IMPACTS OF GENERATION AND TRANSMISSION DELAYS ON ELECTRIC SYSTEMS EXPANSION SCENARIOS

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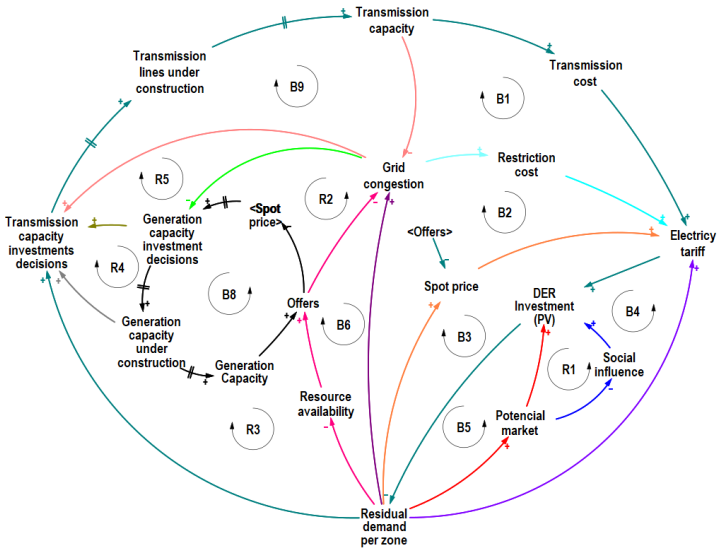
Overview

The implementation of variable renewable energy (VRE) sources is a key commitment to reducing emissions. VRE technologies have become increasingly cost-competitive, driving their widespread adoption in power generation across many countries. However, the development of electrical transmission infrastructure has lagged behind, as planning and development timelines for transmission projects often exceed those of VRE generation projects. Environmental and social challenges further contribute to delays, exacerbating these issues. This misalignment negatively impacts the achievement of renewable capacity targets, discourages new investments, and undermines system reliability. Furthermore, it can create gaps between market needs and planning, distort market signals, and disrupt the anticipated evolution of the electrical system. The objective of this study is to analyze the impact of misaligned development timelines for transmission and VRE generation projects on the evolution of the Colombian electrical market, using a System Dynamics approach.

Methods

In order to model the the electricity market, the planning times and delays were based on the models proposed by De Zubiría Arango, 2023 and Herrera et al., 2018, where the long-term expansion of the electric system is addressed through system dynamics. System dynamics is a methodology that aids in understanding the electric system by examining the causal relationships involved, feedback loops, and delays, allowing for a coherent simplification of a complex system (Ford, 1998). The following figure illustrates the balancing and reinforcing feedback loops in the simplified causal diagram of the model. It shows how generation needs are influenced by residual demand and price, while being regulated by distributed generation. Furthermore, generation needs and system constraints contribute to an increase in transmission requirements. However, both generation and transmission expansions face delays from the identification of the need to their commissioning in the system. In light of this, the model was calibrated to the Colombian case, considering planning timelines for both generation and transmission projects. This means that projects were planned in advance. Currently, efforts are underway to incorporate economic decision-making into generation and transmission investments.

Figure 1.Simplified causal diagram



Results

The model considers the installed capacity, resource availability, demand, hydrology, transmission lines between zones, and distributed generation within the country. It conducts an ideal dispatch, generates an average price for the country, and installs new capacity in generation and transmission as needed. The following figures illustrate the main variables of three different scenarios: a baseline scenario where planning times are not taken into account, and new projects are installed as needed without prior scheduling; a second scenario that includes delays in power generation but does not consider transmission planning times; and a third scenario that incorporates delays in both power generation and transmission, accounting for the full planning and execution process.

Figure 2. Total Generation Capacity

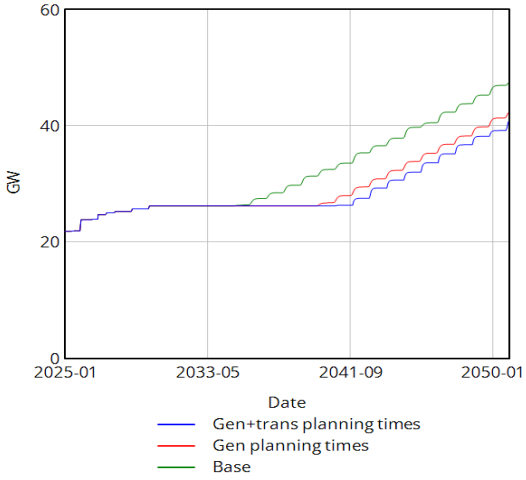


Figure 3. Electricity Tariff

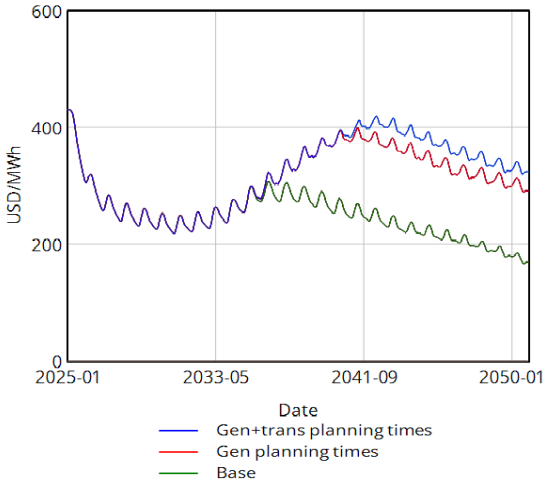


Figure 5. Mean availability margin

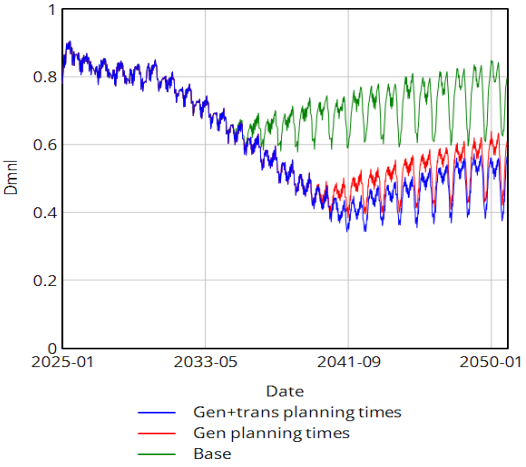
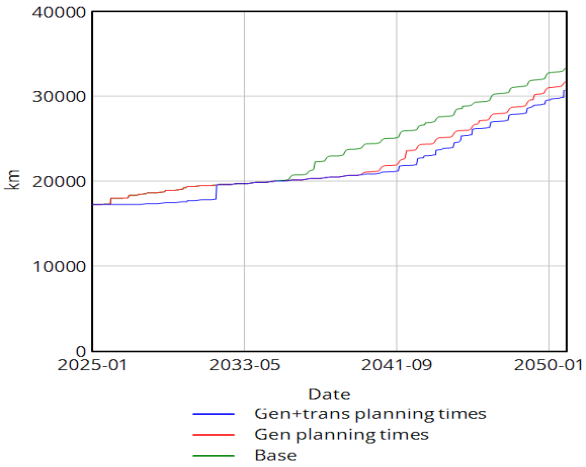


Figure 6. Total transmission



Conclusions

The results highlight how long-term generation and transmission needs impact the expansion of the Colombian electrical system. However, depending on the timing of investments, different generation sources and transmission requirements will be needed. The model expands resources based on the needs of the power system, meaning that when economic factors are incorporated, decisions may arise that alter the technologies required by the system. With the current state of the model, various scenarios have been explored, enabling the analysis of the effects of battery integration, resource complementarity, and high penetration of renewable energies into the system.

References

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Ford, A. (1998). System Dynamics and the Electric Power Industry. *System Dynamics Review*, *13*, 57–85. https://doi.org/10.1002/(SICI)1099-1727(199721)13:1%3C57::AID-SDR117%3E3.0.CO;2-B

Herrera, M., Cosenz, F., & Dyner, I. (2018). Alternative Energy Policy for Mitigating the Asynchrony of the Wind-Power Industry's Supply Chain in Brazil. In *Innovative Solutions for Sustainable Supply Chains* (pp. 199–221). Springer, Cham.