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Wind energy resources in South America under climate change

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ABSTRACT

This work evaluates future variations in wind resources in South America by considering the newest and most complex climate-change scenarios – the Shared Socioeconomic Pathways (SSPs). A multi-model ensemble of global climate models is constructed to compare wind power density values at the end of the century (2081-2100) with a baseline period (1995-2014). Three climate-change scenarios are considered, representative of high (SSP5-8.5), intermediate (SSP2-4.5) and low (SSP1-1.9) emissions pathways. The findings reveal remarkable increases in wind resources (over 100%) in regions of Brazil, Paraguay, Uruguay and Venezuela. Conversely, notable reductions (up to 50%) are predicted along the western coast of the South American continent, particularly in South Chile, Peru and Ecuador. These substantial changes must be taken into account in strategising the growth of the wind industry and its pivotal role in achieving the decarbonisation of the energy sector in South America.

Keywords: Renewable Energies, South America, SSPs, Wind Energy, Climate Change.

NOMENCLATURE

Abbreviations	
CMIP6	Coupled Model Intercomparison Project Phase 6
GCM	Global Climate Model
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
MME	Multi-model ensemble
NDC	Nationally Determined Contribution
SSPs	Shared socioeconomic pathways

1. INTRODUCTION

Wind energy has recently experienced a significant surge in installed capacity globally, largely driven by international policies aimed at addressing climate change. This study is centred in South America, where countries signatories to the Paris Agreement have submitted their respective Nationally Determined Contributions (NDCs), outlining a number of actions to achieve the goal of limiting global warming to 1.5°C.

Due to its technological maturity, wind energy is expected to assume a central position in these NDCs. However, the availability of wind energy is sensitive to shifts in the atmospheric circulation which may be caused by climate change. In other words, while wind energy serves as a potent instrument for decarbonising the energy sector and addressing climate change, it is also greatly influenced by climate change itself.

The most recent and complex climate-change scenarios are the Shared Socioeconomic Pathways (SSPs) [1], introduced by the Intergovernmental Panel on Climate Change (IPCC). The SSPs establish pathways for greenhouse gas (GHG) emissions and societal development that lead to certain levels of radiative forcing in the year 2100. The SSPs have been employed by the CMIP6 (the sixth phase of the Coupled Model Intercomparison Project) to generate climate projections through Global Climate Models (GCMs) [2]. These projections have been used to evaluate the effects of climate change on wind resources in multiple regions and scales, e.g., globally [3], Europe [4], North America [5], the UK [6], China [7], offshore Northern Europe [8], Australasia [9], offshore China [10] and the offshore Mediterranean Region [11]. It became apparent in these studies that the SSPs anticipate more significant changes than previous scenarios.

There is an apparent bias in the geographical distribution of these studies, with the lion's share focusing on the Northern Hemisphere. To date, the evolution of wind energy resources under climate change has not been studied in South America in the context of the SSPs. This gap serves as a motivation for this work.

Changes in wind resources as a result of climate change are investigated in South America by using projections on near-surface wind speed from the GCMs involved in the CMIP6 activities. More specifically, three

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scenarios are considered: SSP5-8.5, the high-emissions scenario, characterised by an intensive consumption of fossil fuels in economic development; SSP2-4.5, the intermediate scenario, where current policies remain relatively unchanged; and SSP1-1.9, a low-emissions scenario representing the accomplishments of the Paris Agreement. The latter is a novelty of the latest scenarios of climate change and has not been included in many previous studies. It is, however, included in this work for comparison purposes. Indeed, by comparing its results with those of the intermediate and high-emissions scenarios it is possible to assess the efficiency of the climate policies advocated by the Paris Agreement.

2. MATERIALS AND METHODS

2.1 GCMs

All the models participating in the CMIP6's ScenarioMIP activities with projected daily-averaged, near-surface wind speed data under the three climate change scenarios are considered [2].

2.2 Multi-model ensemble

This work employs a multi-model ensemble (MME) to study changes in future wind energy. This approach was proven to reduce to a great extent individual uncertainties of the GCMs, thus leading to more reliable results. Here, the models are validated in the region, and those with the best performance are included in the construction of the MME. Historical data of all GCMs are validated with data sourced from the ERA-5 database [12], a conventional choice in this type of study.

Twenty years' worth of data (1995-2014) from each GCM are validated against historical data of the ERA-5 of the same period employing the Kolmogorov-Smirnov test, which tests whether two samples belong to the same distribution. All the data from the models is remapped into a regular 1.5°×1.5° grid, and the statistical similarity of the time series is tested at each grid point following the methods and criteria presented in [5].

The five models that more accurately reproduce the past-present winds in the region are included in a multi-model ensemble, constructed following [4]. The selected models are CanESM5, CNRM-ESM2-1, MIROC6, MPI-ESM1-2-LR and MRI-ESM2-0.

In the following, wind power density [11] values are calculated for wind projections of the MME in the long-term future (2081-2100) and compared with historical data of the same MME (1995-2014), and thus variations in wind resources are ascertained.

3. RESULTS AND DISCUSSION

The historical mean wind power density shows different wind resource patterns in the study area (Fig. 1). The most energetic wind resources (approaching 800 Wm^{-2}) occur in oceanic areas off the coasts of Argentina and South Chile. Conversely, the weakest wind resources (<50 Wm^{-2}) occur in the equatorial regions, i.e., Colombia, Peru and, especially, Ecuador – corresponding to areas sheltered from the trade winds coming from the East. Generally, offshore regions present higher wind resources than their onshore counterparts, highlighting the potential of offshore wind.

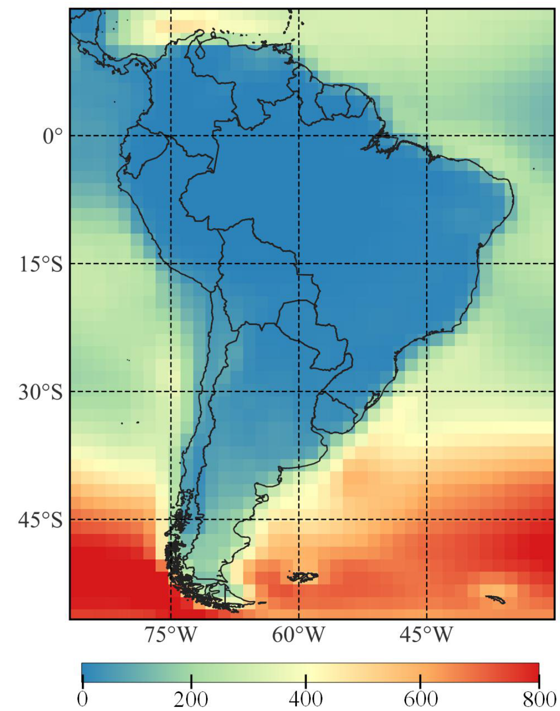

Fig. 1. Historical (1995-2014) mean wind power density (Wm^{-2}) in South America

Long-term changes (2081-2100) with respect to historical (1995-2014) values are presented in Fig. 2. Generally speaking, changes are of greater magnitude with higher radiative forcing.

Important growth in wind energy resources is predicted in Brazil, Venezuela, Paraguay and Uruguay. These increases can reach 120% in the southern states of Brazil and Paraguay in the scenarios with augmented emissions, i.e., SSP2-4.5 and SSP5-8.5 (Fig. 2). Conversely, important decreases are anticipated along the west coast of South America, especially in Southern Chile, Peru, Ecuador and Colombia – reaching ~50% in the scenarios with augmented emissions.

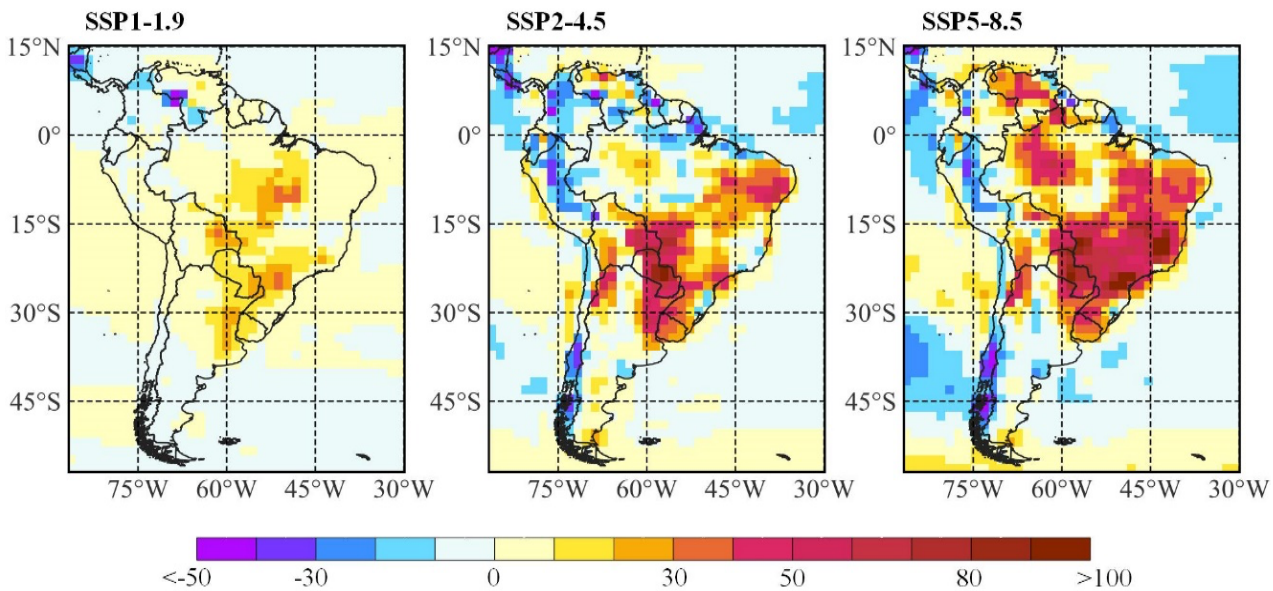

Fig. 2. Variations in mean wind power density in the long-term (2081-2100) according to the multi-model ensemble wind projections.

These decreases hold significant implications. The southern regions of Chile have been identified as the areas with the greatest wind resources in the continent (Fig. 1), thanks to the prevailing westerlies. However, decreases of ~50% in mean wind power density may have significant negative effects on the future wind industry. At the other extreme, wind resources in Peru and Ecuador have been proven to be the least energetic in the South American continent, both offshore and onshore (Fig. 1). Decreases in these areas could further reduce the economic viability of future initiatives.

Results show remarkable long-term evolution in energy relative to the baseline in SSP2-4.5 and SSP5-8.5, much greater than in Europe [4] or North America [5], where changes in wind power density rarely exceed 30%. It would appear that global wind resources in these scenarios are poised to increase substantially in concentrated areas in Tropical Regions, such as those identified in this work, in West Africa [13] and Australasia [9], in stark contrast with a widespread, less pronounced decrease in regions of the Northern Hemisphere – Europe [8], North America [5] or China [7].

The low-emissions scenario (SSP1-1.9), seldom studied in this type of work, anticipates lesser long-term changes relative to the baseline than its counterparts. However, it is important to highlight that these changes are still of significance. Growth of up to 30% is anticipated in certain regions of Brazil and Paraguay (Fig. 2). Interestingly, important decreases in wind power density, surpassing 50%, appear in a relatively small area between Venezuela and Colombia. These highly localised features warrant further research.

4. CONCLUSIONS

The impacts of climate change on wind energy resources in South America were examined. Data on projected wind speed from Global Climate Models were used, considering three climate-change scenarios. GCMs were validated in the region of study and a multi-model ensemble was constructed.

Wind projections anticipate substantial changes in wind resources in all three scenarios, especially in SSP2-4.5 and SSP5-8.5 – the scenarios with augmented emissions. Increases in wind power density that can surpass 100% are predicted in large areas of the South American continent – Brazil, Paraguay, Uruguay and Venezuela. In contrast, reductions of 50% in wind power density are projected along the region's West coast, particularly prominent in South Chile, Peru and Ecuador. This concentration of reductions along the west coast is noteworthy, for it encompasses regions both with the greatest wind resources (Southern Chile) and the weakest (the Peruvian coast) in the South American continent.

The implications of these findings are of paramount importance for the wind industry in the region, given the significant and contrasting changes anticipated. According to projections, wind resources may double or halve depending on whether climate-change policies align with SSP2-4.5 or SSP5-8.5. In this sense, areas that were previously disregarded for wind energy development may become of interest, whereas existing and planned wind projects may be severely impacted by resource reductions.

Of particular interest is the low-emissions scenario (SSP1-1.9), a pathway where the objectives of the Paris Agreement are fulfilled. The results show that even eventual success in achieving those goals would imply significant changes to wind resources – albeit smaller than under the other scenarios.

This study serves as a large-scale, initial investigation of the changes in wind resources in South America. General trends were evaluated and regions with substantial projected changes in wind resources, identified. These regions can be the objective of smaller-scale studies and downscaling initiatives to gain a better understanding of regional dynamics and evaluate their implications in local projects. In the future, it will be crucial to examine whether climate change policies align with specific scenarios and, on these grounds, to anticipate the corresponding changes to wind resources.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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