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To cite this article: Leonardo Castillo N *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **154** 012002

View the article online for updates and enhancements.

Climate conditions of the "El Niño" phenomenon for a hydro-eolic complementarity project in peru

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Abstract. Northern Peru is threatened by the consequences of a natural phenomenon called "El Niño", mainly during the months of December to April. In the summer of 2017, this event reported strong climatic variations with intense rains, increasing the water levels of the Chira and Piura rivers, filling the Poechos reservoir, together with flooding and mudding. However, from an energetic perspective, these climatic alterations have a strong potential to increase the availability of the wind and hydro renewable energies in northern Peru. This work performs an evaluation of the hydro-eolic complementarity as part of the sustainability of energy systems. The study includes evaluation of historical records of wind velocity and water flow rates. It then evaluates correlation, analysis, and estimates the hydro and wind energy potentials generated by this phenomenon. The implications of the "El Niño" phenomenon are mostly negative. Nonetheless, it is possible to take advantage of higher wind and water flow rates with a hybrid energy system. The results obtained show a high degree of complementarity both normal and "El Niño" phenomenon condition in northern Peru.

1. Introduction

Originally the term El Niño was used by fishermen in Paita (city of northern Peru in Piura) to describe the warming of the sea in the North Pacific Peruvian (from southern Ecuador) and rains that were presented at Christmas time and for periods of several months (Carrillo, 1892) [1]. Bjerknes (1966, 1969) [2], [3] documents consistent heating anomalies of the Peruvian sea on the border with Ecuador and relates this behavior to both the warming of the tropical Pacific Sea and to the planetary scale changes of the tropical atmosphere, the "South Oscillation ". Hence the term ENOS (El Niño oscillation of the south) is derived. The warm phase of ENOS is called the El Niño while the cold phase is called La Niña (Wang et al., 2012) [4].

ONI (Oceanic El Niño index) is an estimated ENSO index or measure that determines periods of warming over the years along the Pacific coast. These values are reported on the National Oceanic and Atmosferic Administration (NOAA) Web site. It is evidenced, that the maximum values ONI reached indices of up to 2.2 and were given in the years 1982/1983 and 1997/1998.

During the last few decades, the implications that El Niño leaves in the north of Peru are mostly negative, but it is possible to obtain benefits for the energy sector. This paper analyses time series and introduces the concept of "complementarity" which includes two extraordinary events 1982/1983 and 1997/98.

Considering the technical challenges and the current state of the energy market, solutions must be proposed for the take-off of the capacities of renewable energies. The complementarity between different intermittent sources seeks an optimal balance between the total amount of energy produced and its stability over time. This complementarity reduces the variability of energy production, combining systems that have of minimum and maximum energy generation during different periods of time.

Based on new environmental, social and economic policies, the integration of renewable energies is a focus of attention in many countries. As a result, these systems become more attractive when we identify complementarity with other sources of generation. Therefore, the development of renewable energy systems that seek to "empower" intermittent power production is a key point in the sustainability of future energy systems.

2. Review of data

2.1. Historical records

For the development of work in the region of Piura will analyze a hydrometric station in the River Chira and two weather stations. The measurement stations to be analyzed are shown in Table 1:

Table 1. Locations of stations

Station	Latitude	Longitude	Altitude	Years
Pte. Sullana - Q(m3/s)	4°53'29"	80°41'28"	36	1972-2015
San Miguel - Vv (m/s)	5°18'14"	80°40'50"	20	1975-2015
Miraflores - Vv (m/s)	5°10'0"	80°36'0"	30	1995-2015

We note that records 2016 and 2017 years are not available within the official institution of Peru.

2.2. Final stage

The Chira River comes from a watershed regulated by the Poechos Reservoir. Upstream of the reservoir, the contributing flow is a border with Ecuador. For our case, measurements will be analyzed in the section downstream of the reservoir, near the city of Piura. The average monthly flow rate for the entire analyzed data is 99.57 m3/s and the maximum value corresponds to the month April 1983 with 1645.97 m3/s. Figure 1 shows the monthly flow rate, where the maximum values for the summer periods of 1982/1983 and 1997/1998 stand out. Figure 2 shows the monthly average values and the flows to a persistence of 95% at monthly level.
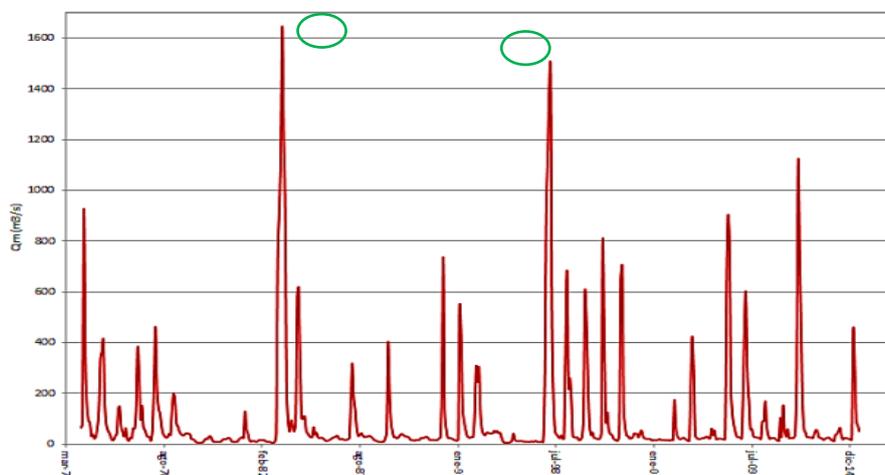
**Figure 1**. Monthly flow regime of the Chira river – Sullana bridge

2.3.Wind speed regimen

The San Miguel station has an average wind velocity of 4.5 m/s and a maximum value of 9.2 m/s registered in November 1986. The Miraflores station has an average wind velocity of 2.5 m/s and a maximum value of 4.8 m/s registered in September 1995.
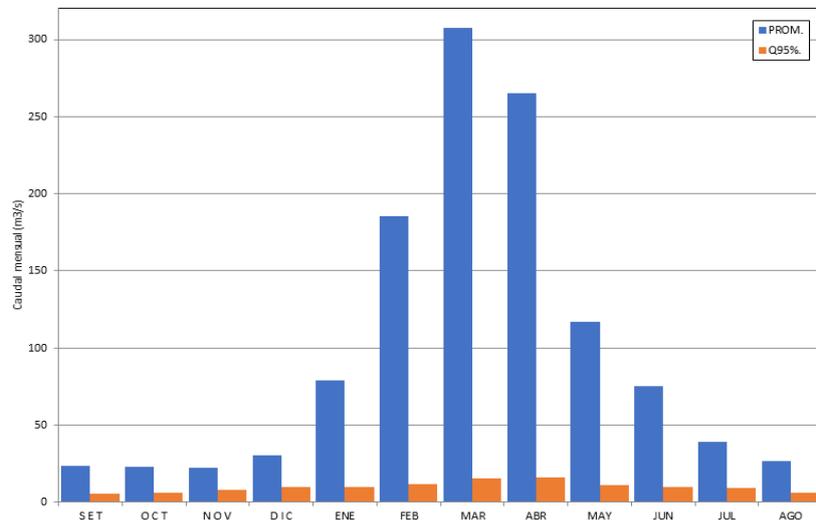
Figure 2. Average monthly flows of the Chira river on the Sullana bridge

To be able to obtain a more representative value of the wind speed it is necessary to describe it as a function of the distribution of known probability. The Weibull type distribution is best suited for monthly wind speed data (E. Akpinar, 2005) [5]. In the present work, the model HYFRAN (Hydrological Frequency Analysis) of the National Institute of Scientific Research Water Land and Environment (INRS-ETE) of the University of Quebec was applied for the adjustment of the distribution and obtaining of the parameters. Figure 3 shows the average speed regime obtained from the Weibull distribution month to month.
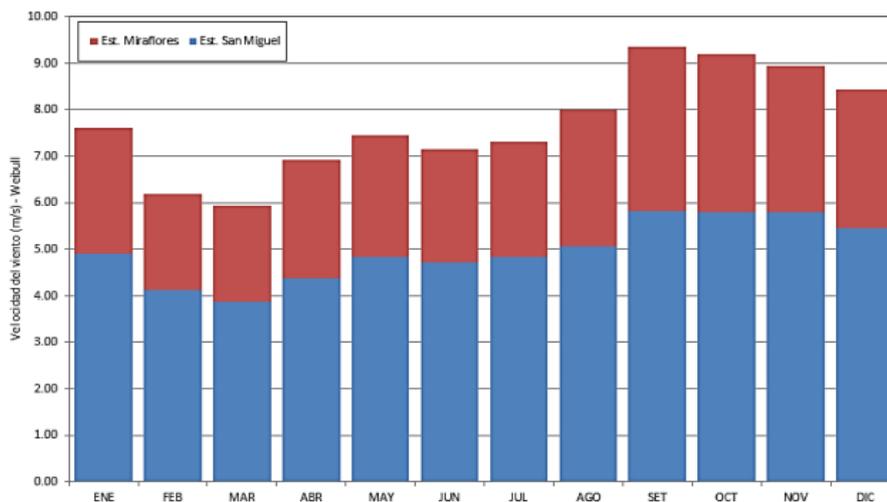
Figure 3. Average monthly speeds (m/s)

3. Methodology

As a first assessment, the complementarity of the flow rate regime with the wind speeds at the monthly level will be analysed. A simple method of execution and interpretation is by determining the Pearson correlation coefficient (δ). This coefficient varying between -1 and +1 is a value that measures the degree of covariance between different linearly related variables.

In the case of "complementarity", what we are looking for is to know if the relationship is perfect negative: when exactly to the extent that increases one variable decreases the other. Once verified the possibility of complementing energy projects, will estimate the hydroelectric and wind potential under an assumed stage. There will be applied the concept of an index of complementarity (Beluco et al., 2008). [6]

Beluco et al. [6], proposes an index to evaluate how two different types of energy are complemented. The proposed complementarity index considers three types of complementarity:

- Complementarity in time (Kt): Evaluates the time lag and compares in which days of the year happen the maximum and minimum of water a wind generation.
- Complementarity in energy (Ke): Compares the total amount of energy that water generation can produce and the total amount of wind energy that can be generated.
- Complementarity in energy availability (Ka): evaluates the amplitude of the variations between

The maximum level and minimum energy level available, for both water generation and wind. Based on these three concepts, the complementarity index is K = Kt * Ke * Ka.

4. Results

4.1.Complementarity with registered average values
From the recorded data, the average flow and wind velocity values are analysed. Within the scenarios, it is considered the effect of not considering the years of El Niño (1972/1973 and 1982/1983). Table 2 shows the average values recorded per station (QCC, ESM and EMI scenarios) and the average values without El Niño (QCS scenario).

Table 2. Average values of data

QCC: Flows (m3/s) with El Niño – Pte. Sullana											
Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
79.05	185.43	307.66	264.98	116.73	75.15	39.33	27.15	23.64	22.79	22.51	30.39

QCS: Flows (m3/s) without Niño – Pte. Sullana											
Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
42.76	144.66	260.93	201.25	81.28	52.19	34.40	25.43	24.46	23.52	23.18	25.37

ESM Wind velocity (m/s) – Est. San Miguel											
Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
4.46	3.79	3.57	3.98	4.39	4.27	4.37	4.62	5.27	5.26	5.27	4.95

EMI: Wind velocity (m/s) – Est. Miraflores											
Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
2.44	1.84	1.82	2.27	2.35	2.19	2.24	2.69	3.25	3.12	2.90	2.71

Table 2 shows that the average flow values for the Chira River vary significantly in the summer period if we do not consider the years of El Niño, reaching a decrease of up to 46% in January.

Table 3 gives the results of complementarity with values close to -1, which indicates a contrast of max/min between variables.

4.2.Complementarity with insurable values
The same complementarity assessment is done with insurable values. For the case of flows, the flow is available for a persistence of 95% for small hydroelectric plants in the past. For the case of wind speeds, the most probable value obtained from the parameter is worked and adjusted with the distribution of Weibull. More detail See Table 4.

Table 3. Complementarity results to average values – Pearson Coefficient

| Variables	δ
QCC-ESM	-0.85
QCC-EMI	-0.74
QCS-ESM	-0.82
QCS-EMI	-0.72

In Table 5 there happen the results of the coefficient of Pearson with values near to -1, what indicates a complement between variables at the level of available values. This complementarity is evidenced in Figure 4.

Table 4. Insurable average values

QCC: Flows (m3/s) with El Niño – Pte. Sullana											
Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
10.12	11.91	15.36	16.39	11.22	9.92	9.33	6.34	5.68	5.94	8.01	9.76

QCS: Flows (m3/s) without Niño – Pte. Sullana											
Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
9.80	11.91	15.35	16.267	11.04	9.89	9.315	6.13	6.08	6.44	23.18	25.37

ESM Wind velocity (m/s) – Est. San Miguel											
Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
4.89	4.11	3.87	4.37	4.84	4.71	4.83	5.05	5.82	5.79	5.79	5.44

EMI: Wind velocity (m/s) – Est. Miraflores											
Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic
2.72	2.07	2.06	2.54	2.61	2.44	2.47	2.95	3.52	3.40	3.14	2.98

Table 5. Complementarity results to insurable values-Pearson Coefficient

Variables	δ
QCC-ESM	-0.83
QCC-EMI	-0.78
QCS-ESM	-0.81
QCS-EMI	-0.77
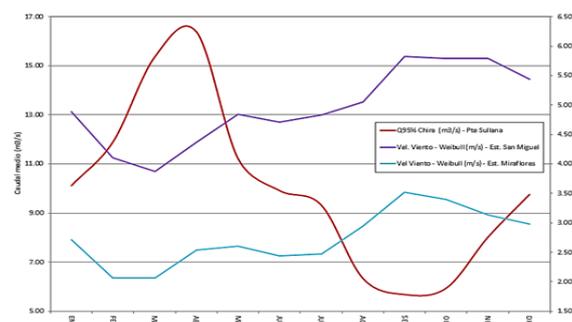
Figure 4. Comparison of flow rate regime with wind speed at monthly level

4.3.Complementarity by the index of A. Beluco et. Al.

$$Ph = \gamma * Q_{95\%} * H * n$$
$$Pe = Cp * 0.5 * \rho * A * V^3$$

Table 6. Results of energy y generation

Month	Ph (MW)	Pe (MW)	Ph (MW)	Pe (MWh)
Jan	2.4	0.33	1773.4	246.8
Feb	2.8	0.20	1884.3	132.3
Mar	3.6	0.16	2690.6	122.3
Apr	3.9	0.24	2778.4	170.5
May	2.6	0.32	1965.4	239.3
Jun	2.3	0.30	1681.6	213.4
Jul	2.2	0.32	1634.3	237.8
Aug	1.5	0.37	1110.6	271.8
Sep	1.3	0.56	963.2	402.7
Oct	1.4	0.55	1040.7	109.7
Nov	1.9	0.55	1358.5	396.5
Dec	2.3	0.46	1709.6	339.8

Table 7. Complementarity Index

Equation	Parameters	Results
$K_t = \dfrac{\|d_h - d_s\|}{\sqrt{\|D_h - d_h\|\|D_s - d_s\|}}$	d_h: day of lower availability of hydropower d_s: day of lower availability of wind energy D_h: day of greater availability of hydric energy D_s: day of greater availability of wind energy	$d_h=258$ $d_s=74$ $D_h=105$ $D_s=288$ $K_t=1.017$
$K_e = 1 - \sqrt{\left(\dfrac{E_h - E_s}{E_h + E_s}\right)^2}$	E_h: Water energy per year E_s: Wind energy per year	$E_h=20.59$ GWh $E_s=3.18$ GWh $K_t=0.268$
$K_t = \begin{cases} \left[1 - \dfrac{(\delta_h - \delta_s)^2}{(1 - \delta_s)^2}\right] \\ \left[\dfrac{(1 - \delta_s)^2}{(1 - \delta_s)^2 + (\delta_h - \delta_s)^2}\right] \end{cases}$ *Para* $\delta_h \leq \delta_s$ *Para* $\delta_s \leq \delta_h$	$\delta_s = 1 + \dfrac{E_{s,max} - E_{s,min}}{E_{s,prom}}$ $\delta_h = 1 + \dfrac{E_{h,max} - E_{h,min}}{E_{h,prom}}$	Es,max=409.7 MWh Es,min=122.3 MWh Es,prom=265.2MWh Eh,max=2778.4 MWh Eh,min=963.2 MWh Eh,prom=1715.9MWh $K_t= 0.999$
$K = K_t K_e K_a$	Complementarity Index	K=0.272

In the order to determine the water and wind generation, we are based on the following technical approach: the reach of the Chira River where the flows are analyzed, from the downstream point of the reservoir to the Sullana Bridge, there is a runway of 34 Km with a gap (H) of approximately 30 m. We'll assume a hydroelectric project with a global efficiency (n) of 80%.

In the case of the wind generation, we will assume a wind turbine Vestas V100-1.8MW with an area swept rotor (A) of 7 850 m2. In addition to considering the factor of Beltz (Cp) 59 % for the useful potency.

Table 6 shows the results of the calculations by applying the power equations.

Finally, we will obtain the parameters of the complementarity index to validate that the flow behavior (including the data for El Niño) can be complemented by a wind project in the region. Table 7 it shows the equations and results of the procedure given by Beluco et al. [6]

The results shown in Table 7 are beneficial because there is a good complementarity in time (Kt) and energy availability (ka). Regarding the complementarity of energy (Ke), can be managed and adapted to better design conditions that allow optimization of the system.

The flow and wind conditions in the northern region of Peru are suitable for implementing a complementarity project assuming the entire historical record including the periods of El Niño.

5. Conclusions

The average monthly flow of the Chira River is 99.57 m3/s and the maximum value during the last few decades correspond to the month April 1983 with 1645.97 m3/s. A phenomenon of El Niño may imply a multiplicative factor in the flow of approximately 15 times.

The San Miguel station has an average wind velocity of 4.5 m/s and a maximum value 9.2 m/s registered in November 1986. The Miraflores station has an average wind velocity of 2.5 m/s and a maximum value of 4.8 m/s registered in September 1995. The area for the San Miguel area has higher speeds for its use.

The Pearson coefficient indicates the high complementarity between the variables of flow and wind velocity at monthly level, with a value of -0.81 close to the unit.

The complementarity index of Beluco et al., can be optimized based on established design conditions. In this paper, it has obtained a crude hydroelectric power under a flow to persistence of 95% and for an efficiency of 80%. In the case of the wind project the calculation only considers the potency a typical wind turbine.

It is possible to take advantage of the generation of energy in the northern area of Peru, trough hydro-eolic complementarity projects. A next step is to evaluate the technical feasibility of a hydroelectric project that can take advantage of the increase in flow in events of El Niño.

A next step is to proceed with the measurements and monitoring in order to be able to validate the complementarity and process on based on statistics and modelling.

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