Pathways to a 100% Renewable Power System: Investments, Flexibility, and Battery Storage in Bolivia's Energy Transition

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Introduction

Raising oil prices and stronger awareness of the impacts of climate change has led the Bolivian government to consider developing polices aimed at supporting the adoption of decentralized energy sources. The paper focuses on the expansion of generation units, transmission networks, and particularly on utility-scale battery storage systems to enhance system flexibility, especially with significant solar and wind integration. The study develops four distinct pathways representing different policy directions for Bolivia's power system, emphasizing the role of battery storage in providing flexibility. Hydropower expansion is excluded due to environmental concerns, highlighting the importance of battery storage. The PyPSA-Earth open-source model is used for optimization, tailored to represent the Bolivian power system accurately.

Methods

The methodology involves validating and configuring the PyPSA-Earth model specifically for the Bolivian power system. This process includes updating several configurations and datasets after a comprehensive validation process. The study designs four development pathways for the Bolivian power sector, differing in extendable technologies, emission reduction targets, and maximum battery storage capacity. Each pathway's optimization is conducted year by year, considering the necessary investments to meet the increasing demand and decreasing CO2 limits. The model's objective function includes yearly operational costs and annualized investment costs for expanding generation units, transmission networks, and energy storage systems. The four pathways are designed to represent different policy directions and technological scenarios for Bolivia's power system, excluding hydropower expansion due to environmental concerns. The pathways analyzed are:

- **Baseline:** This scenario assumes a "business as usual" approach without any specific constraints on CO2 emissions or generation technologies. It aims to meet power demand using the most cost-effective options available, serving as a reference case for comparison with other pathways.

- **National Strategy:** This pathway models the Bolivian power system based on national expansion targets, incorporating yearly minimum capacities per technology as planned by the Bolivian government. It includes all technologies and does not impose an emission cap, aiming to reflect Bolivia's current expansion strategy without aiming for carbon neutrality.

- **RES-CAP (Renewable Energy Sources with Carbon Cap):** This scenario restricts the amount of allowed carbon emissions, decreasing linearly each year until reaching zero emissions in 2035. Only renewable energy sources (excluding hydropower) are permitted to be extended by the model to satisfy power demand, emphasizing the role of battery storage without a capacity limit.

- **RES-CAP-BAT (Renewable Energy Sources with Carbon Cap and Battery Limitation):** Similar to RES-CAP, this pathway also aims for zero emissions by 2035 with an exclusive focus on renewable energy sources. However, it introduces a limitation on battery storage extension to investigate the impact of a realistic battery storage capacity on the system's ability to meet demand and achieve carbon neutrality.

The results examine the total system costs, needed generation capacity expansion, and dispatch for each pathway, providing insights into the feasibility and implications of each scenario for Bolivia's energy transition.

Expected Results

The results showcase significant differences in total system costs, needed generation capacity expansion, and dispatch across the four pathways. The National Strategy pathway, which aligns with Bolivia's current expansion targets, is the most cost-effective, while pathways aiming for a fully renewable system without emission caps (RES-CAP and RES-CAP-BAT) are considerably more expensive. The RES-CAP pathway, with no battery restriction, requires unrealistic high battery storage capacities to meet demand, whereas the RES-CAP-BAT pathway, with a battery restriction, faces challenges in meeting demand due to insufficient battery storage. The sensitivity analysis on CO2 emission restrictions shows that relaxing the net-zero goal slightly improves system reliability but still requires significant investments in renewable generation and storage capacities. The study underscores the critical role of battery storage in achieving emission targets and the interdependence between solar PV penetration and available storage capacity.

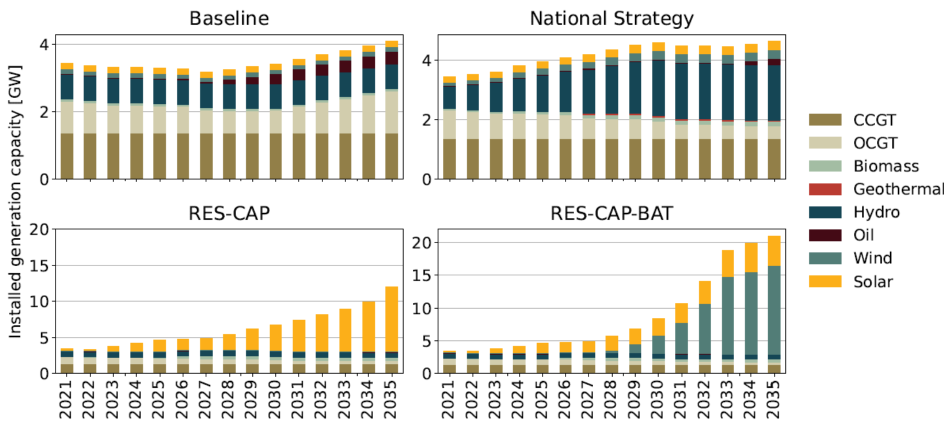

Figure 1Development of the generation capacity from 2021 to2035 of all pathways

Conclusions

The paper provided insights into the feasibility and implications of different policy choices and technological scenarios for Bolivia's energy transition towards a 100% renewable power system by 2035. Main conclusions are as follows:

- The National Strategy pathway, which aligns with Bolivia's current expansion targets, is the most cost-effective approach for transitioning to a renewable power system.
- Pathways aiming for a fully renewable system without emission caps (RES-CAP and RES-CAP-BAT) are significantly more expensive due to the high costs associated with unrealistic battery storage capacities or insufficient storage to meet demand.
- The sensitivity analysis on CO2 emission restrictions indicates that a slight relaxation of the net-zero goal can improve system reliability but still requires substantial investments in renewable generation and storage capacities.
- Battery storage plays a critical role in achieving emission targets, and there is a strong interdependence between solar PV penetration and available storage capacity.
- The study highlights the importance of considering environmental concerns, such as the exclusion of hydropower expansion due to its potential negative impact on tropical ecosystems and associated greenhouse gas emissions.
- The PyPSA-Earth model, tailored for the Bolivian power system, provides a valuable tool for optimizing the transition pathways and analyzing the impact of utility-scale battery storage on the future power system.
- The results underscore the trade-offs between costs and emissions, emphasizing the need for strategic planning in the energy transition to ensure cost-effectiveness while meeting climate goals.