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On the wave energy resource of Peru

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ABSTRACT

This is the first assessment of the wave energy resource in Peru, an emerging country with an increasing energy demand and a high dependence on fossil fuels. On the basis of wave buoy measurements, we characterize the offshore wave energy resource and analyze its temporal variability, comparing the results with those obtained in previous works for other regions. A wave propagation numerical model (SWAN) is used to determine the nearshore spatial distribution of wave energy. A total of 357 offshore sea states, representing 90% of the wave energy and 94% of the time in an average year, were propagated. The wave energy in Peru presents a resource exceeding by more than seven times the total electric demand of the country. Because of the large amount of resource available and its low seasonal variation, wave energy must be considered in Peru as an alternative to conventional energy resources.

1. Introduction

Peru (Fig. 1) is an emerging country with an increasing energy demand. The total energy consumption per year is higher than 180 TW h, of which about 18% corresponds to electricity (Fig. 2) [1]. Motivated by a good macroeconomic situation in spite of the international crisis, the annual electricity demand has been growing at a 7% on average over the last years, reaching 40.7 TW h in 2013 [2]. According to the governmental forecasts, by 2030 this demand would increase to 119 TW h, i.e., four times the current value [1].

On the other hand, Peru has a high dependence on non-renewable sources, being its energy demand satisfied in more than a 70% by fossil fuels. The total electric demand of the country is almost supplied with hydropower and natural gas, as can be observed in Fig. 2. Regarding the use of non-conventional renewable sources, solar, biomass and hydroelectric (<20 MW) have been exploited over the last years, but they play a residual role, representing in 2013 only 2.5% of the total electric power production.

To satisfy the increasing energy demand and to achieve an efficient and diversified energy mix, the Peruvian Energy Policy for the period 2010–2040 promotes projects based on non-conventional renewable energies. In addition, to promote the development of the renewable sector, several policy incentives are offered, which include priority dispatch for renewable electricity, accelerated depreciation for investments in machinery or equipment, and technology-specific auctions.

Among these non-conventional renewable, geothermal energy and wind energy have a big potential for their harnessing, with annual resource estimated in 26 [3] and 675 TW h [4], respectively. Furthermore, this year the two first wind farms have entered in operation in the country and more are planned for the incoming years. As for marine energies and, particularly, wave energy, there are not ongoing projects for their exploitation and their resource is unknown.

Wave energy, which has seen significant development in recent years [5], constitutes an alternative to other energy sources in the medium term. Some of its advantages are: the high energy density [6], the good predictability [7] or the reduced negative environmental impacts on the beaches [8], the marine ecosystems [9] or the wave climate [10]. Nonetheless, the variability of the resource in several time-scales and the harsh marine environment make the developing of efficient and cost-effective converters a technically demanding task. In fact, although there are about one hundred technologies for wave energy conversion [11], most of them are still in a testing or pre-commercial stage and require further research. For example, the damping of turbines [12], the control techniques of generators [13], the integration of devices in breakwaters [14], the definition of wave loadings [15] or even the design of new WECs as the SSG [16], are features currently under development.

On the other hand, since the wave climate has a high spatial variability conditioning the efficiency of the WECs, a wave energy resource assessment is required to optimize the electric production

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Fig. 1. Location of the country.

[17]. Furthermore, possible synergies with other renewable [18] and different technologies of conversion should be considered to define the optimum location of a power plant [19]. In this sense, the wave energy resource has been analyzed already in many regions, such as: western France [20], Australia [21], Northern Spain [22], the SE Bay of Biscay [23], the Korean Peninsula [24], Italy [25], the US Pacific Northwest [26], the Azores Islands [27], California [28], China [29] or Portugal [30].

In this work we present the first estimation of the wave energy resource in Peru, a country dependent on fossil fuels and with a growing energy demand. On the basis of wave buoy measurements, we draw a general picture of the resource and its seasonality. In addition, the most representative offshore sea states are propagated towards the coast by means of a numerical model to map the wave energy distribution in the nearshore. Based on the results, we examine the potential and the possibilities of the wave energy resource in the country.

This paper is structured as follows. In Section 2, the offshore wave data set, the main parameters and the numerical model employed for the propagations are described. The results of the simulated wave propagations from offshore towards the coast are presented in Section 3. In addition, the characteristics of the available wave resource in Peru are defined and described. In Section 4, the conclusions of the resource assessment are drawn along with their implications for the Peruvian energy system.

2. Material and methods

2.1. Offshore data and wave parameters

The wave data of an offshore buoy was used in this work. The dataset covers the period from 01/01/2007 to 31/12/2012 with one hour time interval. The wave conditions of each hourly sea state or case were characterized with three wave parameters: the

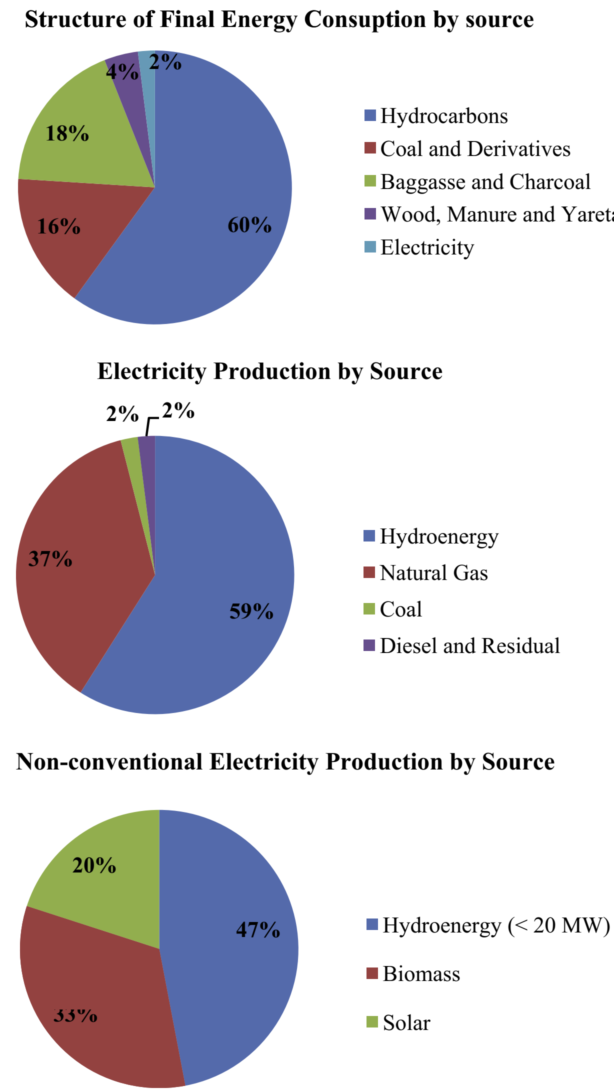

Fig. 2. Peruvian energy mix [1].

significant wave height, H_s (m), the energy period, T_E (s) and the mean wave direction, θ_m (°). The first and second parameters are obtained as a function of the spectral moments, which are computed as:

$$m_n = \int_0^{2\pi} \int_0^{\infty} f^n S(f,\theta) df d\theta \tag{1}$$

where f is the wave frequency in Hz; and $S(f,\theta)$ is the directional power spectrum density function in $m^2\ Hz^{-1}\ deg^{-1}$. The significant wave height is representative of the total energy of the spectrum and is given by:

$$H_s = 4\sqrt{m_0} \tag{2}$$

The energy period, T_E, which corresponds to the period of a single sinusoidal wave with the same energy as the sea state, is given by:

$$T_E = \frac{m_{-1}}{m_0} \tag{3}$$

and was selected in preference to other periods in accordance to previous works on wave energy resource assessment. Finally, θ_m is defined as:

$$\theta_m = \arctan \frac{\int_0^{2\pi} \int_0^{\infty} \sin\theta S(\theta,f) df d\theta}{\int_0^{2\pi} \int_0^{\infty} \cos\theta S(\theta,f) df d\theta}. \tag{4}$$