RESEARCH SUMMARY

The Dynamic Impact of Market Integration: Evidence from Renewable Energy Expansion in Chile

by Luis E. Gonzales, Koichiro Ito, and Mar Reguant

KEY TAKEAWAYS

1. Expansion of renewable energy is one of the most urgent and important challenges for addressing climate change. A decade ago, the principal challenge for decarbonizing the electricity sector was technological: wind and solar technologies were not cost competitive with conventional fossil fuels. Today, the challenge is how to deliver power from renewable-rich areas to the areas where there is the highest demand.

2. The authors develop a simple theoretical model that characterizes the impacts of renewable integration into the market. They then test their theoretical predictions by studying empirical evidence from Chile—one of the very first countries to have tackled this challenge by enhancing electricity market integration.

3. With a better-connected transmission grid, the price of electricity throughout the region becomes more balanced. Prices increase in renewable-rich areas and decrease in the demand centers far from renewables.

4. The grid expansion leads to an increase in renewable generation and decrease in the cost of electricity, replacing higher-cost fossil fuel plants in some cases. Solar generation increased by 51 percent in Chile, indicating that the expansion incentivizes new entries and investment of renewables—a crucial market force to accelerate decarbonization. Further, the cost of electricity declined by 12 to 5 percent.

5. The cost of expanding the grid provides long-run benefits to consumers and investors, with the cost quickly recovered in less than 5.5 years in Chile due to reductions in generation cost and improvements in environmental quality.

6. As nations throughout the world consider the build out of transmission infrastructure to spread the use of renewable energy, the study provides important insights. These insights could be useful, for example, in the United States where the Infrastructure Investment and Jobs Act contains a significant investment in transmission expansion and renewable energy.

Introduction

Effective and economical expansion of renewable energy is one of the most urgent and important challenges for addressing climate change. The electricity sector generates one of the largest shares of global greenhouse gas emissions along with the transportation sector. In addition, a significant part of the transportation sector is expected to be electrified in the near future. Decarbonizing electricity generation is therefore critical to addressing climate change.

A decade ago, the principal challenge for decarbonizing the electricity sector was technological: wind and solar technologies were not cost competitive with conventional fossil fuels. Today, with costs down dramatically, the challenge many countries are facing is how to deliver power from renewable energy to where consumers live. In many countries, transmission grids were originally built for conventional power plants such as thermal plants, which can be placed reasonably close to demand centers. However, renewable-rich areas are often located far from the areas where there is the highest demand, such as large urban centers. Therefore, with the current transmission network, many countries have a problem of disconnection between renewable-rich regions and demand centers.

Two problems arise from this division between renewable-rich regions and demand centers. First, when renewable supply exceeds local demand, electricity system operators have to curtail electricity generation from renewables to avoid system breakdowns, even though this means discarding what is essentially zero-cost, zero-emissions electricity. Second, with plentiful, near-zero cost electricity, the cost of electricity in these regions is very low, and sometimes negative. In other words, consumers are being paid to use electricity.

These two problems discourage both new entries and investment in renewable power plants. Indeed, many countries have started to realize these problems are among the first-order policy questions. For example, the Infrastructure Investment and Jobs Act in the United States, which became law in November 2021, includes significant investment in transmission line expansion and the development, demonstration, and deployment of clean energy technologies.

Research Design

The authors examine this challenge by providing theoretical and empirical analyses on the impacts of transmission build-out and renewable expansion in wholesale electricity markets. They begin by developing a simple theoretical model that characterizes the impacts of this renewable integration into the market. Market integration allows lower-cost power plants to export and replace production from higher-cost power plants, which improves efficiency. However, producers may also have the incentive to invest in new renewable capacity that will be more profitable as the market for it expands. This would add more renewable capacity to the market and decrease electricity costs.

The authors test these theoretical predictions by studying two large changes that recently occurred in the Chilean electricity market. Until 2017, two major electricity markets in Chile—Sistema Interconectado Norte Grande (SING) and Sistema Interconectado Central (SIC)—were completely separated with no interconnection between them. Recently, this separation was recognized as an obstacle to expanding renewable energy because renewable-intensive regions (near Atacama desert) are located far north from demand-centered regions (near Santiago, the capital city). To address this problem, the Chilean government completed a new interconnection between these two markets in November 2017, and an additional extension transmission line in June 2019.

The act of combining these two transmission networks into one provided the authors' with a unique research environment for comparing their model assumptions to a real-life scenario. The authors used hourly unit-level marginal cost, hourly node-level demand, hourly node-level market clearing prices, hourly unit-level electricity generation, and plant characteristics such as capacity, technology, year built, and investment to study the impacts of the integration.

Findings

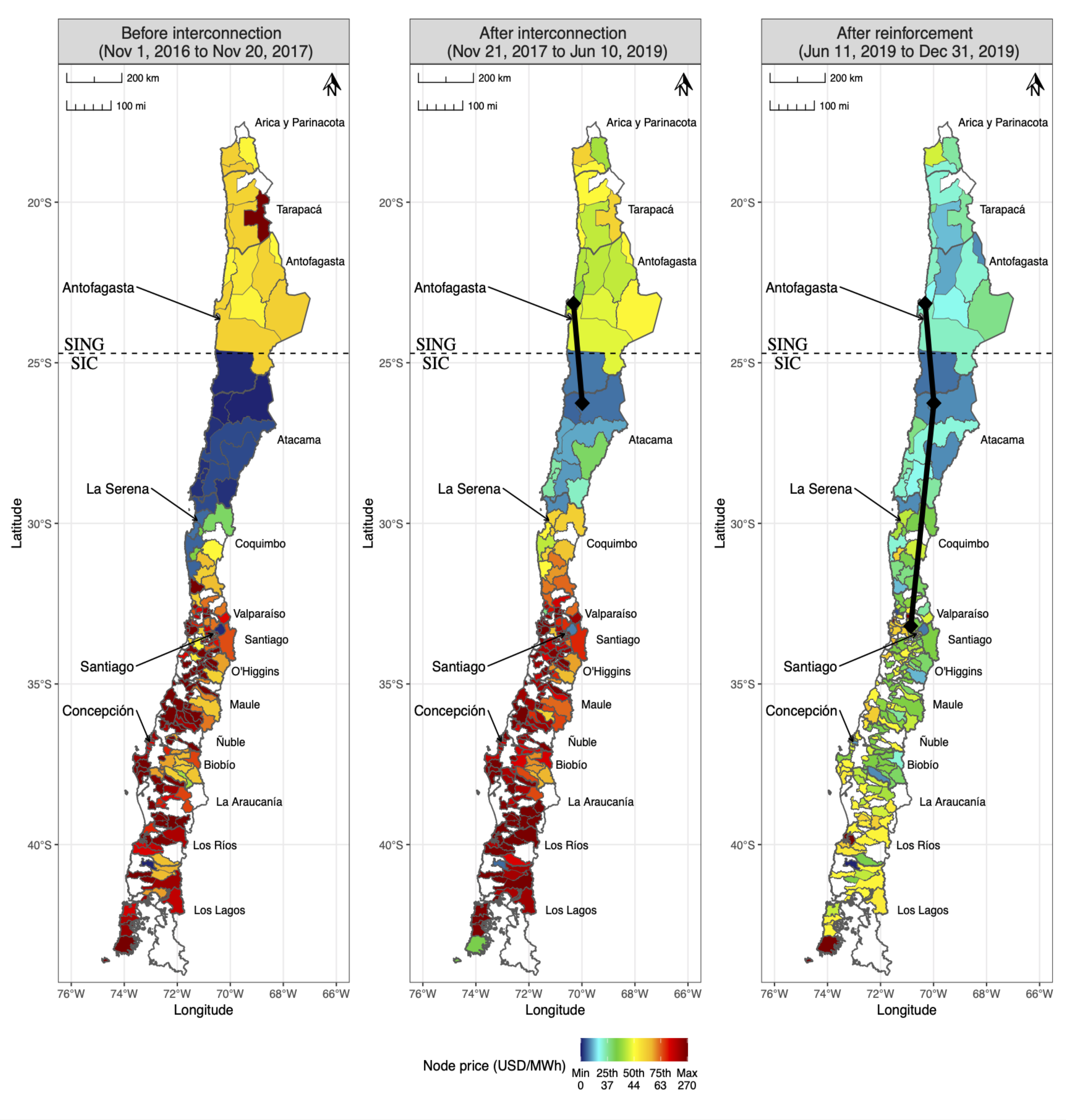
With a better-connected transmission grid, the price of electricity throughout the region becomes more balanced. When Chile had two separate grid systems, the price of electricity between the two regions was substantially different. For example, the node price of electricity at noon was $46.22 per megawatt hour on average in the renewable-rich SING region and $57.73 per megawatt hour on average in the SIC market before the market integration took place. Further, the renewable-rich Atacama desert (within SING) produced more solar than local demand. Once the two systems were integrated to become one system (SEN), the price difference leveled off, with the average node price for SEN being $50.16 per megawatt hour at noon. Prices increased in the renewable-rich areas and decreased in the demand centers far from renewables (i.e. in and around Santiago).

The grid expansion led to an increase in renewable generation and a decrease in the cost of electricity. First, the authors found that the market integration allowed lower-cost power plants, including renewables, to increase their production, which replaced production from higher-cost plants—providing empirical evidence for their theoretical prediction that gains from trade improve efficiency and cost.

Further, the authors examined how the market integration affected the entry of new renewable capacity. They discovered that a rapid growth in renewable capacity started right around the first announcement of the market integration in 2015, which was two years before the completion of the transmission line construction in

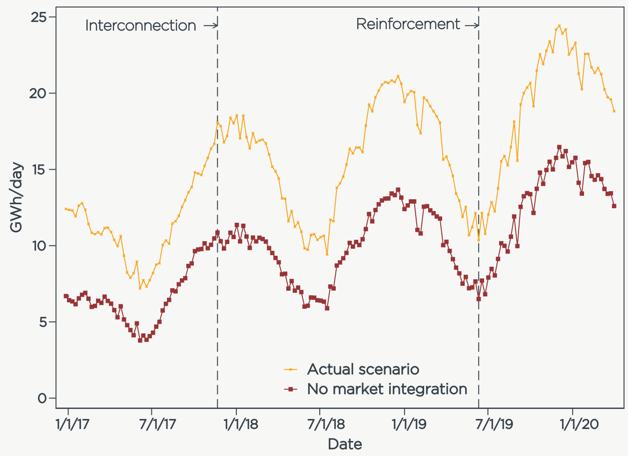
> "When weighing whether to invest in new transmission lines, policymakers should consider not only the direct benefits of carrying renewable energy to new areas, but also the fact that the expansion incentivizes the investment of new renewable power, becoming an important market force that leads to further decarbonization. These costs also pay back as fossil fuels get displaced, having the co-benefit of reduced air pollution and other environmental and health improvements."
>
> **KOICHIRO ITO, ASSOCIATE PROFESSOR, HARRIS SCHOOL OF PUBLIC POLICY, UNIVERSITY OF CHICAGO**

Figure 1 · Impacts of Market Integration on Spatial Variation in Electricity Prices



Note: These heat maps examine spatial heterogeneity in wholesale electricity prices. The authors calculate the province-level average node prices and make heat maps for the three time periods: 1) before the interconnection, 2) after the interconnection but before the reinforcement, and 3) after the reinforcement. They use the percentiles of the node price distribution to define color categories as shown in the legend. The maps also include names of regions, major cities, and the locations of the interconnection and reinforcement transmission lines.

Figure 2 · Solar Generation



Note: The authors use the structural model and counterfactual simulations to compute market equilibria for two scenarios. The first scenario is the actual scenario in which market integration happened (the interconnection in November 2017 and the reinforcement in June 2019). The second scenario is a counterfactual case in which the market integration did not happen, but the dynamic impact on power plant entry was incorporated—some entry would not happen in the absence of market integration because such investment would become unprofitable. This figure presents total electricity generation from solar plants (GWh/day) for these two scenarios. Each dot represents the weekly average of solar generation per day in GWh.

2017. In addition, they found that the prices in renewable-intensive regions were near zero during this rapid increase in renewable capacity and increased to a profitable level for renewables only after the market integration. This evidence suggests that renewable investors made their investment decisions based on the anticipation of the market integration. As a result of the integration, solar generation increased by 51 percent. Further, the cost per megawatt hour of electricity decreased by 12 to 5 percent.

The cost of the transmission expansion is quickly recovered due to the environmental and investment benefits. The cost of expanding the grid provides long-run benefits to consumers and investors. In the case of Chile, the increased investment in solar energy and decrease in fossil fuel energy led to an environmental and health benefit for consumers in the form of, for example, reduced air pollution. The authors find these factors allowed the cost of the grid expansion to be recovered in less than 5.5 years.

Policy Implications

The authors' build a theoretical model to show the impact of transmission grid expansion and renewable integration into a market and confirm the theoretical predictions from their model using empirical evidence from Chile—one of the very first countries to have tackled this problem by enhancing electricity market integration. The study finds that market integration not only helps renewable energy to be transmitted to demand centers but also incentivizes new entries and investment of renewables, which is a crucial market force to accelerate decarbonization. As nations throughout the world consider the build out of transmission infrastructure to spread the use of renewable energy, the findings and underlying model provide important insights. These insights could be useful, for example, in the United States where the Infrastructure Investment and Jobs Act contains a significant investment in transmission expansion and renewable energy.

About EPIC

The Energy Policy Institute at the University of Chicago (EPIC) is confronting the global energy challenge by working to ensure that energy markets provide access to reliable, affordable energy, while limiting environmental and social damages. We do this using a unique interdisciplinary approach that translates robust, data-driven research into real-world impacts through strategic outreach and training for the next generation of global energy leaders.