COMPLEMENTARITY OF ENERGY SOURCES IN THE COLOMBIAN ELECTRICITY MARKET: A SYSTEM DYNAMICS APPROACH

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Overview

A rapid transition of the electricity matrix to one where renewable energy predominates is necessary to mitigate and adapt to climate change. Fortunately, over the last years non-conventional renewable energy sources (NRES) have become a cost-competitive alternative to supply power around the globe (Jurasz et al., 2020). However, a significant technological challenge that persists is how to increase shares of NRES in energy systems while maintaining reliability (Bekirsky et al., 2022). Some characteristics of these sources, such as their intermittency, variability, and non-dispatchability, propose difficulties to their integration into the power systems.

One solution that has become more attractive for researchers over the years is the complementarity nature of NRES to facilitate the integration of a large proportion of them to the electricity matrix (Jurasz et al., 2020). The aggregation of multiple intermittent generators can reduce the variability and the uncertainty of the system, either from statistical smoothing of a single technology employed over multiple geographical areas or from combining technologies that use different energy sources (Hart et al., 2012).

Additional to the mitigation of climate change, Colombia has another motive for their increasing interest on NRES. With approximately 68% of its installed capacity consisting of hydroelectric power plants, the country is highly dependent on its hydrology as a source of energy. This dependency on water resources puts it at risk of shortages and high electricity prices, especially when experiencing periods of long droughts due to the ENSO phenomenon (Parra et al., 2020). Alternative energy sources, like thermal generation plants, serve as a backup to make up for energy shortfalls. The main problem with these energy sources is that they involve high operating costs as well as high CO2 emissions, making them a less desirable option.

Non-conventional renewable energy is an alternative to respond to the risk of energy deficit by hydroelectric plants. Recent studies have demonstrated the existence of seasonal complementarity patterns between NRES and water resources in Colombia (Gonzalez-Salazar & Poganietz, 2021). Taking advantage of this complementarity, Colombia could act strategically to protect itself against risks derived from dependence on hydroelectric resources, without the need to expand its thermal generation capacity.

However, in addition to complementarity between water resources and solar and wind resources, the country needs complementarity between renewable energy projects (even when generating from the same resource). If most of the NRE generation is located in places with the highest availability of solar and wind resources, the energy matrix will be less dependent on hydrology. Nevertheless, it could become dependent on the climate conditions and other factors of that specific area where projects are concentrated.

The energy market is a complex system where a large number of variables interact, creating feedback loops, delays and uncertainty. System Dynamics is an ideal approach to analyze the effects of different policies and incentives to complementarity on reliability and prices in the Colombian electricity market.

Methods

The energy sector in Colombia is a highly complex system where countless variables such as the energy demand, the country's hydrology, the price of fossil fuels, the limitations of the transmission system, among many others, influence its general behavior. These variables are constantly changing, and each one of them involves some degree of uncertainty that makes it impossible to predict its behavior at any given point in time. Moreover, there are feedback loops within the system, as well as information delays, that make the relationships between the different variables non-linear, and therefore more difficult to understand.

As if the energy sector was not complex enough, the undergoing transformation towards a cleaner and more diverse energy matrix means the intermittency of the non-conventional renewable energy sources must also be taken into account to analyze the system's capacity more accurately.

We develop a simulation model to analyze the effects of complementarity between NRE projects in the Colombian electricity market. The model considers the hydroclimatic variability, as well as the hourly variations of the electricity demand and price, to simulate an hourly dispatch. The profitability of new renewable energy projects is estimated under different scenarios regarding remuneration schemes and incentives to complementarity. Based on that profitability, investment decisions in different technologies and locations are made, which will then influence electricity prices, closing a feedback loop that results in counterintuitive results.

Results

By simulating the incorporation of NRE projects under the current Colombian electricity market, it was possible to identify some behaviors in the cumulative electricity generation that could bring disadvantages to the system.

The model showed that, without incentives or other interventions from the government, investment on renewable energy projects is more profitable in specific regions of the country, where solar and wind resources are much more available. This could cause investors to prefer specific regions of the country to locate their projects.

However, if most projects are located in the same regions, their generation profiles will be similar. This will result in a highly intermittent cumulative offer from NRES, which will be challenging to balance the system and will affect security of supply in case any unexpected event occurs in any of these regions (such as sudden changes in climate conditions, damages to the transmission lines, etc.). The model results show that locating most projects in the same region can lead to shortages and extremely high energy prices. To guarantee a reliable and affordable electricity supply, renewable energy projects should be located in different regions of the country, where solar radiation and wind profiles are complementary, even though the total amount of electricity generated by those projects will be lower.

Conclusions

Renewable energy projects shouldn't be concentrated in a specific area of the country. The problem is, not all regions in the country are equally attractive for investors, because they do not have as much solar and wind resources, and therefore, their total generation is lower, affecting the projects' ROI.

Considering that most of the investment on renewable energy will come from private funding, projects' profitability is a key factor when making investment decisions. Based on the simulation results, we recommend the implementation of alternative remuneration schemes, policies and incentives, to help regions of the country with less resources, but more convenient availability profiles, become attractive for investors. This will facilitate and accelerate the construction of new renewable energy projects that are complementary to each other, ensuring a clean, reliable and affordable energy matrix.

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