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Future projections of wind resource in a mountainous archipelago, Canary Islands

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ABSTRACT

Large-scale atmospheric patterns and near-surface winds are expected to be modified in the future due to climate change, altering the availability of wind resources on a regional scale. These possible changes are especially important in isolated power systems, as is the case for a great percentage of the islands. High-resolution climate regionalization is therefore necessary to assess the future projections of wind resource, mainly in the case of orographically complex territories, such as The Canary Islands. In this work, WRF was used to perform a dynamic regionalization in this Archipelago, using the pseudo-global warming technique to compute the initial and boundary conditions from a reanalysis dataset and from the monthly mean changes obtained from the simulations of fourteen global climate models included in the Coupled Model Intercomparison Project Phase 5 (CMIP5). Projections of mean wind, wind energy density and extractable wind power were obtained for two future decades (2045–2054 and 2090–2099) and for two different greenhouse gas scenarios (RCP4.5 and RCP8.5) and the results were compared with those for 1995–2004. Statistically significant changes in wind resource were found in some areas, mainly during summer. Most of these areas correspond to zones where at present wind farms are located.

1. Introduction

The Canary Islands is a Spanish archipelago, being the most populated territory of all the outermost regions in the European Union. It is located to the North-West of the African coast, centered approximately at 28°N, 16°W. This archipelago is made up of seven islands: Tenerife, Fuerteventura, Gran Canaria, Lanzarote, La Palma, La Gomera and El Hierro, and additional islets. The electricity system of Canary Islands is broken down into six electrically isolated subsystems, one per island except for Lanzarote and Fuerteventura, whose grids are joined by a submarine cable. The fact that the systems are isolated, which increases the difficulty of system optimization as a whole, to ensure the quality of the service, and the variability of the renewable energy production due to changing weather conditions, makes the development of the renewable energy market more difficult than in larger power systems. However, the Archipelago, due to its climate characteristics, has an abundant supply of renewable energy sources, mainly from the wind and sun. Renewable energies are particularly relevant in El Hierro, where a wind-hydro power station has been connected to five wind-powered generators, creating the first isolated territory in the world to meet all its energy needs using renewables [1]. For this reason, some plans for wind energy development in The Canary Islands have been implemented in the recent decades [2]. At present, the total installed power is approximately 3000 MW. From all this power, 1729 MW correspond to fuel/gas, 918 MW are generated by combined cycle power stations, 166 MW are provided by solar photovoltaic plants and 154 MW by wind farms [3]. The energy demand in The Canary Islands presents a clear annual cycle, with a higher power consumption during summer and at the beginning of autumn and with lower demand during spring. In Fig. 1 the annual cycle for the last two years is plotted, based on the data provided by the transmission agent and operator of the Spanish electricity system [4]. The annual cycle of the wind energy production in the Archipelago is also shown in the figure, where the higher production corresponds to summer, when the trade winds are stronger and more persistent.

Selecting a location for wind farm placement involves several factors, such as adequate land rights, official permits, environmental impact assessment, proximity and convenient access to existing power grids, investors and, of course, adequate wind to achieve the expected level of energy production. Since the wind

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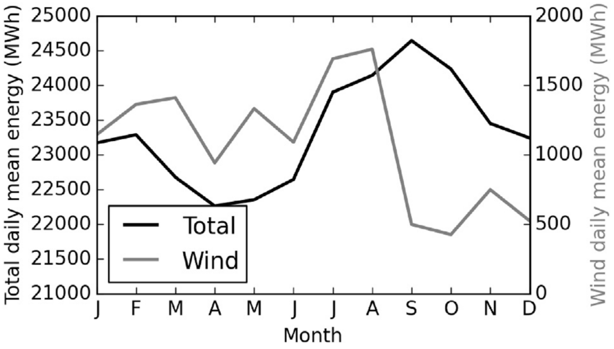

Fig. 1. Total energy demand and wind energy production in the Canary Islands, expressed as daily mean values, for the last two years (2014 and 2015).

power density is proportional to the cube of its speed [5], small changes in wind speed can make significant difference in the output of a wind farm. At any particular location, the wind direction and speed depends on several factors, such as synoptic atmospheric circulation, surface energy flows and local surface properties and topography. Due to these complex relationships, a detailed wind climatology is necessary to assess wind resources in a region. Formerly, these climatologies were mainly obtained from weather station data. However, due to the costs associated with the installation of a sufficient number of stations, needed to obtain a detailed map of wind resources, the results from numerical weather prediction (NWP) models are increasingly used [6].

Changes in synoptic wind patterns are expected in the future due to global climate change, which in turn will cause a modification of the winds at a regional scale, affecting the potential to generate power at a particular location. These possible changes in wind resources could influence the choice of preferential locations for wind farms, especially if long-term operation and investment is planned. Global climate models (GCMs) have been used as an effective tool to simulate many aspects of large-scale and global climate and to study the possible changes due to the global warming. Many of these studies are regularly summarised in the IPCC (Intergovernmental Panel on Climate Change) reports. Although GCMs incorporate the main characteristics of the general circulation patterns, their applicability to regional climate impact studies is limited because their typical spatial resolutions are in the order of hundreds of kilometers, which is too coarse to provide useful climate information for applications at regional-scale regimes. Furthermore, at those coarse resolutions, the topography is not well represented, which is an additional disadvantage to properly solve the physical processes in some regions, such as in those where the orography is complex. To overcome these inconveniences, regional climate models (RCMs) are required, allowing a better and more precise description of atmospheric events that are produced at smaller scales. In this way, statistical and dynamical downscaling methods have been developed in recent decades to improve the projections of local climate simulations provided by GCMs.

Several climate regionalization studies have investigated the potential future changes in wind for Europe [7–9] and other continents or countries [10–12] using different regional climate models (RCM) and specifically for Spain [13], with a higher spatial resolution. They found a general decrease in wind speed, especially in the centre of the Iberian Peninsula and on the Mediterranean coast. However, these studies did not include the Canary Islands, which are distant from the European continent and with such a complex topography that requires RCM simulations with high spatial resolution.

This work aims to estimate future changes in wind properties in the Canarian Archipelago, in the middle and at the end of this century. In this study the pseudo-global warming (PGW) method [14–16] has been used to perform a dynamical regionalization of wind climatology for The Canary Islands, and the Weather Research and Forecasting (WRF) model [17] was selected as the regional climate model (RCM).

The outline of this article is as follows. The configuration of WRF to obtain wind simulations for present and future periods is described in Section 2. In this section the observational data used to compare wind simulation assessment and the corresponding statistical indicators used to evaluate wind speed, wind energy density and extractable wind power are also exposed. In Section 3 the results for both, present period simulation assessment and future projections, are presented. Finally, the conclusions are summarised in the last section.

2. Methodology and data

In this section the configuration of the WRF model and the input data of projected scenarios obtained through the PGW method from the reanalysis data and from the results of the CMIP5 global climate models are explained. The observational data used for the model assessment and the metrics chosen for this study are also exposed. Finally, the procedures used to estimate the wind energy density and the extractable wind power are outlined.

2.1. Model setup

WRF, version 3.4.1, was used to perform the downscaling simulations, using three domains in a double-nested configuration, with spatial resolutions of 45, 15, and 5 km (Fig. 2). All of these domains have been discretized with 32 vertical eta levels. The selection of the physical parameterizations, to represent the different sub-grid scale atmospheric processes, was done according to previous studies in the same area [18,19]. Thus, radiation schemes were set to the Community Atmosphere Model, version 3 (CAM3), for computing both longwave and shortwave radiation fluxes [20]. In the coarser resolution domains, D1 and D2, where the fluxes cannot be explicitly resolved, Kain-Fritsch cumulus parameterization [21] was used, and no cumulus parameterization was applied in the innermost domain, which has an horizontal resolution under 10 km. The planetary boundary layer was characterized using the Yonsei University scheme [22] and the land surface using the Noah model [23]. Finally, the WRF double-moment 6-class (WDM6) [24] was used as a cloud microphysics scheme.

In this work the PGW approximation was used for climate regionalization following the same configuration used in a previous study [26], in which future changes in temperature and precipitation were analysed. Thus, WRF initial and boundary conditions for a recent period (1995–2004) were directly taken from ERA-Interim reanalysis data [27]. This constitutes one of the main advantages of this method, because the errors in simulating observed climate caused by biases in the boundary conditions from global climate models are largely diminished [14]. For future periods, in our case 2045–2054 and 2090–2099, initial and boundary conditions for the WRF integrations are given by the sum of a climate perturbation signal to the same ERA-Interim data used for the present simulation. This signal was computed, for those variables of interest, from the results of 14 GCMs (Table 1) projections averaging their monthly mean values [26]. All the GCM projections belong to the Coupled Model Intercomparison Project Phase 5 (CMIP5). For each future period two different greenhouse gas concentration pathways, the CMIP5 RCP4.5 and RCP8.5 scenarios [28] were used. These scenarios represent middle and high emission assumptions, using emission pathways which lead to radiative forcings of 4.5 and