A study of the balancing of wind and solar energy resources in Andalusia

F.J Santos-Alamillos, D. Pozo-Vázquez*, J.A. Ruiz-Arias, V. Lara-Fanego, and J. Tovar-Pescador.

Department of Physics, University of Jaén, 23071, Jaén (Andalusia), Spain.

*Corresponding Author, dpozo@ujaen.es

Abstract

The balancing of the wind and solar energy resources in Andalusia (southern Iberian Peninsula) is analyzed based on the analysis of a simulation with the Weather Research and Forecasting (WRF) Numerical Weather Prediction (NWP) model. The simulation covered the year 2007, with a spatial resolution of 9 km and a temporal resolution of 1 hour. A Barnett-Preidendorfer Canonical Correlation Analysis was carried for the wind and solar energy daily integrated values, derived from the simulation, over the study area. The region of the study is located in a transition zone from middle latitudes to subtropical climates, with the Atlantic Ocean and the Mediterranean region in the southern bound. In addition, the region presents areas of complex topography. As a consequence, differential weather and climate conditions are observed across the region. Preliminary results showed the existence of important extensions in the study region with a considerable balancing between the solar and wind energy resources at daily scale during the winter. Namely, the western area and the Mediterranean coast of the study region and the Gibraltar strait area.

1. Introduction

Increasing the share of the renewable energy generation is a key tool to deal with the climate change and energy security issues. As a consequence, for the next decades it is expected and important growth of the electricity generation provide by renewable energy, mainly wind and solar, in many European countries, particularly, Spain. Current power system operation is running a supply on demand system that is expected to be absolutely reliable. This has led to a power system based on highly controllable supply to match a largely uncontrolled demand. On the other hand, the main characteristic of renewable energy (mainly solar and wind) that distinguishes them from conventional power plant, is that the output varies accordingly to the available resource. Therefore, wind and solar energy cannot be scheduled like conventional power plants. This is commonly perceived as a challenge at high shares, since accommodating the renewable energy output can cause problems with the conventional system balancing methodologies. Since penetration rates of renewable energy are expected to continue increasing, a rethinking of the existing balancing paradigm may be required. If the power system is large enough, the variability of the solar and wind energy generation can eventually be balanced, at least partially.

The future power supply system with high penetration of the renewable energies requires sustainable reinforcement of the transmission system, to increase the storage capacities and to analyze weather-related spatial and temporal fluctuations of wind and solar energy generation over a long period and large area.

An important area of research is to analyze if the net variability in the combined output of many variable renewable energy plants, based on different resources (mainly wind and solar), at different location over a wide area, is smoother than the output of individual power plants (von Bremen 2010). Note that differential weather and climate conditions of certain areas may result in local or spatial balancing effects between different renewable energy resources. The knowledge of this balancing could mitigate the fluctuating renewable resources generation, helping to accommodate high shares of renewable energy into the power system.

In this work, we present preliminary results of a comprehensive study of the spatio-temporal balancing between the wind and solar energy resources in Andalusia (southern Spain). This study is based on the analysis of the output of simulation with Weather Research and Forecasting model (WRF; Skamarock et al., 2008) numerical prediction model (NWP). NWP models are almost the only tools suitable to carry out this kind of studies, since they are able to provide wind speed and solar radiation estimates over large extensions, covering long period of time and with a high spatial and temporal coherence (the same regular grid). Particularly, the integration used in this study covered the year 2007, with 9 km of spatial resolution and a temporal step of 1 hour. Spatio-temporal balancing was analyzed based on the Canonical Correlation Analysis (CCA). Only results for the winter season are here. The work is organized as follows. Firstly, in section 2, the study area is presented. Then, in section 3, the methodology is described, including a description of the WRF set up and the CCA. In section 4 the results and some preliminary conclusions will be provided.

2. Study area

The region of the study is Andalusia, in the southern part of Iberian Peninsula (Figure 1), covering around 87.000 km^2. The region is located in a transition zone (latitudes 35º30´ to 38º30´ N and longitudes 7º30´ to 1º30 W) from middle latitudes to subtropical climates, with the Atlantic Ocean and the Mediterranean region in the southern bound. Two different parts, from the topographic point of view, can be considered in the region. The western part, covering around 40.000 km^2, is an almost homogeneous flat area, with about 100 m of mean elevation. On the other hand, the eastern part presents a very complex topography, with several mountain areas, reaching up to 3482 m of elevation (the highest elevation of the Iberian Peninsula) in the Sierra Nevada National Park. A unique characteristic of the this eastern area is the steep elevation gradients than can be found, with more 2000 m in less than 40 km from the coast. The combination of the former factor give rise to the existence differential weather and climate conditions across the region, from pure Mediterranean climate conditions near the coasts, to continental climate in the interior and even mountain climate in some regions. As a consequence, even the relatively small area of study, the region presents a wide variability of the wind and solar resources. Therefore, this balancing study makes sense.

Figure 1. Study region and spatial configuration for the dynamical downscaling with the WRF model. The two rectangles represent the two nested domains of the WRF model integration set up.

3. Methodology

3.1 Dynamical downscaling

The WRF set up includes two nested domains (Figure 1). The outer domain has a spatial resolution of 27 km, covering the Iberian Peninsula and the Northern part of Africa. The second domain has a spatial resolution of 9 km and extends over the southern part of the Iberian Peninsula (including Andalusia). For the two domains, a two-way interaction was used. The model was configured with a total of 27 vertical levels. Topography, land use and land-water masks datasets were interpolated from the USGS global covers with the appropriate spatial resolution for each domain. Initial and boundary conditions for the simulation were taken from the National Centre for Environmental Prediction (NCEP), with 1º x 1º spatial resolution and 3 hours temporal resolution. Following Ruiz-Arias et al. (2008), the parameterization selected for the longwave radiations is the RRTM scheme and for the shortwave radiation, the Dudhia Scheme. The Kain-Fritsch scheme has been use for cumulus and the YSU PBL scheme for the boundary layer. Finally, for microphysics, the Thompson Graupel scheme has been used as well as the Noah land-surface model. The integration was run for the year 2007 with an hourly temporal resolution for each domain. The global solar radiation was directly obtained from the outputs of the models for the second domain. Wind speeds corresponding to the second eta level (30 m) were extracted. In a previous work (Santos-Alamillos et al., 2010), the WRF model was found to be able to properly reproduce the wind speed and solar radiation at the temporal and spatial resolution used in this work in the study region. Based on these variables, daily integrated wind and solar energy values were computed at each grid.

3.2 Balancing Study

The Barnet-Preisendorfer CCA method (Barnett and Preisendorfer, 1987) was used to analyze the balancing between the wind and solar energy resources in the study region. This multivariate analysis technique allows decomposing the variance of two fields of variables (solar energy and wind energy at each grid point in our case) into different paired modes of variability (modes of variability) such the time series representing these modes (PC series), presents the maximum correlation. To understand the underlying physics of the balancing, maps describing the meteorological synoptic situation associated with the CCA patterns were obtained. Particularly, composites maps of the anomalies of the solar radiation and wind speed corresponding to 5 maximum/minimum anomalies of the wind energy PC series were obtained.
The CCA analysis was carried out for the different seasons and for the annual period (2007). Furthermore, the balancing analysis was carried out also based on filtered data. Particularly, wind and solar energy data were filtered to account for the synoptic effects (2-4 days bandpass filter). Results of this filtered analysis aim to provide information of the balancing effect that produces the frontal synoptic patterns when crossing the study region. Finally, the balancing between the solar field and the wind energy field delayed one day was also analyzed. This delayed balancing analysis aims to provide information useful for the sizing of the storage capacity of stand-alone hybrid solar-wind power generation systems. Only results during winter, for non filtered and non delayed fields are presented in this work.

4. Results and conclusions

Table 1 presents the results for CCA analysis during the winter, for non-filtered and non-delayed fields. Particularly, the first 5 paired canonical patterns, ordered by decreasing correlation, are presented. These first 5 modes explain about 90% of the solar energy and about 80% of the wind energy variance. The first mode accounts for about 49% of the solar energy variance and more than 30% of the wind energy variance.

Table 1. Results of Barnett-Preisendorfer CCA for Winter.

	Expl. Var. (%) Solar Energy	**Expl. Var. (%) Wind Energy**	**Correlation**
Mode 1	38.14	30.98	0.55
Mode 2	26.31	7,35	0.51
Mode 3	3,05	22,07	0,41
Mode 4	3,8	11,58	0,14
Mode 5	16,1	7,46	0,1
Total	87,4	79,44	

Figure 2 presents the spatial patterns, time series and synoptic situation associated with the second canonical mode. This second mode explains the 26.31% and 7.35% of the variance for solar and wind energy respectively, with a canonical correlation of 0.51. There is a balance between the wind and energy resources over several areas in the region. Particularly, this mode shows spatially homogeneous negative loading for the solar energy in the whole region (Figure 1a). For the wind energy, high positive loadings are found in the western part of the study region (Figure 1b), over the Gibraltar strait and over the Mediterranean coast of the study area. This means the existence of a balancing between the solar and wind resources over these areas of high positive loadings (high loading factor of the solar and wind patterns and of opposite sign). Analyzing the synoptic situation associated with this canonical mode, the balancing is explained by the presence of a low pressure center localized over the study area (Figure 1 d). The associated frontal system brings high wind speed values (positive anomalies) at the western part of the study area, enhanced by topographic features as in the Gibraltar strait. On the other hand, this frontal activity brings cloudy conditions to the whole study area and, then, negative solar energy anomalies.

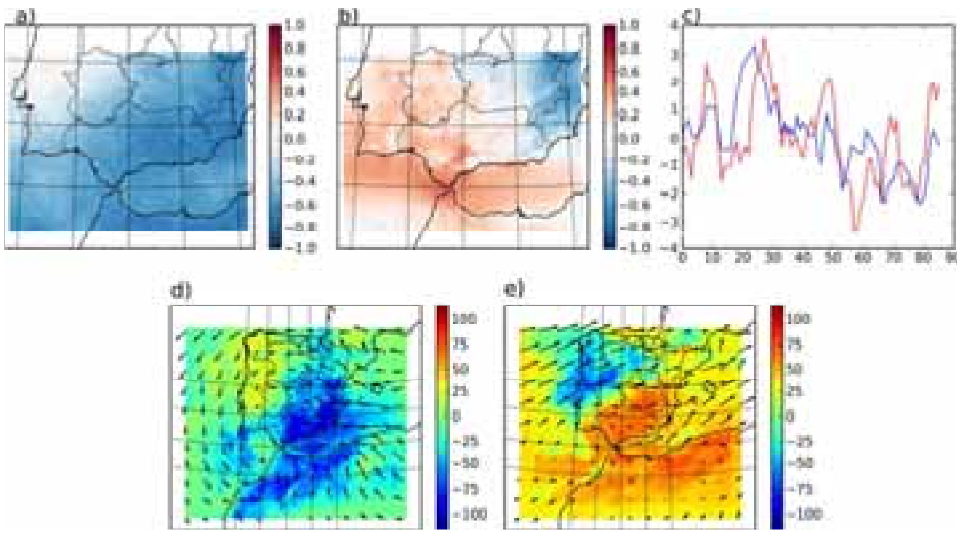

Figure 2. Spatial patterns, time series and synoptic situation associated with the second canonical mode of the Winter CCA analysis. Figure a) and b) show the loadings factors for solar energy and wind energy fields, respectively. Figure c) shows the temporal series associated with the solar energy (red) and wind energy (blue). Figure d) shows the composite of the synoptic situation corresponding to the 5 maximum anomalies of the wind energy time series. Particularly, solar radiation (background colors, vertical scale) and wind speed composite anomalies (arrows) are represented. Figure e) as in d) but referred to the 5 minimum anomalies.

To sum up, the previous results shows the existence of important extension in the study region with a considerable balancing between the solar and wind energy resources at daily scale during the winter. This study is part of a comprehensive analysis of the wind and solar energy resources in the study region. Additionally analysis are now being undertaken to further evaluate the existence of balancing during other seasons of the year, for synoptic filtered data and delayed fields.

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