Mitigating the impact of El Niño–Southern Oscillation on hydropower by complementing it with solar and wind power in Latin America

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Key Messages

Exploiting the complementarity between solar, wind and hydropower could potentially compensate for fluctuations in hydropower (the current backbone of Latin America energy systems) during and outside of the El Niño–Southern Oscillation.

A smart mix of renewables could reduce the variability of power generation caused by climate in Latin America, cost-effectively avoiding further expansion of gas-based power generation and reduce emissions

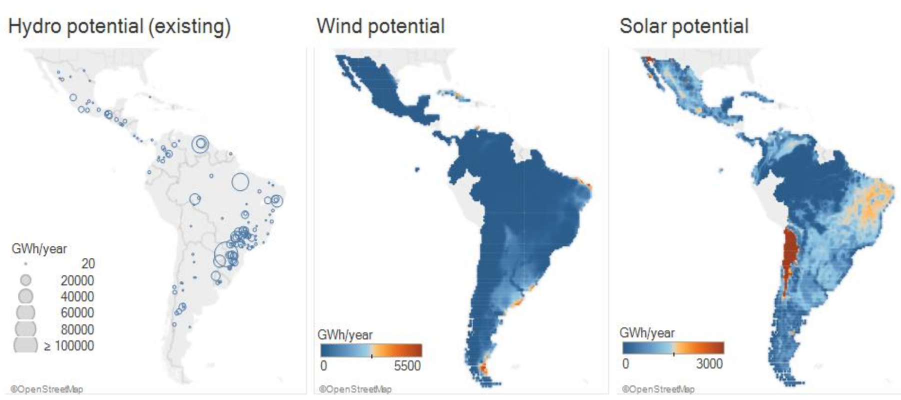


Figure 1. Technical annual energy potential for hydro, wind and solar power (GWh/year).

Introduction

Latin America has the largest share of renewable energy for power generation in the world, but has historically been dependent on hydropower, and is vulnerable to long-term phenomena like the El Niño–Southern Oscillation (ENSO). The region is currently experiencing a steady increase in gas-based power generation along with a rapid growth in non-hydro renewables, mainly aimed at improving reliability. Nevertheless, the uptake of gas power plants counteracts the mitigating effects of renewable energy sources (RES) on climate change. Thus, exploiting complementarities between hydropower and other renewables could reduce the need for fossil fuel based power plants while mitigating the impact of ENSO on hydropower.

This policy briefing investigates to what extent improved deployment of wind turbines and solar photovoltaic cells (PV) could complement existing hydropower and mitigate the impacts of ENSO on it [1]. The technical energy potential of wind, solar and hydropower is substantial, as shown in **Figure 1.** We use a meteorological reanalysis dataset to model the variations in wind, solar and hydropower throughout the entire 20th century and their association with different ENSO phases in the same period. A statistical algorithm is then used to identify locations at national and regional levels offering the maximal level of complementarity.

Our analysis indicates that exploiting the complementarity between renewable energy resources has the potential to cost-effectively compensate the fluctuations of hydropower and reduce the variability of power generation caused by climate in Latin America.

Impacts of El–Niño Southern Oscillation (ENSO)

The El Niño–Southern Oscillation is a large-scale ocean-atmosphere climate interaction that manifests as a fluctuation in sea-surface temperature (El Niño) and air pressure of the overlying atmosphere (Southern Oscillation) across the Pacific Ocean [1]. ENSO is active during two alternating and irregular phases, a warming (El Niño) and a cooling (La Niña) phase, and it is inactive during neutral phases. Warming and cooling phases last several months and have a strong influence on rainfall patterns, droughts, floods [2], hydropower generation [3], and prices of commodities [4]. Higher temperatures and droughts caused by ENSO result in a higher water demand for irrigation and reduced electricity from hydropower dams and thermal power plants. This leads to higher demand for fossil fuels and a rise in energy prices. Conversely, ENSO has a strong influence on flood risk and its associated economic damage and loss of life [2]. El Niña and La Niña have been found to strongly affect renewable power generation in the North-Western parts of the United States, Central and South America, Iberian Peninsula, South China, South-east Asia, and Australia [3, 5, 7–9]. ENSO-related extreme events are expected to increase in the future [10–12]; however, its connection and response to global warming is largely uncertain [13].

Key results

The results show that adding 136 GW of wind and solar power (see **Figure 2**) to 109 GW of the existing hydropower modelled has the potential to cost-effectively compensate the fluctuations of hydropower and reduce the variability of renewable power. This is the case not only during drought ENSO phases but also outside ENSO events [1]. The overall impact of these wind and solar sites is substantial, as they could generate half the annual hydropower output.

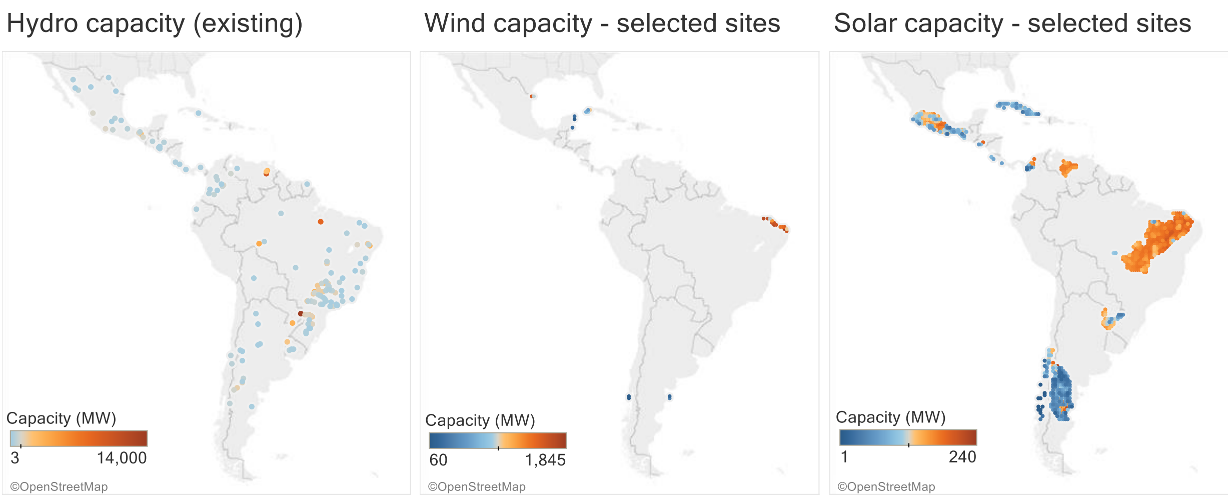
In most countries, hydropower is the resource with the largest fluctuations in power generation on monthly and annual bases, both during drought ENSO phases and outside of ENSO events (neutral phases).

Hydropower could be utilized at as low as 10% of its total capacity during dry months. The reduction in hydropower is further exacerbated during droughts and accounts for 3–16% on an annual basis compared to neutral ENSO phases. On the contrary, solar and wind power remain largely unaffected [1].

The lower seasonal fluctuation of solar and wind compared to hydropower and the high complementarity among the selected sites could lead to various benefits once they are combined [1].

Firstly, the amount of renewable power that is constantly available during all months of the year could increase by up to 5-fold both in neutral and drought ENSO phases.

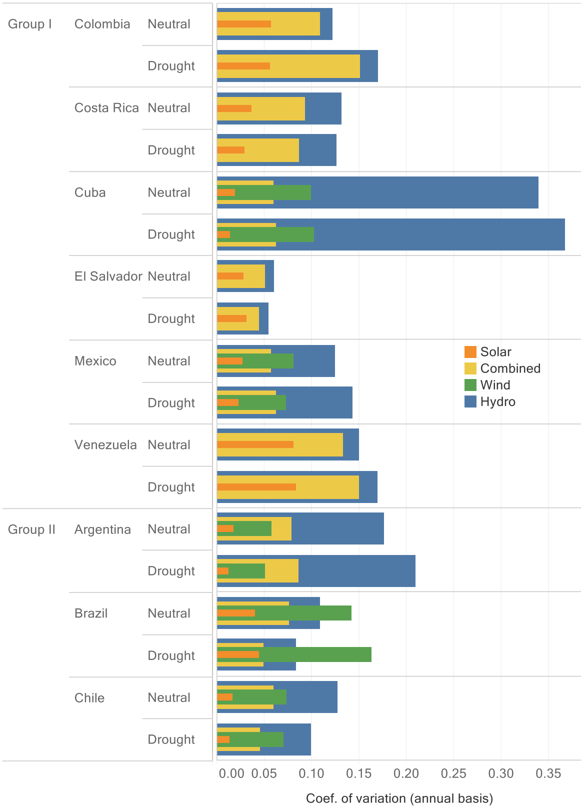
Secondly, the monthly and annual variability of combined renewable power generation (coefficient of variation in **Figure 3**) could significantly reduce compared to hydropower in neutral and drought ENSO phases. This reduction could be as large as 80% in Cuba and 50% in Argentina and Chile.



Type	Argentina	Brazil	Chile	Colombia	Costa Rica	Cuba	El Salvador	Mexico	Venezuela	Grand Total
Hydro	6,903	73,117	777	3,385	257	3	419	8,953	15,180	108,995
Solar	14,884	66,789	2,042	1,477	234	2,994	342	14,697	4,665	108,123
Wind	501	20,784	132			3,093		2,967		27,477
Grand Total	22,288	160,691	2,951	4,862	491	6,090	762	26,617	19,845	244,596

Figure 2: Power capacity by resource for the selected sites in MW. Power capacity is here defined as the full-load output of a power generation unit and is expressed in megawatts.

Figure 3: Coefficient of variation (the ratio of the standard deviation to the mean of a variable and is unitless) of the annual power generation by resource in neutral and drought ENSO phases. Variability is here defined as how dispersed or spread out a set of data is. A lower variability indicates a lower uncertainty and risk. Thus, coefficient of variations closer to zero are preferable.



Thirdly, combining multiple wind, solar and hydropower sites could decrease by up to 50% the variability of individual sites that are geographically spread.

Fourthly, in most countries, new solar and wind sites could economically compete with new gas plants, and in some cases with existing gas plants. The levelized cost of electricity (LCOE) of 0.09–0.23 $/kWh of new solar and wind sites is comparable to that of new gas plants (0.1–0.2 $/kWh). Nonetheless, dispatchability of renewable energy may imply additional costs (e.g., storage) that requires further investigation.

Despite the potential benefits, several of the wind and solar resources identified here are spatially heterogeneous, which might pose challenges for connection not only to the transmission and distribution networks but also to load centres. These results could be used for improved planning of generation capacity and regional transmission grids, as well as for mitigating the risk of assuring reliability of supply during droughts. Further investigation is required to analyse the integration of these resources into existing and future power networks at regional and country-levels.

Further investigations

Further investigations are needed into the following:

- Integration of the identified resources into existing and future power networks at regional and country-levels is required.
- Short-term complementarity between renewables to evaluate adequacy of supply and profitability.
- The potential amount of CO_2 emissions and investments that could be avoided with the substitution of gas-power plants.

Recommendations

- **It is recommended that future policies aim at exploiting the complementarities between solar, wind and hydropower,** as this could lower the carbon footprint of energy supply while reducing the variability of renewable energy supply during and outside of El Niño–Southern Oscillation (ENSO) events. This results in resilience against climate change.
- **Exploiting the complementarities between renewables could be of particular interest for Cuba, Mexico, Argentina, Brazil, and Chile.** In these countries the variability of renewable power generation could be reduced by more than 65%. The difference between drought and neutral ENSO phases is not significant.
- **A decision-making process is needed that recognizes the complementarities between different renewable energy generation types and locations.** Most solar–hydropower combination seems to be more advantageous than a wind–hydropower combination. However, the average levelized cost of electricity (LCOE) of wind power is lower than that of solar power in all investigated countries. The variations of the LCOEs are noteworthy, allowing for competitive solar–hydropower combinations at specific sites.
- The findings could be used for improving the planning of generation capacity and regional transmission grids, as well as for mitigating the risk of assuring reliability of supply during droughts.

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Notes

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