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EVALUATION OF THE ENERGETIC POTENTIAL OF SWELL FOR THE CANARY ISLES

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Abstrac

A summary of the methodology and calculations on the Canary Isles tidal power potential.

The background data have been provided by the Spanish State Ports *(Puertos del Estado),* an institution dependent on the Spanish Ministry for Public Works (Ministerio de Fomento).

Swell data have been obtained from WANA points and by means of the different beacons placed along the Canary Isles coasts which measure the height and period of swell.

In the event of dealing with real swelling, the swell analysis will be done statistically, assuming that swelling is a stochastic process nearly – stationary. This condition forces the interruption of swell registers at time intervals relatively short, but long enough to be statistically reliable. These time intervals in which swelling registers are divided for analysis are called sea states. The statistical analysis of sea states constitutes what is called short term wave analysis. At present, the State Ports controlled Average Wave Network, divides wave registers in 1 hour time sea states.

WAM is a third generation model which solves the transportation equation without any limitations in the energy spectrum shape. To this effect, a customization of the non-linear transference function and the specification of the dissipation functions were necessary.

Keywords: Energetic; Swell; Wave

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ENERGETIC POTENTIAL OF SWELL

A summary of the methodology and calculations on the Canary Isles tidal power potential are presented on this section.

The background data have been provided by the Spanish State Ports (Puertos del Estado), an institution dependent on the Spanish Ministry for Public Works (Ministerio de Fomento).

Swell data have been obtained from WANA points and by means of the different beacons placed along the Canary Isles coasts which measure the height and period of swell.

Calculation of the estimated wave power potential

For a given set of waves with an H (m) height and a T (s) period, the average energy per horizontal area unit, E (W), is obtained by means of the expression:

$$E = \frac{1}{8} \cdot \rho \cdot g \cdot H^2 \tag{1}$$

Where ρ is the water density (Kg/m^3) and g is the acceleration of gravity (m/s^2).

In order to know the magnitude of this energy, it is worth determining the average power of swell per width unit Pw (W/m), which crosses a vertical plane perpendicular to the wave propagation direction. For regular swelling, such average flow of energy can be determined by means of the expression:

$$Pw = E \cdot C_g \tag{2}$$

where Cg is the group swiftness or the energy carrying speed. Such a speed is given by:

$$C_g = \frac{c}{2} \cdot \left(1 + \frac{2 \cdot k \cdot h}{sen\,(2 \cdot k \cdot h)} \right) \tag{3}$$

where $c = \frac{L}{T}$ is the wave swiftness, $k = \frac{2 \cdot \pi}{L}$ is the wave number, h is the water depth and L is the wavelength, that can be obtained from the period and depth by solving the dispersion equation:

$$L = \frac{g \cdot T^2}{2 \cdot \pi} \cdot \tan(2 \cdot k \cdot h) \tag{4}$$

At undefined depths, when h/L > 0.5, the equations (3) and (4) are simplified to:

$$C_g = \frac{c}{2} \tag{5}$$

$$L = L_0 = \frac{g \cdot T^2}{2 \cdot \pi} \tag{6}$$

and the average power (2) is simplified to:

$$Pw = \frac{1}{32\pi} \rho g^2 H^2 T \approx 981 H^2 T \quad (W/m) \tag{7}$$

As seen, average power has a linear growth alongside the period, and a square growth in relation to the wave height.

In the event of dealing with real swelling, the swell analysis will be done statistically, assuming that swelling is a stochastic process nearly – stationary. This condition forces the interruption of swell registers at time intervals relatively short, but long enough to be statistically reliable. These time intervals in which swelling registers are divided for analysis are called sea states. The statistical analysis of sea states constitutes what is called short term wave analysis. At present, the State Ports controlled Average Wave Network, divides wave registers in 1 hour time sea states.

Short term statistical analysis of wave registers is customarily done on the frequency domain, by obtaining the function that represents the distribution of energy in angular frequencies, $\omega = 2 \cdot \pi / T$ and directions, θ, called directional spectral density function, $S(\omega, \theta)$ on the free surface of the ocean, which represents an average of the total energy in the existing time on every frequency interval $\Delta\omega_i$ and on every direction interval $\Delta\theta_j$. If swell component "i, j" is defined as the waves contained in the frequency $\Delta\omega_i$, $\Delta\theta_j$, such component will be assigned a height H_{ij} and its average energy per area unit (W/m^2) will be:

$$E_{i,j} = \frac{1}{8} \cdot \rho \cdot g \cdot H_{i,j}^2 \tag{8}$$

The total average energy per swell unit area in a sea state is to be obtained as the sum of all energy corresponding to all components:

$$E = \frac{1}{8} \cdot \rho \cdot g \cdot \sum_{\Delta\omega_i} \sum_{\Delta\theta_j} \frac{1}{2} H_{i,j}^2 = \rho \cdot g \cdot \int_{-\pi}^{\pi} \int_{0}^{\infty} S(\omega, \theta) \cdot d\omega \cdot d\theta \tag{9}$$

The average wave power will be obtained as the sum of energy flows of all the components, according to the expression:

$$Pw = \frac{1}{8} \cdot \rho \cdot g \cdot \sum_{\Delta\omega_i} \sum_{\Delta\theta_j} H_{i,j}^2 \cdot C_{gi,j} = \rho \cdot g \cdot \int_{-\pi}^{\pi} \int_{0}^{\infty} S(\omega,\theta) \cdot C_{gi,j} \cdot d\omega \cdot d\theta \tag{10}$$

In the event of being at undefined depths, h/L > 0.5, the expression (10) will be simplified to:

$$Pw = \frac{1}{32} \cdot \rho \cdot g^2 \cdot \sum_{\Delta\omega_i} \sum_{\Delta\theta_j} H_{i,j}^2 \cdot T_{i,j} = \frac{1}{2} \cdot \rho \cdot g^2 \cdot \int_{-\pi}^{\pi} \int_{0}^{\infty} \omega^{-1} \cdot S(\omega,\theta) \cdot d\omega \cdot d\theta \tag{11}$$

If we integrate the directional spectral density function on all the direction spectrum, a scalar spectral density function on the free surface of the ocean, $S(\omega)$ is obtained:

$$S(\omega) = \int_{-\pi}^{\pi} S(\omega, \theta) \cdot d\theta \tag{12}$$

In order to be able to obtain the directional spectral density function, the register and analysis of temporary series of several swell parameters (free surface, speed, etc.) is required. Whereas to obtain the scalar spectral density function for the free surface of the ocean the register and analysis of only one parameter is required. Therefore, equipments for directional swelling measures are more expensive than those for scalar measures. Nowadays, most of the existing instrumental information belongs to scalar buoys.

The frequency where the maximum of spectral density function is found is called peak frequency, ω_p and its associate period, peak period, T_p. The direction where the maximum spectrum is found it is called peak direction, θ_p or main propagation direction.

From the spectral density function a series of parameters is obtained which provides condensed information about the characteristics of the analysed register. Among these parameters it is worth mentioning the spectral moments and the sea state parameters derived thereof.

The order moment, n, on the scalar spectral density function is defined as:

$$m_n = \int_{0}^{\infty} \omega^n S(\omega)\, d\omega \quad ; n = 0, 1, 2, ... \tag{13}$$

The zero order moment, m_0, or the area under the spectrum, matches the square root of the average quadratic movement, $\eta_{\rho ms}$ of the free sea state surface and is proportional to the energy per sea state unit area (9). From the zero order moment it is defined the height of the sea state zero moment order, H_{m0}, by means of:

$$H_{m0} = 4.004\sqrt{m_0} \tag{14}$$

Where the process is narrow band and the wave height distribution is Rayleigh, it may be demonstrated that:

$$H_{m0} = 4.004 \cdot \eta_{rms} = H_s \tag{15}$$

Where H_s is the height of a significant wave, or average height of the N/3 highest waves on a free surface register made up of N waves.

The first two moments are especially relevant, as they are used to define the average frequency, $\overline{\omega}$, the average period, $\overline{T}$ and the average period for the rising passage through zero, Tz:

$$\overline{\omega} = \frac{m_1}{m_0}; \quad \overline{T} = 2\pi\frac{m_0}{m_1}; \quad \overline{T_z} = 2\pi\sqrt{\frac{m_0}{m_2}} \tag{16}$$

A parameter that facilitates a measure of the energy concentration round the spectrum peak is the dimensionless spectral width, ν, given by:

$$\nu^2 = \frac{m_0 m_2}{m_1^2} - 1 \tag{17}$$

Parameter ν facilitates a measure of the spectral width and has been theoretically proved that is inversely proportional to the average number of waves in a group. Equation (17) indicates that when all energy is concentrated on a single frequency, $\omega = \overline{\omega}$, then $\nu_2 \rightarrow 0$. When energy is scattered in many frequencies, then ν is incremented. A typical value in gales is ν = 0.3.

The average propagation direction is determined from this directional spectrum through the expression:

$$\theta_m = \arctan\left(\frac{\int_0^{2\pi}\int_0^{\infty}\sin\theta \cdot S(\omega,\theta)\cdot d\omega \cdot d\theta}{\int_0^{2\pi}\int_0^{\infty}\cos\theta \cdot S(\omega,\theta)\cdot d\omega \cdot d\theta}\right) \tag{18}$$

Once the scalar spectral density function of the free surface on a sea state is obtained, and after some hypothesis, the theoretical distribution functions of the different wave register parameters can be formulated, such as the height of wave, the period and the direction. These distribution parameters are expressed according to the spectral moments.

Average wave power, as a general rule given through the spectral density function by means of the expression (10), can be simply approached if the distribution of wave heights and their periods are known. A single approach to the energy flow at undefined depths can be obtained by making a scan with the sea states formula (11) with an average JONSWAP spectrum and H_s, T_Z and A variables. Variable A will oscillate in 0.34 and 0.57 depending on the wave spectrum to be evaluated.

Adjusting the energy flows to a (7) type function which to the effects of data analysis is used as Pw per kW/m is obtained:

$$Pw = A H_s^2 T_z \quad (kW/m) \tag{19}$$

Methodology used for the calculation of estimated swell power potential and results obtained

In order to evaluate the average wave power existing in the Canary Isles, formula (19) has been used as well as Tables for height-period from years 2002 to 2007 from the Swell database, Banco de Datos Oceanográficos de Puertos del Estado [State Ports Oceanographic Data Bank], an institution depending on the Spanish Ministry for Public Works (Ministerio de Fomento). To this effect, the following approximation $T_e \approx 0.8572 \times T_p$ will take place, where H_s and T_p. are the evaluated data.

Pw (kW/m)		Tp (s) 1	2	3	4	5	6	7	8	9	10	12
Hs (m)	0											
	0,5		0,080	0,133	0,186	0,239	0,292	0,346	0,399	0,452	0,505	0,585
	1,0	---	0,399	0,665	0,931	1,197	1,462	1,728	1,994	2,260	2,526	2,925
	1,5	---	1,037	1,728	2,420	3,111	3,802	4,494	5,185	5,877	6,568	7,605
	2,0	---	1,994	3,324	4,653	5,983	7,312	8,642	9,971	11,301	12,630	14,625
	2,5	---	3,271	5,451	7,631	9,812	11,992	14,173	16,353	18,534	20,714	23,985
	3,0	---	4,866	8,110	11,354	14,598	17,842	21,086	24,330	27,574	30,818	35,684
	3,5	---	6,781	11,301	15,821	20,342	24,862	29,383	33,903	38,423	42,944	49,724
	4,0	---	9,014	15,024	21,033	27,043	33,052	39,061	45,071	51,080	57,090	66,104
	4,5	---	11,567	19,278	26,989	34,701	42,412	50,123	57,834	65,546	73,257	84,824
	5,0	---	14,439	24,064	33,690	43,316	52,942	62,567	72,193	81,819	91,445	105,883
	7	---	23,612	39,354	55,096	70,837	86,579	102,320	118,062	133,803	149,545	173,157

Source: http://www.puertosdetenerife.es

Table 1. General data table from year 2004 used in the calculations of the average wave power.

To calculate the wave energy, formula (19) will be used with a conversion for Mw h year/m:

Energy (Mw h year/m) = Probability x Pw x 8760/1000/100

WAM Model and WANA simulation Points on the Canary Isles

WAM is a third generation model which solves the transportation equation without any limitations in the energy spectrum shape. To this effect, a customization of the non-linear transference function and the specification of the dissipation functions (Ozger *et al*, 2004) were necessary. WAM is formulated for spherical coordinates and uses an implicit method of integration.

This method tends to make spectrums wider than if more rigorous methods were used (Curran, Whittaker and Stewart, 1998). When numerically solving the source terms, on the whole, the solution is not stable. Therefore, a restrictor in the growth of wave energy is used according to frequency and timing. Hersbach and Janssen (1999) found that the original WAM restrictor is not suitable for high geographical resolutions. Therefore, they suggested a restrictor depending on the speed of friction and high-frequency cut-off (Falcão and Rodrigues, 2002).

In WAM it is assumed that waves are generated in the same direction as wind, and an empirical growth coefficient (restrictor) is used. Although helpful in high seas, in shore areas these considerations may not be valid (Falcão and Rodrigues, 2002; Falcão, 2002; Setoguchi *et al*, 2001). Therefore, tests were performed with a WAM adapted for its use on high spatial resolutions, mainly on shore areas, where modifications for propagation, inclusion of the effect of currents, bed friction and bed breaking were carried out. The authors concluded that when using a small timing, WAM is numerically stable in cases of growth with limited fetch. Therefore, problems become more numerical than physical. In spite of this, the growth restrictor (Falcão and Rodrigues, 2002; Sen, 2000) was also implemented.

WAM has been adopted by centres from all over the World for their operational use, including The National Center for Environmental Prediction (NCEP), United Kingdom Meteorological Office (UKMO), The European Centre for Medium-Range Weather Forecasts (ECMWF), and the U.S. Naval Oceanographic Office (NAVOCEANO). With experience, some model tendencies were found; for instance, the subforecasts of storm peaks and swelling events.

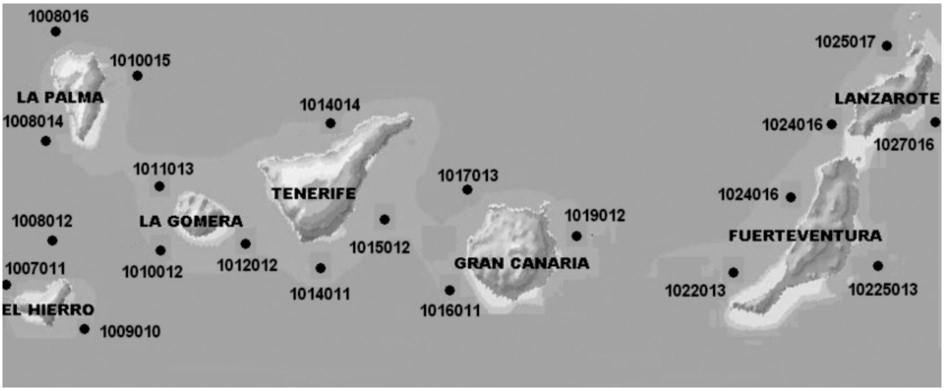
Some comparisons have shown that the influence in using either superficial winds, or superficial strength, is not significant.

WAM, as compared to buoy data (Tucker, 2001), provided good results, although there is evidence about its slow answering to variable conditions, possible due to the low resolution of wind fields. Impact on the assimilation of data in the prediction of swelling has been very limited. Furthermore, the assimilation effect disappeared in one hour after the testing time.

WAM model, although in use at different parts of the world by researchers and climate prediction centres, however, it has not been sufficiently analysed in terms of its validity for limited seas such as the Mediterranean. One of the few works carried out is the implementation by Cavaleri et al. (1991), Dell'Osso et al. (1992), where model tests with measures showed that, in order to obtain reliable predictions, it is necessary to have horizontal resolutions, with a cell size of, at least, 40 km.

WANA Simulation Points

The following Figure shows the location of all the evaluated WANA points in order to determine the energetic wave power potential of the Canary Isles.



Source: Own elaboration, 2008.

Figure 1. Representation of the WANA points location on the Canary Isles.

Results obtained from the analysis of monthly maximums for significant wave height (Hs) and period (Ts)

Below are shown the results obtained from the analysis of monthly maximums for significant wave height (H_s) and period (T_s). In order to summarise the swell climate on every WANA point studied, Tables for maximum height and period per month and per year are obtained. Average values of the analysed parameters are shown.

El Hierro WANA Point 1009010

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	1,92	3,27	8,32	19,97
2003	1,85	3,62	5,85	16,82
2004	1,37	2,92	8,6	13,07
2005	1,17	2,77	9,42	14,97
2006	1,77	3,47	6,2	12,55
2007	2,07	3,12	6,41	11,52
Prom.	1,690	3,270	7,460	13,810

WANA Point 1008012

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,15	4,75	8,17	16,45
2003	2,02	4,82	7,5	17,22
2004	1,5	3,55	11,3	15,27
2005	1,32	3,52	3,97	14,7
2006	2,22	4,32	9,15	14,2
2007	2,75	3,95	10,17	12,75
Prom.	1,990	4,150	9,340	15,090

WANA Point 1007011

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,15	5,32	9,95	14,95
2003	2,07	5,2	11,4	17,6
2004	1,75	3,87	10,67	14,9
2005	1,55	3,92	11,1	14,82
2006	1,97	4,55	11,65	14,2
2007	2,15	4,02	13,52	14,65
Prom.	1,940	4,480	11,382	15,187

Source: Own elaboration, 2008.

Table 3. Summary of the H_S and T_P seasonal maximums for El Hierro.

La Gomera WANA Point 1012012

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	1,72	3,42	9,5	15,4
2003	1,7	3,35	8,17	16,87
2004	1,57	2,8	11,65	15,42
2005	1,35	2,52	9,97	12,72
2006	1,57	2,67	10,47	13,37
2007	1,62	2,62	11,72	13,3
Prom.	1,588	3,897	10,247	14,513

WANA Point 1010012

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,1	4,05	9,47	15,02
2003	1,92	3,9	7,65	17,06
2004	1,6	3,07	9,62	14,9
2005	1,42	3,2	8,55	14,27
2006	2	3,75	8,55	14,27
2007	2,35	3,4	8,75	13,9
Prom.	1,898	3,562	8,765	14,993

WANA Point 1011013

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,15	4,15	10,02	15,4
2003	1,95	3,92	8,27	16,87
2004	1,95	3,32	11,6	14,72
2005	1,37	3,2	10,15	15,02
2006	2,12	3,72	9,15	16
2007	2,45	3,15	10,72	15,27
Prom.	1,998	3,577	9,985	15,547

Source: Own elaboration, 2008.

Table 4. Summary of the H_S and T_P seasonal maximums for La Gomera

La Palma WANA Point 1010015

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,32	4,3	9,45	14,45
2003	2,27	4,15	6,92	15,45
2004	2,2	3,6	8,27	14,67
2005	1,82	3,3	10,75	11,32
2006	2,5	3,65	10,57	15,1
2007	1,62	2,62	11,72	13,3
Prom.	2,227	3,750	9,260	14,193

WANA Point 1008014

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	1,5	3,95	9,05	15,09
2003	1,4	3,85	8,4	17,22
2004	0,92	3,07	12,6	13,62
2005	0,92	2,92	9,35	14,55
2006	1,5	3,65	11,67	14,25
2007	1,72	3,65	12,7	14,47
Prom.	1,327	3,515	10,628	15,002

WANA Point 1008016

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,42	5,67	9,65	16,82
2003	2,32	5,4	9,6	17,22
2004	3,2	4,22	11,37	15,37
2005	2	4,3	9,55	14,87
2006	2,3	4,87	10,67	14,17
2007	2,55	4,12	10,07	13,72
Prom.	2,315	4,763	10,257	15,362

Source: Own elaboration, 2008.

Table 5. Summary of the H_S and T_P seasonal maximums for La Palma

Tenerife WANA Point 1015012

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	1,22	1,95	4,79	6,27
2003	1,25	1,37	4,95	6,37
2004	0,9	1,22	5,5	6,45
2005	0,72	1,05	5,07	5,6
2006	2	3,2	6,67	8,05
2007	2,47	2,05	7,57	7,8
Prom.	1,427	1,882	5,788	6,757

WANA Point 1014014

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,12	5,17	11,65	16,82
2003	2,07	4,95	11,35	16,87
2004	2,02	3,62	11,6	15,6
2005	1,72	3,62	11,1	14,8
2006	2,05	3,8	10,5	14,32
2007	2,05	3,5	11,45	15,7
Prom.	2,005	4,110	11,108	15,685

WANA Point 1014011

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	1,32	2,6	5,07	8,4
2003	1,27	1,9	5,07	14,15
2004	0,9	1,82	4.22	9,72
2005	0,75	1,55	4,35	9,6
2006	1,9	2,15	6,27	12,15
2007	2,37	2,75	6,95	11,55
Prom.	1,418	2,128	5,322	10,928

Source: Own elaboration, 2008.

Tables 6. Summary of the H_S and T_P seasonal maximums for Tenerife

Lanzarote WANA Point 1025017

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	3,02	4,36	9,82	16,82
2003	2,8	5,62	9,27	16,87
2004	2,5	4,1	10,52	16,02
2005	2,02	4,42	9,52	14,85
2006	2,42	4,07	9,52	14,07
2007	2,9	3,97	9,97	16,95
Prom.	2,61	4,42	9,77	16,03

WANA Point 1027016

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	3,17	4,4	8,22	11,25
2003	3,05	4,4	8	3,47
2004	2,6	3,52	8,47	12,15
2005	2,07	3	7,12	13,15
2006	2,37	3,1	9,45	11.7
2007	2,87	3,52	8,3	14,02
Prom.	2,68	3,65	8,27	12,62

WANA Point 1024016

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,09	5,72	9,82	16,82
2003	2,72	5,57	9,27	16,87
2004	2,37	4	10,5	15,82
2005	1,97	4,32	9,57	15,07
2006	2,35	4,07	9,75	14,55
2007	2,77	3,87	11,42	17,12
Prom.	2.51	4,59	10,05	16,04

Source: Own elaboration, 2008.

Tables 7. Summary of the H_S and T_P seasonal maximums for Lanzarote

Fuerteventura WANA Point 1023014

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,77	5,5	9,65	16,82
2003	2,52	5,35	10,75	17,32
2004	2,17	3,8	11,25	15,72
2005	1,87	4,05	9,27	15,05
2006	2,22	3,87	9,7	14,34
2007	2,52	3,85	12,42	15,05
Prom.	2,34	4,40	10,50	15,75

WANA Point 1025013

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,57	3,15	7,47	8,02
2003	2,3	2,85	7,3	9,02
2004	1,77	2,2	8,2	8,22
2005	1,47	1,65	6,87	6,57
2006	2,55	2,02	6,8	6,92
2007	2,25	2,62	8,1	8,27
Prom.	2,20	2,41	7,79	7,83

WANA Point 1022013

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,77	5,22	9,65	16,82
2003	2,57	5,12	9,27	16,87
2004	2,22	4,22	10,35	15,75
2005	1,9	3,82	9,25	15,22
2006	2,3	3,65	9,52	13,65
2007	2,67	3,92	11,12	13,8
Prom.	2,40	4,33	9,86	15,35

Source: Own elaboration, 2008.

Table 8. Summary of the H_S and T_P seasonal maximums for Fuerteventura

Gran Canaria WANA Point 1017013

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,35	3,52	7,32	11,87
2003	2,3	3,65	7,62	15,45
2004	2,25	3,2	8,27	12,8
2005	1,8	2,97	7,82	12,75
2006	2,22	2,8	8,9	10,87
2007	2,47	3,3	9,22	15,3
Prom.	2,23	3,24	8,19	13,17

WANA Point 1016011

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	1,55	2,52	5,35	8,32
2003	1,47	1,82	5,2	8,02
2004	1,25	1,67	4,75	9,92
2005	1	1,65	4,4	5,87
2006	1,97	2,02	6,25	6,8
2007	2,5	2,5	7,15	13,25
Prom.	1,62	2,03	5,51	8,69

WANA Point 1019012

Year	Hs (m)		Tp (s)	
	Summer	Winter	Summer	Winter
2002	2,45	3,82	7,3	9,87
2003	2,4	4	7,62	15,62
2004	2,25	4,82	10,4	15,17
2005	1,87	3,12	9,35	13,77
2006	2,15	2,9	7,25	9,65
2007	2,5	3,22	7,7	12,65
Prom.	2,27	3,64	8,27	12,78

Source: Own elaboration, 2008.

Table 9. Summary of the H_S and T_P seasonal maximums for Gran Canaria

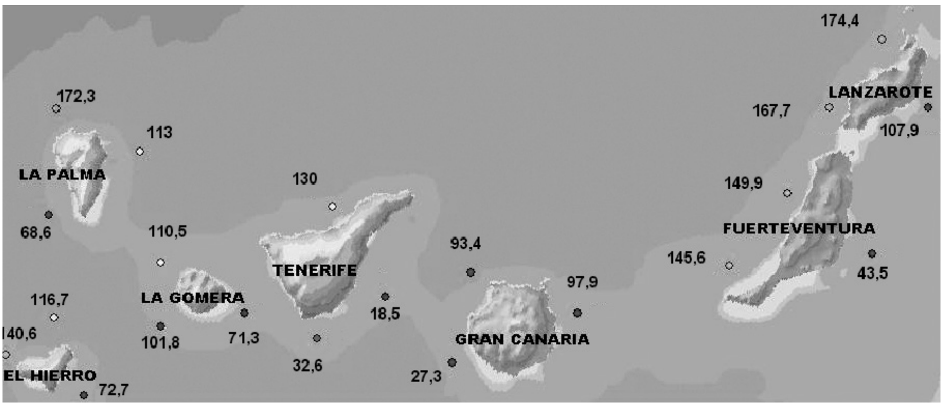
Ocean waves are classified according to its period. Summer season waves are to be classified within wind swell (which corresponds to waves of every size and wave longitude, which propagates in different directions) and those from winter season within ground swell (perfect sinusoidal waves, regular, parallel and of great length and width).

Available wave power in the Canary Isles

Below are shown the results obtained after having studied the different WANA simulation points data for every one of the islands in the Canary Isles archipelago and for a period of time between the years 2002 and 2007.

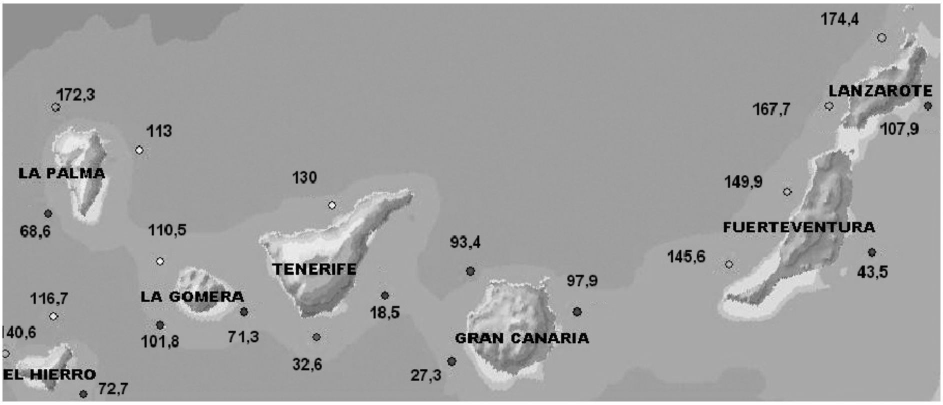
Suitable Area: that is the area that shows enough power to implement energetic Systems. A minimum power of 15 Kw/m has been considered for this area.

Intermediate Area: that area which presents an intermediate power, and, where more detailed Studies (such as gathering data on the spot by means of buoys) should be done, in order to definitely accept or reject such location. For this area, a range oscillating between 13-15 Kw/m has been taken into account.



Source: Own elaboration, 2008.

Figure 10.1. Representation of the average wave power energy (Gwhyear/m) on the Canary Isles archipelago.



Source: Own elaboration, 2008.

Figure 10.2. Representation of average Powers (Kw/m) on the Canary Isles archipelago.

Exclusion Area: those areas that do not reach the necessary minimum power (15 Kw/m) so that, with current energetic systems, the resource exploitation might be profitable. All points showing a power within the 0-13 Kw/m power will be included in this area.

CONCLUSIONS

A fact that corroborates the obtained results is that ports are built in those places which offer a better shelter against the action of swelling and wind. Taking into account the location of the aforesaid ports on every isle of the archipelago, and when comparing them with the Figure where the average Powers are represented, one may see that all ports are located at exclusion areas.

One of the circumstances that will explain the results obtained is the given proximity between some isles, as well as, their steep orography –with big mountains and pronounced cliffs– that will emphasize even more the well-known "shadow effect".

If we focus on the most western isles (Lanzarote and Fuerteventura), we will appreciate that those are the isles that show the highest amount of energy of the entire archipelago. This is due to their being first affected by the trade winds, and therefore those winds will transfer a great part of their kinetic energy to the water surface, giving rise to waves with a higher amount of energy in comparison with other points in the archipelago. As may be seen on the Figure, both isles have suitable areas for the implementation of wave power capturer systems.

On the analysed WANA points for the isle of Lanzarote, we observe a marked seasonal variation that may come beyond the 2 m in significant wave height and the 6 s of period between summer and winter months.

The isle of Fuerteventura shows seasonal variations of more than 2 m in significant wave height and of 5 s periods, in two out of the three studied points. On the third one (WANA Point 1025013), located east of the island, seasonal variation is minimal. This is due to the fact that this point is more protected from the action of the trade winds, due to the "shadow effect" provoked by the island of Lanzarote, which gives rise to the difference between the summer and winter times being virtually non-existent.

Apart from everything that has been said before, as may be seen on the types of swelling Figure, the Canary Isles are affected by a Westerly swelling. Therefore, it stands to reason that main Powers may be located on every island's north-west areas, whilst on those waters located to their east, lower energetic potentials may be found, as they are more sheltered against the action of this kind of swelling.

When focusing on the isle of Gran Canaria, we may see that it does not have either suitable or intermediate areas, just exclusion areas. On the whole, it shows the lowest energetic potentials in the whole archipelago. This fact might have an explanation, as it is more than likely that both the isle of Lanzarote and that of Fuerteventura may provoke some "shadow effect" over Gran Canaria, so that the trade winds may not completely affect the island.

The same might happen with a westward swell, as western isles will give rise to a screening that will diminish this area's potential.

Some seasonal variations exist at the tested points, but these are little when compared to those on the other isles.

Taking into account all of this, one may say that the isle of Gran Canaria is the one which finds itself better protected from the action of the trade winds and swell. Therefore, it represents the lowest energetic potentials. Thus, the implementation of ocean energetic Systems is quite complicated as it does not have enough resources.

With regards to the western isles, the only one that shows a well defined suitable area is La Palma. This island is quite exposed to the action of the trade winds, the north part being the first to get them. In addition, it is also quite affected by a westerly swell. This isle would be totally capable of implementing wave power capturers.

The isle of El Hierro has a suitable area, located north of the island. It also presents an intermediate area, which, as said before, deals with areas where the no-implementation of these systems cannot be absolutely discarded. A more detailed study would be needed, with on the spot data gathering by means of using sensing buoys and a much longer sampling period in order to obtain data closer to reality.

The isle of La Gomera may be expected to be exerting some kind of "shadow effect" over the isle of El Hierro. But, in short, it is well exposed to the trade winds and a westward swell.

When paying attention to the isle of La Gomera, some intermediate areas are observed to the north (exposure to the trade winds action in May), whilst other locations on the isle are exclusion areas, mainly originated from the lack of potential, due to the proximity of the isle of Tenerife, giving rise to a clear "shadow effect".

Lastly, the isle of Tenerife counts on intermediate areas in the north, whilst in other locations potentials are practically reduced to a minimum. The proximity of the isle of de Gran Canaria is more than likely responsible for this situation, as well as the geography of the isle, as the Anaga massif –to the north–, is going to slow down the advance of the trade winds, preventing their way out to the south.

On the other hand, due to the proximity to the isle of La Gomera, it is probable that it may be less affected by the westward swell.

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POTENCIAL ENERGÉTICO DEL OLEAJE

Resumen

El presente apartado se presenta un resumen con la metodología y calculo del potencial mareomotriz del archipiélago canario.

Los datos base han sido suministrados por Puertos del Estado, organismo dependiente del Ministerio de Fomento español.

Los datos de oleaje han sido obtenidos a partir de puntos WANA y por las diferentes boyas situadas en las costas de canarias que realizan mediciones de altura y período del oleaje.

Cálculo del potencial estimado de energía del oleaje

Para un conjunto de ondas de altura H (m) y período T (s), la energía media por unidad de área horizontal, E (W), se obtiene mediante la expresión:

$$E = \frac{1}{8} \cdot \rho \cdot g \cdot H^2$$

donde ρ es la densidad del agua (Kg/m^3) y g es la aceleración de la gravedad (m/s^2).

Para conocer la magnitud de esta energía, interesa determinar la potencia media del oleaje por unidad de anchura Pw (W/m), que atraviesa un plano vertical perpendicular a la dirección de propagación de la onda. Para un oleaje regular, dicho flujo medio de energía se puede determinar mediante la expresión:

$$Pw = E \cdot C_g$$

donde Cg es la celeridad de grupo o la velocidad con que se transporta la energía.

En el caso de tratarse de oleaje real, el análisis del oleaje se realiza de forma estadística, asumiendo que el oleaje es un proceso estocástico cuasi - estacionario. Esta condición obliga a cortar los registros de oleaje en intervalos de tiempo relativamente cortos, pero con suficiente duración como para dar fiabilidad a la estadística. Estos intervalos de tiempo en los que se dividen los registros de oleaje para su análisis se denominan estados de mar y el análisis estadístico de estados de mar constituye lo que se denomina análisis del oleaje a corto plazo. En la actualidad, la Red de Medida de Oleaje controlada por Puertos del Estado, divide los registros de oleaje en estados de mar de 1 hora de duración.

El análisis estadístico a corto plazo de los registros de oleaje se realiza habitualmente en el dominio de la frecuencia, obteniéndose la función que representa la distribución de energía por frecuencias angulares, $\omega = 2 \cdot \pi / T$ y direcciones, θ, denominada función de densidad espectral direccional, S(ω, θ) de la superficie libre del mar, la cual representa la energía total promediada en el tiempo existente en cada intervalo de frecuencia $\Delta\omega_i$ y en cada intervalo de dirección $\Delta\theta_j$. Si se define la componente "i,j" del oleaje como a las ondas contenidas en el intervalo de frecuencias $\Delta\omega_i$, $\Delta\theta_j$, a dicha componente le corresponderá una altura H_{ij} y su energía media por unidad de área (W/m^2) será:

$$E_{i,j} = \frac{1}{8} \cdot \rho \cdot g \cdot H_{i,j}^2$$

Metodología utilizada para el cálculo del potencial estimado de energía del oleaje y resultados obtenidos

Para evaluar la potencia media del oleaje existente en las Islas Canarias se ha utilizado la formula (19) y las Tablas alturas-periodo desde los años 2002 al 2007 de la base de datos del Oleaje, suministrada por el Banco de Datos Oceanográficos de Puertos del Estado, organismo dependiente del Ministerio de Fomento Español.

Modelo WAM y Puntos de simulación WANA en las islas canarias

El WAM es un modelo de tercera generación que resuelve la ecuación de transporte sin ningún limitante de la forma del espectro de energía; para ello fue necesario una parametrización de la función de transferencia no lineal y la especificación de las funciones de disipación. El WAM está formulado para coordenadas esféricas y usa un método implícito de integración.

Este método tiende a hacer los espectros más anchos que si se utilizaran métodos más rigurosos. Al resolver numéricamente los términos fuente generalmente la solución no es estable por lo que un limitador en el crecimiento de la energía del oleaje es utilizado en función de la frecuencia y del paso de tiempo. *Hersbach y Janssen (1999)* encontraron que el limitador original del WAM no es adecuado para altas resoluciones geográficas por lo que propusieron un limitador que dependía de la velocidad de fricción y de la frecuencia alta de corte.

En el WAM se asume que las olas son generadas en la misma dirección del viento y se utiliza un coeficiente empírico de crecimiento (limitador), práctico para mar abierto, aunque en zona costera estas consideraciones pueden no ser válidas realizan pruebas con el WAM adaptándolo para su utilización en altas resoluciones espaciales principalmente en zonas costeras y en las cuales se han realizado modificaciones de la propagación, inclusión del efecto de corrientes, fricción por fondo y ruptura por fondo. Los autores concluyen que utilizando un paso de tiempo pequeño el WAM es numéricamente estable para casos de crecimiento con *fetch* limitado por lo que los problemas se vuelven numéricos más que físicos. A pesar de esto el limitador de crecimiento fue también implementado.

Tipos de zonas

Zona Apta: Es la zona que presenta potencial suficiente para implantar sistemas energéticos. Para esta zona se ha considerado una potencia mínima de 15 Kw/m.

Zona Intermedia: Aquella que presenta un potencial intermedio y que sería necesario realizar estudios más minuciosos (como la toma de datos in situ mediante el uso de boyas), para poder aceptar o descartar definitivamente dicha ubicación. Para esta zona se ha considerado un rango que oscila entre los 13-15 Kw/m.

Zona de Exclusión: Son las zonas que no poseen el potencial mínimo (15 Kw/m) necesario para que con los sistemas energéticos actuales sea rentable la explotación del recurso. Estarán dentro de esta zona todos los puntos que presentes potenciales dentro del intervalo 0-13 Kw/m.

Un hecho que corrobora los resultados obtenidos en este estudio, es que los puertos son construidos en los lugares que se encuentran más protegidos de la acción del oleaje y del viento. Teniendo en cuenta la localización de dichos puertos en cada una de las islas del archipiélago y comparándolo con la figura donde se representan las potencias medias, se ve que todos los puertos están ubicados en las zonas de exclusión.

Una de las circunstancias que explica los resultados obtenidos en el presente artículo es la proximidad que hay entre algunas de las islas y la orografía tan escarpada que presentan con grandes montañas y pronunciados acantilados que van a acentuar aún más el conocido “efecto de sombra”.

A parte de todo lo expuesto anteriormente, como se puede aprecia en la Figura de los tipos de oleaje, las Islas Canarias están afectadas por un oleaje de componente oeste, por lo que es lógico que los mayores potenciales se localicen en las zonas del oeste-norte de cada una de las islas, mientras que en las aguas que se sitúan al este de cada una de ellas presenten menores potenciales energéticos ya que se encuentran más protegidas a la acción de este tipo de oleaje.