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Assessment of wind energy potential in Chile: A project-based regional wind supply function approach

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ABSTRACT

Wind energy is now one of the fastest growing renewable energy sources in Chile, making it the second largest market for wind power in Latin America. This paper describes the evolution and the current state of wind power in Chile, presenting the location and performance of all wind farms in Chile. This article also aims to identify the locations of the most cost-effective wind energy potential to be developed in the near future, thus applying a project-based approach. This requires studying each individual wind farm under development or environmental evaluation. This means modeling 70 wind farm projects over the country summing 8510 MW. For each project hourly wind production profiles and histograms are developed, allowing the assessment of variability and spatial and temporal complementarity. The production of neighboring projects injecting their energy in the same transmission bus is aggregated, generating wind production profiles and histograms at transmission level. The Levelized Cost of Electricity of each project is used as a measure of economic feasibility and serves as input to produce wind supply functions for each region. This allows us to identify the most cost-effective wind energy zones for medium-term project development, a valuable input for transmission planners and the regulator.

1. Introduction

1.1. Wind energy development

Wind energy has been one of the fastest growing renewable energy sources over the world during the last decades [1,2]. At the beginning its development was facilitated by incentives and subsidies mainly in developed countries, but increasing thereafter with technology development, reductions in costs, improved access to funding [3], and sustained improvements in the assessment of wind energy potential.

Some developing countries, such as Chile, started later with the wind energy integration on power systems. The initial wind projects were developed with limited know-how, without long-term wind studies, without the aid of a national wind resource maps or any sort of national prospective of wind resources, leading to low-performance and high average energy costs.

1.2. Chile wind energy potency and incentives under the new energy law

In Chile, geographical characteristics, such as the long coastline, valleys and large mountain range, make the conditions for the movement of air masses, creating multiple sites with significant wind potential [4], estimated recently at nearly 40,000 MW potential available [5].

Likewise, the development of renewable energy has been proposed as a *government policy*. In 2013, the Chilean non-conventional renewable energy law (Law #20,698) incentivized renewable energy by imposing a 20% quota of renewable energy sales by 2025. Wind has been one of the main sources to meet this requirement. Besides this law, the government's *energy agenda* proposes to remove existing barriers to this type of energy, with a commitment of 45% of electricity capacity coming from non-conventional, renewable sources, which will be installed between 2014 and 2025 in the country [6].

In addition to its good wind energy potential, Chile is considered one of the most attractive countries to invest in alternative renewable energy in the region, because it is one of the main economies on the continent, occupying the first place in human development, GDP per capita, life expectancy, as well as political

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stability, absence of violence, access to capital and clear regulation [7]. Furthermore, higher local energy prices, which are often above USD 100/MWh, make a big share of the projects profitable, without the need of any source of subsidy. The Chilean government is trying to capitalize this advantage now through its energy policy. These features make Chile a very attractive country for the development of renewable projects.

The current political stage of the electrical system in Chile focuses on two processes linked to the transmission system, which allow improvements in the scenario for the incorporation of wind energy. These are a new integrated national market and the development of renewable energy zones:

- **Integrated national market:** It has been proposed to develop a long 500 kV transmission line connecting the two main Chilean electricity markets (as shown in Fig. 1.). The future interconnection between the northern system (SING) and the central-southern one (SIC) will improve access conditions for several new project developments and increase the energy prices for a big share of renewable projects (Alleviating congestion will increase both Spot and PPA prices) [8].
- **Renewable energy zones:** The second process is the study and possible development of new transmission for the connection of potential renewable energy zones. These are areas where a high energy potential has been properly assessed and real solutions are proposed to facilitate their development through connecting lines for shared use (mainly for wind, solar and mini-hydraulic developments).

The objective of this article is to identify potential wind projects and potential renewable energy zones as candidates to be integrated to the national electricity systems over the medium- term; a process that could take from a few months to years. Serving this purpose the rest of this paper is organized as follows. First, the state of operating wind farms is presented in Section 2. Section 3 introduces necessary notations and modeling concepts for estimating wind farm production. A deterministic technique is proposed, which is used to estimate the wind farm production in each potential site, considering air density variation and wind farm production losses. Section 4 describes wind power hourly profiles, analyzing the tendencies in each zone/region of the country. An economic assessment is also presented. Wind supply curves of main buses of the power system are analyzed in Section 5. The aggregate production from all wind farm projects is discussed in Section 6. The operating reserves required to deal with wind uncertainty and variability is discussed in Section 7. Finally,

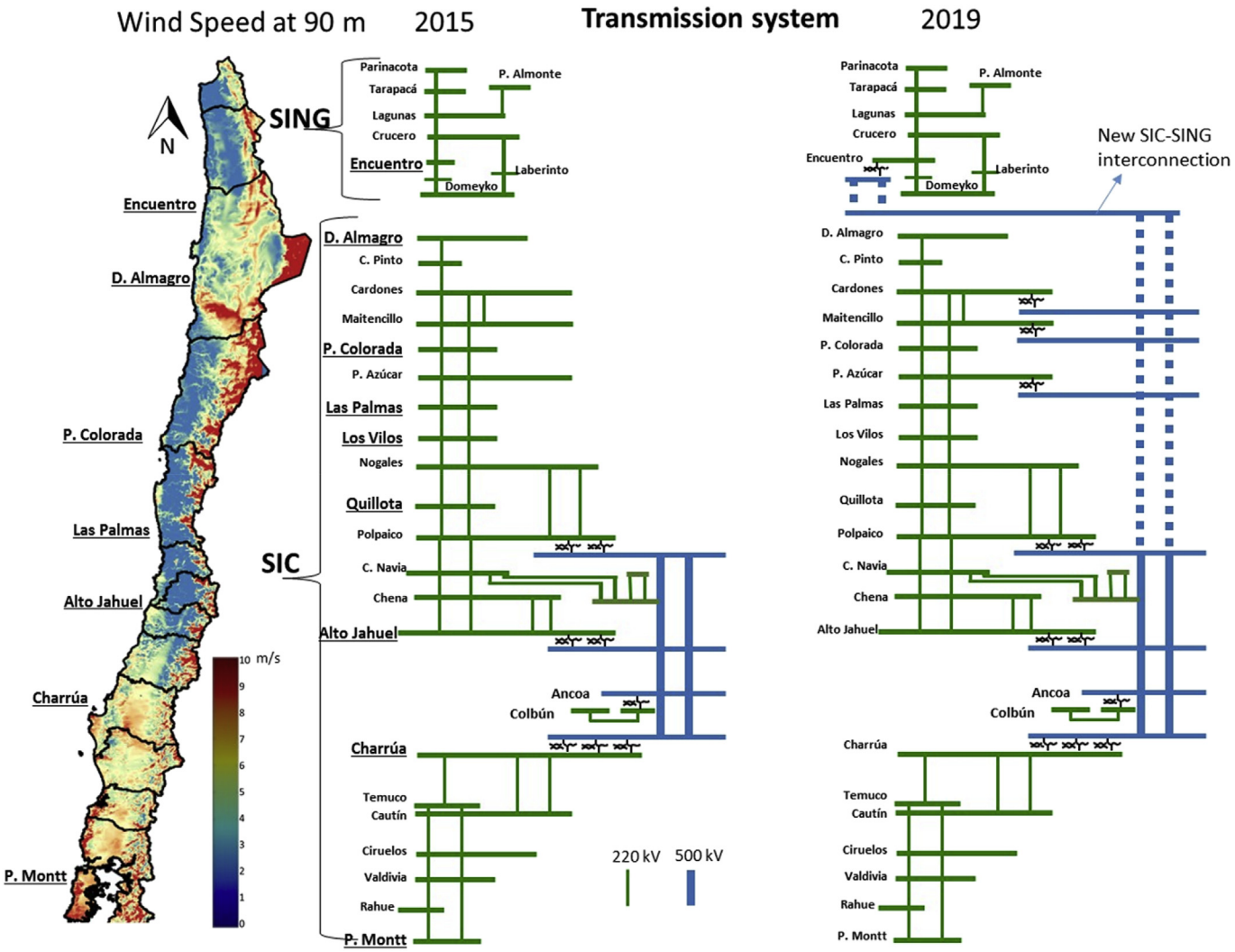

Fig. 1. Wind resource (Source: own elaboration using data from Ref. [9]) and expected evolution of the Chilean transmission network.