore heel along with the waves. Therefore, taking equation 1 into account, an ideal beam value of 6 metres was obtained, in order to be able to take advantage of all types of waves in any of the 4 zones mentioned above. Although a 7-metre beam catcher could be used in 3- second peak period waves, a 1-metre safety margin is applied.

On the other hand, to calculate the power of the mass, the force of the mass must first be known:

$$\boldsymbol{Fx = m \cdot a = m \cdot g \cdot sin\theta - \mu \cdot m \cdot g \cdot cos\theta} \quad (6)$$

Where Fx is the force of the mass on the axis parallel to the plane of free fall, a is the maximum acceleration of the mass, g is gravity which has a value of 9.81m/s2 in this particular case, θ is the angle of the plane or the angle of heel of the WEC in this case, μ is the dynamic friction coefficient which will have a value of 0.05 since the mass is expected to move from side to side thanks to Teflon versus Teflon rails [23] and m is the value of the mass. This mass, in order not to affect too much the stability of the WEC by being on one side of the beam and also not to cause too high an initial heeling which is difficult to overcome with the slope of the waves, will have to be an acceptable value as it would be the case of 300 kilograms of mass for a collector having a total displacement of 300 tonnes, i.e. 0.1% of the weight of the WEC.

Once the calculated force is available, the work done by the mass (W) can be obtained.

$$\boldsymbol{W = Fx \cdot B} \quad (7)$$

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B being the collector beam and therefore it will have a value of 6 metres. Finally, to know the power of the mass (P), the following formula shall be applied:

$$\boldsymbol{P} = \frac{\boldsymbol{W}}{\boldsymbol{t}} \qquad (8)$$

Where t is the time for the mass to fall through the inclined plane. To calculate this time the following equation is required:

$$\boldsymbol{x} = \boldsymbol{v_0} \cdot \boldsymbol{t} + \frac{\boldsymbol{a} \cdot \boldsymbol{t}^2}{2} \qquad (9)$$

Where v_0 is the initial velocity of the mass, which will be taken to be zero. Simplifying the formula would be as follows:

$$\boldsymbol{t} = \sqrt{\frac{2\boldsymbol{x}}{\boldsymbol{a}}} \qquad (10)$$

The acceleration can be calculated using equation 6.

3. - RESULTS

To improve the accuracy of the wave data, in this case the data will be taken the BiMEP (Biscay Maritime Energy Platform) data provided by the Environmental Hydraulics Institute at the University of Cantabria (IHCantabria) [24]. These data are enhanced by having wave data every hour of the day for one year from 1 March 2020 to 28 February 2021 inclusive. These data have an accuracy of 0.25 metres of significant height and 0.5 seconds of peak period. After analysing these data, it was decided to keep the data from November to April in order to exclude the months of lower wave activity and to know the power that can be extracted in the months of higher activity. Table 5 shows the frequency of swell occurrence between the months and the area mentioned.

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	Peak period(s)																						
Significant wave height (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	TOTAL
0.5	0.11	0.29	1.09	1.09	0.17	0.20	0.17	0.11	0.03	0.03	0.06	-	-	-	-	-	-	-	-	-	-	-	3.36
0.75	0.06	0.80	0.92	1.75	0.95	0.83	0.32	0.63	0.32	0.23	0.03	-	-	-	-	-	-	-	-	-	-	-	6.83
1	-	0.06	0.63	2.30	0.89	1.38	0.89	0.86	0.92	0.92	0.43	0.17	0.26	0.29	0.14	0.03	-	-	-	-	-	-	10.16
1.25	-	0.03	0.52	0.49	0.34	0.49	0.77	1.21	1.44	1.32	0.46	0.63	0.52	0.55	0.11	0.03	-	0.06	-	-	-	-	8.96
1.5	-	-	0.17	0.34	0.49	0.49	0.69	1.03	0.83	0.75	0.37	0.80	0.83	1.18	0.60	0.11	0.06	0.03	0.06	0.03	-	-	8.87
1.75	-	-	-	0.20	0.63	0.83	0.60	0.55	0.92	0.43	0.72	0.77	1.21	1.09	1.09	1.12	0.23	0.60	0.20	0.03	0.03	0.03	11.28
2	-	-	-	0.03	0.37	0.66	0.75	0.80	0.43	0.95	0.46	0.63	1.18	1.41	1.72	1.81	0.63	0.52	0.37	0.03	-	-	12.74
2.25	-	-	-	-	-	0.69	1.00	0.43	0.46	0.66	0.49	0.37	0.52	0.86	0.92	1.58	0.98	0.49	0.52	0.06	-	-	10.02
2.5	-	-	-	-	-	0.37	0.63	0.80	0.26	0.72	0.49	0.43	0.20	0.49	0.57	0.89	0.63	0.40	0.26	0.63	0.55	-	8.32
2.75	-	-	-	-	-	0.09	0.11	0.29	0.20	0.49	0.26	0.29	0.34	0.40	0.37	0.60	0.60	0.26	0.34	0.11	0.11	-	4.88
3	-	-	-	-	-	0.11	0.11	0.20	0.40	0.37	0.26	0.06	0.09	0.14	0.17	0.40	0.34	0.06	0.26	0.09	-	-	3.07
3.25	-	-	-	-	-	0.06	0.03	0.17	0.23	0.43	0.26	0.09	0.06	0.00	0.11	0.37	0.29	-	0.03	0.26	-	-	2.38
3.5	-	-	-	-	-	-	0.03	0.03	0.03	0.09	0.34	0.06	0.03	0.17	0.06	0.26	0.17	-	-	-	-	-	1.26
3.75	-	-	-	-	-	-	-	0.06	0.06	0.20	0.32	0.32	0.17	0.11	0.06	0.03	0.06	-	-	-	-	-	1.38
4	-	-	-	-	-	-	-	-	0.17	0.23	0.29	0.09	0.03	0.09	-	-	0.09	-	-	-	-	-	0.98
4.25	-	-	-	-	-	-	-	-	0.06	0.03	0.03	0.46	0.20	0.06	0.06	-	0.06	0.03	-	-	-	-	0.98
4.5	-	-	-	-	-	-	-	-	0.03	0.17	0.55	0.34	0.23	0.03	-	0.06	0.03	0.03	-	-	-	-	1.46
4.75	-	-	-	-	-	-	-	-	-	-	0.40	0.20	0.14	0.09	0.11	0.06	0.03	0.03	-	-	-	-	1.06
5	-	-	-	-	-	-	-	-	-	-	0.14	0.03	-	-	0.06	0.03	0.03	0.03	-	-	-	-	0.32
5.25	-	-	-	-	-	-	-	-	-	-	0.11	0.14	-	-	-	-	0.06	-	-	-	-	-	0.32
5.5	-	-	-	-	-	-	-	-	-	-	0.11	0.14	-	-	0.03	-	0.03	-	-	-	-	-	0.32
5.75	-	-	-	-	-	-	-	-	-	-	-	0.03	-	0.06	0.00	-	0.03	-	-	-	-	-	0.11
6	-	-	-	-	-	-	-	-	-	-	-	-	-	0.06	0.00	-	-	-	-	-	-	-	0.06
6.25	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.09	0.06	-	-	-	-	-	-	0.17
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.06	-	-	-	-	-	-	0.17
6.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.23	0.03	-	-	-	-	-	-	0.26
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.29	-	-	-	-	-	-	-	0.29
TOTAL	0.17	1.18	3.33	6.20	3.85	6.20	6.11	7.18	6.77	8.01	6.57	6.06	6.00	7.09	6.92	7.52	4.33	2.53	2.04	1.23	0.69	0.03	100.00

Table 5. Wave types in the BiMEP between November 2020 and April 2021 inclusive.

The colour coding used in Table 5 indicates the following frequencies of occurrence:

- ≥1%, green, representing 27.96% of all the waves of these types.
- 0.75% to 0.999%, blue, representing 20.47% of all the waves of these types.
- 0.5% to 0.749%, yellow, representing 18.17% of all the waves of these types.
- 0.25% to 0.499%, orange, representing 22.07% of all the waves of these types.
- < 0.25%, red, representing 11.34% of all the waves of these types.

As can be seen in the Table 5, the most frequent waves are in the range between 5 seconds and 9.5 seconds of wave period and 1 meter and 2.5 meters of significant height.

Using Equation 4, we obtained the maximum slopes of each type of wave, in radians. To facilitate the interpretation of the data, all wave slope values were converted to degrees (°). These slopes for each wave type can be seen clearly and concisely in Table 6. The colours used in Table 6 follow the same pattern as that used in Table 5.

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	Peak period (s)																					
Significant wave height (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
0.5	14.41	9.22	6.40	4.71	3.60	2.85	2.31	1.91	1.60	1.36	1.18	-	-	-	-	-	-	-	-	-	-	-
0.75	21.62	13.83	9.61	7.06	5.40	4.27	3.46	2.86	2.40	2.05	1.76	-	-	-	-	-	-	-	-	-	-	-
1	-	18.45	12.81	9.41	7.21	5.69	4.61	3.81	3.20	2.73	2.35	2.05	-	-	1.42	1.28	-	-	-	-	-	-
1.25	-	23.06	16.01	11.76	9.01	7.12	5.76	4.76	4.00	3.41	2.94	2.56	2.25	1.99	1.78	1.60	-	1.31	-	-	-	-
1.5	-	-	19.21	14.12	10.81	8.54	6.92	5.72	4.80	4.09	3.53	3.07	2.70	2.39	2.13	1.92	1.73	1.57	1.43	1.31	-	-
1.75	-	-	-	16.47	12.61	9.96	8.07	6.67	5.60	4.78	4.12	3.59	3.15	2.79	2.49	2.24	2.02	1.83	1.67	1.53	1.40	1.29
2	-	-	-	18.82	14.41	11.39	9.22	7.62	6.40	5.46	4.71	4.10	3.60	3.19	2.85	2.55	2.31	2.09	1.91	1.74	-	-
2.25	-	-	-	-	-	12.81	10.38	8.58	7.21	6.14	5.29	4.61	4.05	3.59	3.20	2.87	2.59	2.35	2.14	1.96	-	-
2.5	-	-	-	-	-	14.23	11.53	9.53	8.01	6.82	5.88	5.12	4.50	3.99	3.56	3.19	2.88	2.61	2.38	2.18	2.00	-
2.75	-	-	-	-	-	15.66	12.68	10.48	8.81	7.50	6.47	5.64	4.95	4.39	3.91	3.51	3.17	2.88	2.62	2.40	2.20	-
3	-	-	-	-	-	17.08	13.83	11.43	9.61	8.19	7.06	6.15	5.40	4.79	4.27	3.83	3.46	3.14	2.86	2.62	-	-
3.25	-	-	-	-	-	18.50	14.99	12.39	10.41	8.87	7.65	6.66	5.85	5.19	4.63	4.15	3.75	-	3.10	2.83	-	-
3.5	-	-	-	-	-	-	16.14	13.34	11.21	9.55	8.23	7.17	6.30	5.58	4.98	4.47	4.04	-	-	-	-	-
3.75	-	-	-	-	-	-	-	14.29	12.01	10.23	8.82	7.69	6.76	5.98	5.34	4.79	4.32	-	-	-	-	-
4	-	-	-	-	-	-	-	-	12.81	10.91	9.41	8.20	7.21	6.38	-	-	4.61	-	-	-	-	-
4.25	-	-	-	-	-	-	-	-	13.61	11.60	10.00	8.71	7.66	6.78	6.05	-	4.90	4.44	-	-	-	-
4.5	-	-	-	-	-	-	-	-	14.41	12.28	10.59	9.22	8.11	7.18	-	5.75	5.19	4.71	-	-	-	-
4.75	-	-	-	-	-	-	-	-	-	-	11.18	9.74	8.56	7.58	6.76	6.07	5.48	4.97	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	11.76	10.25	-	-	7.12	6.39	5.76	5.23	-	-	-	-
5.25	-	-	-	-	-	-	-	-	-	-	12.35	10.76	-	-	-	-	6.05	-	-	-	-	-
5.5	-	-	-	-	-	-	-	-	-	-	12.94	11.27	-	-	7.83	-	6.34	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-	-	-	11.79	-	9.18	8.18	-	6.63	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	9.57	8.54	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-	-	-	-	-	9.97	8.90	7.98	-	-	-	-	-	-
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.25	8.30	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.61	8.62	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.96	-	-	-	-	-	-	-

Table 6. Maximum slope of the waves in the BiMEP between November 2020 and April 2021 inclusive.

In addition to these two matrices above, there is a third one in which, applying equation 4, the wave powers can be shown as in Table 7. In this matrix, the colour coding used in the previous two matrices is maintained.

	Peak period (s)																					
Significant wave height (m)	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
0.5	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7	-	-	-	-	-	-	-	-	-	-	-
0.75	1.1	1.4	1.7	1.9	2.2	2.5	2.8	3.0	3.3	3.6	3.9	-	-	-	-	-	-	-	-	-	-	-
1	-	2.5	2.9	3.4	3.9	4.4	4.9	5.4	5.9	6.4	6.9	7.4	7.8	8.3	8.8	9.3	-	-	-	-	-	-
1.25	-	3.8	4.6	5.4	6.1	6.9	7.7	8.4	9.2	10.0	10.7	11.5	12.3	13.0	13.8	14.6	-	16.1	-	-	-	-
1.5	-	-	6.6	7.7	8.8	9.9	11.0	12.1	13.2	14.4	15.5	16.6	17.7	18.8	19.9	21.0	22.1	23.2	24.3	25.4	-	-
1.75	-	-	-	10.5	12.0	13.5	15.0	16.5	18.0	19.5	21.0	22.5	24.0	25.5	27.0	28.5	30.0	31.6	33.1	34.6	36.1	37.6
2	-	-	-	13.7	15.7	17.7	19.6	21.6	23.5	25.5	27.5	29.4	31.4	33.4	35.3	37.3	39.2	41.2	43.2	45.1	-	-
2.25	-	-	-	-	-	22.4	24.8	27.3	29.8	32.3	34.8	37.3	39.7	42.2	44.7	47.2	49.7	52.2	54.6	57.1	-	-
2.5	-	-	-	-	-	27.6	30.7	33.7	36.8	39.9	42.9	46.0	49.1	52.1	55.2	58.3	61.3	64.4	67.5	70.5	73.6	-
2.75	-	-	-	-	-	33.4	37.1	40.8	44.5	48.2	51.9	55.7	59.4	63.1	66.8	70.5	74.2	77.9	81.6	85.3	89.0	-
3	-	-	-	-	-	39.7	44.2	48.6	53.0	57.4	61.8	66.2	70.6	75.1	79.5	83.9	88.3	92.7	97.1	101.6	-	-
3.25	-	-	-	-	-	46.6	51.8	57.0	62.2	67.4	72.5	77.7	82.9	88.1	93.3	98.5	103.6	-	114.0	119.2	-	-
3.5	-	-	-	-	-	-	60.1	66.1	72.1	78.1	84.1	90.1	96.2	102.2	108.2	114.2	120.2	-	-	-	-	-
3.75	-	-	-	-	-	-	-	75.9	82.8	89.7	96.6	103.5	110.4	117.3	124.2	131.1	138.0	-	-	-	-	-
4	-	-	-	-	-	-	-	-	94.2	102.0	109.9	117.7	125.6	133.4	-	-	157.0	-	-	-	-	-
4.25	-	-	-	-	-	-	-	-	106.3	115.2	124.1	132.9	141.8	150.6	159.5	-	177.2	186.1	-	-	-	-
4.5	-	-	-	-	-	-	-	-	119.2	129.2	139.1	149.0	159.0	168.9	-	188.8	198.7	208.6	-	-	-	-
4.75	-	-	-	-	-	-	-	-	-	-	155.0	166.0	177.1	188.2	199.2	210.3	221.4	232.5	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	171.7	184.0	-	-	220.8	233.0	245.3	257.6	-	-	-	-
5.25	-	-	-	-	-	-	-	-	-	-	189.3	202.8	-	-	-	-	270.4	-	-	-	-	-
5.5	-	-	-	-	-	-	-	-	-	-	207.8	222.6	-	-	267.1	-	296.8	-	-	-	-	-
5.75	-	-	-	-	-	-	-	-	-	-	-	243.3	-	275.8	292.0	-	324.4	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	300.2	317.9	-	-	-	-	-	-	-
6.25	-	-	-	-	-	-	-	-	-	-	-	-	-	325.8	345.0	364.1	-	-	-	-	-	-
6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	373.1	393.8	-	-	-	-	-	-
6.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	402.4	424.7	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	432.7	-	-	-	-	-	-	-

Table 7. Energy per meter front of the waves in the BiMEP between November 2020 and April 2021 inclusive.

As previously mentioned, after knowing all the wave data in the BiMEP area, a theoretical calculation could be made of the power that could be achieved by the mass inside the WEC moving from port to starboard and vice versa. This mass is responsible for the intermediate step of converting the mechanical energy of the waves into electrical energy; all that remains to be done is to connect this mass to a generator. It should be noted that, due to the fact that the friction coefficient of Teflon with Teflon has a value of 0.05, the angle of heel of the collector must exceed 2.86º so that the force generated by the weight itself can overcome the frictional force between the parts, so there will be waves that cannot be used, as the mass will not move from its initial position. This can be seen in

Table 8 which shows the time it would take for the mass to fall from port to starboard without taking into account the period of the waves and estimating that the maximum slope of the wave would be fixed.

		Peak period (s)																					
		2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
Significant height (m)	0.5	2.47	3.32	4.45	6.16	9.72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.75	1.95	2.53	3.23	4.09	5.25	7.05	10.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1	-	2.13	2.66	3.27	4.02	4.97	6.33	8.59	14.35	-	-	-	-	-	-	-	-	-	-	-	-	-
	1.25	-	1.88	2.32	2.81	3.38	4.06	4.91	6.07	7.83	11.30	29.84	-	-	-	-	-	-	-	-	-	-	-
	1.5	-	-	2.08	2.50	2.97	3.51	4.16	4.95	6.01	7.54	10.25	18.17	-	-	-	-	-	-	-	-	-	-
	1.75	-	-	-	2.28	2.69	3.14	3.67	4.29	5.05	6.05	7.47	9.83	15.54	-	-	-	-	-	-	-	-	-
	2	-	-	-	2.11	2.47	2.87	3.32	3.84	4.45	5.19	6.16	7.52	9.72	14.59	-	-	-	-	-	-	-	-
	2.25	-	-	-	-	-	1.70	3.06	3.50	4.02	4.62	5.37	6.33	7.67	9.81	14.35	76.96	-	-	-	-	-	-
	2.5	-	-	-	-	-	1.94	2.85	3.24	3.69	4.21	4.82	5.56	6.53	7.88	10.03	14.54	59.45	-	-	-	-	-
	2.75	-	-	-	-	-	2.18	2.68	3.04	3.43	3.89	4.41	5.02	5.79	6.77	8.16	10.37	15.07	72.64	-	-	-	-
	3	-	-	-	-	-	2.41	2.53	2.86	3.23	3.63	4.09	4.62	5.25	6.03	7.05	8.50	10.84	15.96	-	-	-	-
	3.25	-	-	-	-	-	2.65	2.41	2.72	3.05	3.42	3.83	4.29	4.84	5.49	6.30	7.37	8.90	-	17.29	-	-	-
	3.5	-	-	-	-	-	-	2.31	2.59	2.90	3.24	3.61	4.03	4.51	5.07	5.75	6.60	7.73	-	-	-	-	-
	3.75	-	-	-	-	-	-	-	2.48	2.77	3.09	3.43	3.81	4.24	4.74	5.32	6.03	6.92	-	-	-	-	-
	4	-	-	-	-	-	-	-	-	2.66	2.95	3.27	3.62	4.02	4.46	-	-	6.33	-	-	-	-	-
	4.25	-	-	-	-	-	-	-	-	2.56	2.84	3.14	3.46	3.82	4.23	4.69	-	5.86	6.65	-	-	-	-
	4.5	-	-	-	-	-	-	-	-	2.47	2.73	3.01	3.32	3.66	4.03	-	4.93	5.49	6.16	-	-	-	-
	4.75	-	-	-	-	-	-	-	-	-	-	2.91	3.20	3.51	3.85	4.24	4.67	5.18	5.77	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	2.81	3.08	-	-	4.06	4.46	4.91	5.44	-	-	-	-
	5.25	-	-	-	-	-	-	-	-	-	-	2.72	2.98	-	-	-	-	4.69	-	-	-	-	-
	5.5	-	-	-	-	-	-	-	-	-	-	2.57	2.80	-	-	3.56	-	4.16	-	-	-	-	-
	5.75	-	-	-	-	-	-	-	-	-	-	-	2.72	-	3.19	3.45	-	4.02	-	-	-	-	-
	6	-	-	-	-	-	-	-	-	-	-	-	-	-	3.10	3.35	-	-	-	-	-	-	-
	6.25	-	-	-	-	-	-	-	-	-	-	-	-	-	3.02	3.26	3.51	-	-	-	-	-	-
	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.18	3.42	-	-	-	-	-	-
	6.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.10	3.33	-	-	-	-	-	-
	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.03	-	-	-	-	-	-	-

Table 8. Time of mass fall from port to starboard or vice versa according to the wave slopes in table 6.

As can be seen in Table 8, there are times that exceed the wave period, as is the case for most of the waves. It should also be noted that for the mass to move from band to band, only half the wave period is available to make that journey. This means that the mass would not have enough time to get to the other side of the wave and, consequently, there would be less mass power. To approximate the calculations as closely as possible to the power that the mass would reach, the times that are greater than half a period between wave peaks will be applied as the time of maximum use to extract the energy from the mass, or in other words, the period of the wave between its peak and trough. Knowing this, the maximum mass power in kW for each type of wave will be as shown in Table 9.

		Peak period (s)																					
		2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
Significant height (m)	0.5	3.54	1.57	0.73	0.32	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0.75	5.68	2.69	1.38	0.74	0.39	0.19	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1	-	3.80	2.04	1.15	0.67	0.39	0.22	0.11	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
	1.25	-	4.88	2.68	1.56	0.95	0.58	0.36	0.21	0.12	0.05	0.01	-	-	-	-	-	-	-	-	-	-	-
	1.5	-	-	3.32	1.97	1.22	0.78	0.50	0.32	0.20	0.12	0.06	0.02	-	-	-	-	-	-	-	-	-	-
	1.75	-	-	-	2.38	1.50	0.97	0.64	0.43	0.28	0.18	0.11	0.06	0.02	-	-	-	-	-	-	-	-	-
	2	-	-	-	2.78	1.77	1.16	0.78	0.53	0.36	0.25	0.16	0.10	0.06	0.02	-	-	-	-	-	-	-	-
	2.25	-	-	-	-	-	1.36	0.92	0.64	0.45	0.31	0.21	0.14	0.09	0.05	0.02	0.00	-	-	-	-	-	-
	2.5	-	-	-	-	-	1.55	1.07	0.75	0.53	0.38	0.27	0.19	0.13	0.08	0.05	0.02	0.00	-	-	-	-	-
	2.75	-	-	-	-	-	1.74	1.21	0.85	0.61	0.44	0.32	0.23	0.16	0.11	0.07	0.04	0.02	0.00	-	-	-	-
	3	-	-	-	-	-	1.93	1.36	0.96	0.69	0.50	0.37	0.27	0.20	0.14	0.10	0.06	0.04	0.02	-	-	-	-
	3.25	-	-	-	-	-	2.12	1.57	1.11	0.79	0.57	0.42	0.31	0.23	0.17	0.12	0.08	0.05	-	0.01	-	-	-
	3.5	-	-	-	-	-	-	1.80	1.27	0.91	0.66	0.48	0.35	0.27	0.20	0.15	0.10	0.07	-	-	-	-	-
	3.75	-	-	-	-	-	-	-	1.45	1.04	0.76	0.56	0.41	0.30	0.23	0.17	0.13	0.09	-	-	-	-	-
	4	-	-	-	-	-	-	-	-	1.18	0.87	0.64	0.48	0.35	0.26	-	-	0.01	-	-	-	-	-
	4.25	-	-	-	-	-	-	-	-	1.32	0.98	0.73	0.54	0.41	0.31	0.23	-	0.13	0.09	-	-	-	-
	4.5	-	-	-	-	-	-	-	-	1.47	1.09	0.82	0.62	0.47	0.35	-	0.20	0.14	0.11	-	-	-	-
	4.75	-	-	-	-	-	-	-	-	-	-	0.91	0.69	0.52	0.40	0.30	0.23	0.16	0.12	-	-	-	-
	5	-	-	-	-	-	-	-	-	-	-	1.00	0.76	-	-	0.34	0.26	0.18	0.14	-	-	-	-
	5.25	-	-	-	-	-	-	-	-	-	-	1.10	0.84	-	-	-	-	0.20	-	-	-	-	-
	5.5	-	-	-	-	-	-	-	-	-	-	1.20	0.92	-	-	0.43	-	0.21	-	-	-	-	-
	5.75	-	-	-	-	-	-	-	-	-	-	-	1.01	-	0.61	0.48	-	0.23	-	-	-	-	-
	6	-	-	-	-	-	-	-	-	-	-	-	-	-	0.67	0.52	-	-	-	-	-	-	-
	6.25	-	-	-	-	-	-	-	-	-	-	-	-	-	0.72	0.57	0.45	-	-	-	-	-	-
	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.62	0.49	-	-	-	-	-	-
	6.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.67	0.53	-	-	-	-	-	-
	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.72	-	-	-	-	-	-	-

Table 9. Maximum mass power according to the times in table 8 and half periods.

As can be seen in table 9, the maximum power that could be obtained with a mass of 300kg would be 5.68 kW, for a height of 0.75 metres and a period of 2 seconds. This is very interesting in order to know what is the maximum power that can be extracted if the mass were to be coupled with a suitable generator.

4. - DISCUSSION

Given the results obtained from the four locations, it is worth noting that in most of the locations the waves occur most frequently in the area of 7.5 and 12 seconds and between 1 and 2 metres of significant height. Even so, there are differences in terms of these occurrences as the waves with the highest power per metre of wave front are found in the northern part of the Iberian Peninsula, with the point of Galicia having the waves with the highest energy. The negative point of the Galician area is that the swell comes from different directions as can be seen in the swell rose, the position of greatest incidence being the WNW part with slightly less than 35%. In the case of the Andalusian and Canary Islands area, especially in the former, although the waves do not have great power per metre of wave front, they do have a higher slope as they are short period waves and could therefore be better exploited by the future WEC. As for the direction of the swell, on the north coast the WNW direction is prominent, being in the Basque Country the only place where almost 70% of the swell reaches the same direction. Andalusia has a W direction with just over 50% repetition from that direction. As for the Canary Islands, the swell is mostly from the NNE, which almost reaches 50%, but there is also 40% of the swell from a northerly direction.

Taking all this data into account, the ideal place for the location of a WEC that takes advantage of the slopes generated by the swell that will be anchored and fixed in one position is in the Basque Country, as this is the location with the swell mostly coming from one direction. This section, for a device anchored and oriented in the direction from which the swell comes, is of vital importance, so it would prevail over the Galician one, which has a greater swell power, but in different directions. Precisely the power per metre of wave front of the Basque location is much higher than, for example, the Canary Islands, which is the other location with a swell coming from the same direction, and even the Andalusian location, which is weaker in these two sections.

In the more in-depth study of the Basque Country area, it was decided to use the BiMEP data, as it is a test area for offshore devices and is only a few nautical miles away from the location of the first general survey. Thanks to the data collected by the IHCantabria, it can be seen that the waves that occurred between the months of November 2020 and April 2021, both included. In them it can be seen that between that time period there were waves of a shorter period than those shown in Table 2, while in the significant heights there are no very relevant changes, although it is more precise, since there is a lower standard deviation, both in terms of the peak period of the waves and in the significant height. Likewise, Table 6 shows that the most frequent slopes in this area are between 2º and 10º and there are also waves that can have a slope of up to 23.06º, although they are much less frequent. For these more frequent waves, the power per metre of wave front can reach 50kW/m as shown in Table 7.

Regarding wave analysis, in the future, it would be advisable to continue with the study of collecting daily wave data from the BiMEP area in order to verify whether the change in the frequent wave typology of the area is really due to climate change or to a particular annuality in terms of marine climatology. Ideally, however, we would like to average over at least 3 years in order to have a sufficiently high sample size so that storm events or sea storms occurring in one year are hidden among the normal swell and their presence is not so noticeable as in the case of Table 5 where the wave with a significant height of 7 metres and 9 seconds of peak period has a higher frequency of occurrence than the surrounding waves.

Regarding the calculated power, the first thing that stands out is the difference between the power offered by each wave per metre of wave front and the power of the mass. In this aspect, it is normal that the performance decreases, since, as it happens in other systems such as photovoltaic energy, there is always a decrease in power between the available power and the extracted power. Even so, the theoretical maximum power that the mass will have is high enough to try to improve the system and continue to make progress in the design of the WEC in order to have more accurate calculations of heel and therefore of power. One thing to improve could be to use a system that has less friction between its parts as could be the case with a pendulum motion of the mass. Having a lower friction coefficient can considerably improve the energy extraction, as the problem with the mass travel times would be significantly reduced. On the other hand, if it is not possible to reduce this friction, one could try to use shorter travel times, for example, by travelling half a beam and being able to use 2 masses in the same transverse axis of the WEC.

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