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Climate change impacts on wind energy potential in the European domain with a focus on the Black Sea

Richard Davy[a,*], Natalia Gnatiuk[b], Lasse Pettersson[a], Leonid Bobylev[a,b]

[a] Nansen Environmental and Remote Sensing Centre/Bjerknes Centre for Climate Research, Thormøhlens gate 47, N-5006 Bergen, Norway
[b] Nansen International Environmental and Remote Sensing Centre, 14th Line 7, Office 49, Vasilievsky Island, 199034 St. Petersburg, Russia

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ABSTRACT

We may anticipate that climate change will bring changes to the intensity and variability of near surface winds, either through local effects or by altering the large-scale flow. The impact of climate change on European wind resources has been assessed using a single-model-ensemble of the latest regional climate model from the Rossby Centre, RCA4. These simulations used data from five of the global climate models in the contemporary Climate Model Intercomparison Project (CMIP5) as boundary conditions, and the results are publicly available under the COordinated Regional climate Downscaling EXperiment (CORDEX) project. Overall we find a consistent pattern of a decrease in the wind resources over the European domain under both the RCP 4.5 and RCP 8.5 scenarios, although there are some regions, principally North Africa and the Barents Sea, with projected increases in wind resources. The pattern of change is both robust across the choice of scenario, and persistent: there is a very similar pattern of change found in the latter part of the 21st century as in the earlier. A case study was chosen to assess the potential for offshore wind-farms in the Black Sea region. We developed a realistic methodology for extrapolating near-surface wind speeds up to hub-height using a time-varying roughness length, and determined the extractable wind power at hub-height using a realistic model of contemporary wind-turbine energy production. We demonstrate that, unlike much of the Mediterranean basin, there is no robust pattern of a negative climate change impact on wind resources in the studied regions of the Black Sea. Furthermore, the seasonality of wind resources, with a strong peak in the winter, matches well to the seasonality of energy-demand in the region, making offshore wind-farms in the Black Sea region a viable source of energy for neighboring countries.

1. Introduction

The increasing demand for renewable energy sources in the coming decades [1] requires that we have a clear understanding of accessible wind resources, and the susceptibility of these resources to climate change [2]. The wind energy industry has clear ambitions of expansion, with wind energy capacity scenarios ranging from 251 to 392 GW production by 2030 [3], between two to three times the present (2014) capacity. For a location to be suitable for the construction of a wind farm it must have sufficiently high and reliable wind speeds, and for these to not decrease significantly under future climate change. Wind energy potential is strongly dependent upon the strength of near-surface winds which are determined by synoptic-scale variability and local processes, such as those related to orography. Therefore if climate change alters the large-scale flow [4–6] or local conditions such as stratification [7] or surface roughness [8] it can also alter the available wind resources, and indeed it has been shown that this has already happened [8–11]. This is especially important in the long-term planning of new wind-farms given the need for the timing of power generation to match the timing of demand, due to the lack of large-scale energy storage [12].

A common tool to explore the potential for the impacts of climate change on wind energy resources is the regional climate model (RCM). These have the advantage over global climate models that, due to the reduced domain, one can readily run these models at a higher spatial resolution and with more detailed surface processes, to better capture changes to the near-surface winds [13]. The RCM inter-comparison project, EURO-CORDEX [14], has provided an ensemble of historical

Abbreviations: CMIP5, Climate Model Intercomparison Project phase 5; CORDEX, COordinated Regional climate Downscaling Experiment; ECMWF, the European Centre for Medium range Weather Forecasting; EWP, Extractable Wind Power; RCA4, Rossby Centre regional atmospheric model v.4; RCM, regional climate model; RCP, Representative Concentration Pathways; WPD, Wind Power Density

* Corresponding author.
E-mail address: richard.davy@nersc.no (R. Davy).

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Table 1
List of the origin institutions of the different global climate models (from CMIP5) that were used for boundary conditions for the CORDEX regional simulations used here (RCA4), and the model acronyms we use in this manuscript.

Origin of global climate model	Acronym
Institute Pierre Simon Laplace, Paris, France	IPSL-CM5A
Centre of basic and applied research (CERFACS) / Météo-France / The National Centre for Scientific Research (CNSR), Toulouse, France	CNRM-CM5
EC-Earth consortium of national weather services and universities	EC-EARTH
Met Office Hadley Centre, Exeter, UK	HadGEM2-ES
Max Planck Institute for Meteorology, Hamburg, Germany	MPI-ESM-LR

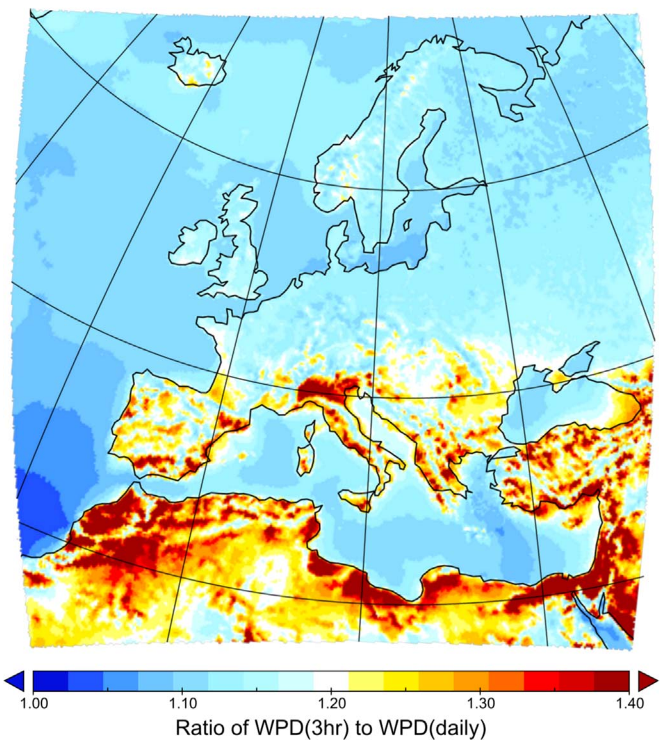

Fig. 1. The ratio of WPD calculated using 3-hourly resolution and daily resolution wind speeds, averaged over the Historical period of the downscaling of CNRM-CM5 data.

simulations and future projections of climate which has been a rich resource for studying the effects of regional climate change on winds [15,16]. However, there are relatively few studies which have used RCM projections to assess the near-surface wind resources using realistic models of wind power production at the typical heights of wind-turbines. This is partly due to the relatively high computational cost of applying realistic power-curve models of extracted wind power as a function of wind speed, and due to the complexities of extrapolating the typical model output of wind speeds at 10 m above the surface, to wind speeds at hub-height [2]. However, both of these factors are important in assessing wind resources due to the dependency of the extrapolation of 10 m wind speeds to hub-heights on local conditions, such as roughness length [17,18], and because a realistic model of extractable wind potential is a primary metric in determining the feasibility of a wind-farm [1]. While it is common to use simple power-law approximations to extrapolate wind speeds to turbine hub-heights [16,19], in this work we developed a roughness-length dependency in our calculation of wind speeds based on established boundary-layer profiles for winds [17].

In this study we have performed an ensemble analysis of the Rossby Centre's latest regional climate model, RCA4 [20] set up for Europe at an approximately 12 km (0.11° on a rotated grid) spatial resolution. Others have assessed the previous iteration of this regional climate model (RCA3) in terms of the reproducibility of wind resources in localized regions [21,22], and have demonstrated that the model performed well in reproducing the past and current wind speed climatology. There are three main sources of uncertainty associated with regional climate model assessments: the choice of global climate model used for the boundary conditions; the choice of regional climate model; and the internal variability of the climate models. An ensemble of RCA4 simulations of European climate is a useful way to assess the robustness of signals of climate change in the wind resources as resolved in the regional model projections. It allows us to quantify the sensitivity of simulated wind resources to the choice of global climate model used to prescribe the boundary conditions. However, it has been shown that the uncertainty in wind speeds that comes from the choice of regional climate model may be comparable to, or greater than that which comes from either the choice of global model or the internal variability [23,24]. Therefore we need to exercise some caution when interpreting results from such a single-model-ensemble of climate projections as used here.

Here we use an ensemble of climate projections to assess the susceptibility of wind resources in the European domain to climate change, with a more in-depth assessment of the potential for offshore wind-farms in the Black Sea region. In Section 2 we discuss the datasets and methodologies used in this paper; in Section 3 we review the single model ensemble for consistency with a contemporary reanalysis product, ERA-Interim; in Section 4 we assess the wind resources in the European domain and the projected changes in the 21st century; in Section 5 we take a case study on the potential for wind farms in the Black Sea region and their susceptibility to climate change; and finally in Section 6 we present our conclusions.

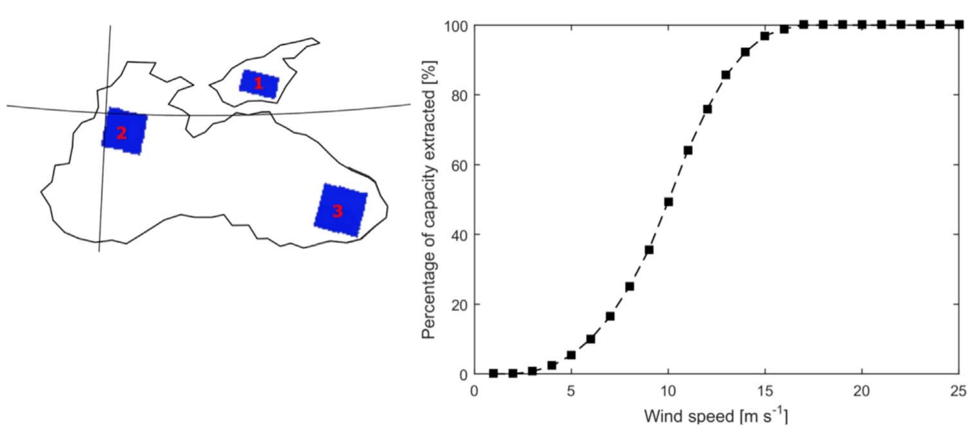

Fig. 2. *Left:* The three regions for which we assess the extractable Wind Power: (1) Azov Sea, (2) NW Black Sea, and (3) SE Black Sea. *Right:* The power-curve of the Enercon E-126 wind turbine, expressed in percentage of the maximum capacity of the turbine [24].