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Impact of intermittent non-conventional renewable generation in the costs of the Chilean main power system ☆

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ABSTRACT

Chile has recently approved a law aiming a target for electricity generation with Non-Conventional Renewable Energy (NCRE) of 20% by year 2025. It is anticipated that most of this NCRE generation will be provided by intermittent energy sources: wind and solar photovoltaic (pv). The economic consequences of intermittent NCRE penetration in the Chilean Central Interconnected System (SIC) are assessed. The NCRE penetration is simulated with a 10-year horizon (2017–2027), considering four scenarios of NCRE penetration: 10%, 15%, 20% and 30% of total generation.

The authors model the hydro-thermal operation of the power system and analyze spot prices, total operation costs and capacity factors. Results show that the average spot price in the SIC, when having an optimal minimum cost generation mix, is 89.7 US$/MWh. As intermittent NCRE penetration increases, some thermal base-load units' capacity factors change producing an increase in the generation cost. Additional transmission capacity is also needed elevating the total cost. The average incremental cost of integrating intermittent NCRE generation is 65.8 US$/MWh when increasing NCRE penetration from 10% to 30%. The effect of fossil fuel price fluctuation is also addressed. Two policy guidance elements are presented: intermittency should be reduced by diversifying the renewable portfolio and penetration costs of intermittent NCRE generation have to be incorporated into their investment or operation costs.

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1. Introduction

Electricity generation provided by renewable energy sources has grown significantly in the past years. The average growth in the 2000–2010 period was 3.9% per year and it reached a total production of 4206 TWh in 2010 (this represented 20% of global power generation) [1]. Renewable energies contribute to the reduction of greenhouse gas emissions, the diversification of the energy generation mix and a higher energy independence of countries. The international community has signed commitments to increase renewable electricity generation with a main objective of reducing CO_2 emissions by 2050. This goal will require doubling the current renewable energy production by 2020 [2]. Chile has not signed any international commitment yet, however, there is a clear intention to acquire one. In this direction, Chile has moved towards promoting non-conventional renewable energy (NCRE)[1] generation by approving a new law that imposes that 20% of total electricity generation has to be provided by NCRE sources by 2025 [3].

A first version of the law, approved in 2007, imposed a quota of 10% by year 2024 and after. This was enacted by assessing the existing renewable sources at that point. Later on 2013, the Parliament and Government considered that doubling the target to 20% was easily achievable, based on the technology improvement of renewable sources and the comparison with other countries' goals. These assessment studies were performed by groups inside the Chilean Energy Ministry and they are confidential up to this moment. It is expected that intermittent NCRE generation will grow quickly in Chile in future years as almost 95% of environmental approved NCRE projects capacity is either from solar pv or wind technologies [4]. This likely growth raises some questions because the integration of intermittent sources of energy presents several challenges [5].

The Chilean power system is comprised of four independent grids. As of December of 2013, the two main grids had more than 99.2% of the total installed capacity [6]. Table 1 shows the total Chilean electricity generation mix. In addition to the required NCRE to be installed to satisfy the current Law, there are many candidate power plants to meet the country's supply NCRE requirements. There are 17,898 MW in projects with approved environmental permits in the SIC (main grid). From these projects, 30% are hydroelectric projects, 26% coal projects and 5% natural gas-fired units [7].

The output of any power plant is subject to uncertainty, however the outputs of wind and solar pv power plants are more variable than any other generation technology.[2]

Intermittent NCRE sources in Chile have a similar variability compared to other countries. During 2012, wind power hourly generation in the SIC presented a coefficient of variation of a 101%, while the single operating solar pv plant (Tambo Real, 1 MW installed capacity) had a power generation standard deviation of 0.33 MW with a capacity factor of around 22%.

Impacts caused by intermittent NCRE penetration vary in type and magnitude depending on the specifics of each power system. Three characteristics can be identified in this matter:

- diversification of the energy matrix,
- energy storage capacity of the system, and
- transmission system quality and capacity.

It has been proved that in a diversified power generation system, high level of intermittent NCRE penetration can be controlled using flexible power units that can adjust their energy output quickly such as hydroelectric plants [8]. However, if a system lacks this type of power plants, conventional thermal units must be used to manage this variability (Kubik et al. pointed out that this is the situation in many countries [9]). This behavior produces cycling,[3] which in thermal units increases maintenance and fuel costs [10].

On the other hand, the storage capacity of a hydro-thermal power system is normally given by reservoirs and pumped storage hydro-plants, essentially because it is more economic [11]. In other words, energy storage allows a better response to sudden changes in supply, i.e. these plants run when NCRE generation decreases and stop running when NCRE generation increases without energy spillage since it is stored for the future.

Finally, an adapted transmission system facilitates the integration of intermittent NCRE sources by reducing temporal fluctuations and minimizing the geographical dispersion surrounding these sources [12]. In weak networks (congested or with a low transmission capacity), new intermittent NCRE capacity will necessarily require additional transmission upgrades [13,14]. Conventional technologies would need transmission upgrades in those situations as well, however the amount would be smaller thanks to better capacity factors. In the case of Chile, Molina et al. found out that the growth of NCRE generation would produce significant congestion on the transmission grid in the long term due to both the location of NCRE nodes and transmission upgrades needed [15].

Impacts produced by the penetration of intermittent NCRE sources have been widely investigated with most studies concluding that these types of sources impose more restrictions and higher costs in the operation of electric power systems [16]. Systems which are mainly composed of coal and CCGT plants generally see generation costs increment mostly because of cycling issues [5,10]. Holttinen et al. analyzed various wind penetration levels concluding that transmission costs could rise up to 270€ per MWh of wind generation and that the requirement of new reserve capacity is equal to 12.5% (5–20%) of the installed wind capacity [13]. Mills et al. found out that, in order to integrate wind

[1] NCRE is a Chilean term for renewable energies that includes solar, wind, geothermal, biomass, mini-hydro-plants (less than 20 MW installed) and future technologies that behave the same way such as tidal or wave generation. This term was created to separate big hydroelectric plants that have existed for a long time in the country.

[2] This paper uses the definition of intermittent source given by Pérez-Arriaga & Battle: a source with a non-controllable variability and partial unpredictability [5].

[3] The variation in the generation of a power plant following load and supply changes is known as cycling.