An analysis of causal relationships between electricity and fossil energy prices: Insights from Texas

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Overview

In global decarbonization efforts, the power sector plays a central role both as one of the largest sources of greenhouse gas emissions [1] and as a key enabler for decarbonizing hard-to-abate sectors through electrification [2]. To meet climate targets, a growing number of countries strive to increase the share of renewable energy sources (RES) in power production while implementing policies to retire carbon-intensive sources. With the rise of RES deployment, an important question is to what degree the electricity price dynamics continue to be driven by (or drive) fossil energy prices [3] and how the linkage between electricity and energy prices has evolved over time. Existing literature has explored these questions using a variety of modeling approaches. For instance, [4] analyzes the causal flows between fuel and electricity prices in the US using a vector error correction model, [5] applies a linear non-Gaussian acyclic model to examine the causal relationships in German and Nordic markets, and, more recently, [3] uses cointegration analysis to explore this relationship in Germany.

This study aims to advance previous research by leveraging state-of-the-art causal inference techniques to examine the more recent power market dynamics, shaped by an increasing share of RES and new natural gas market dynamics. Employing the recently introduced LPCMCI algorithm for time series [6], our analysis captures non-linear causal relationships and accounts for latent (unobserved) variables. We focus on the state of Texas, which provides an interesting case study owing to its abundant fossil fuel and renewable resources and growing investments in wind energy. Specifically, we analyze the causal relationships between (a) the Electric Reliability Council of Texas (ERCOT)'s daily average electricity prices and (b) major natural gas and oil price hubs over the period of 2019-2022. The results of this analysis shed light on the complex and time-evolving information flows and interdependencies between power and fossil fuel markets and provide new insights to policymakers, market participants, and other stakeholders in the context of the ongoing energy transition.

Methods

We start our study by compiling a database including the day-ahead ERCOT hub average price [7], WTI oil price [8], and natural gas prices in four major hubs: Houston Ship Channel (HSC), Waha, Katy, and Henry Hub (HH), which we extract from Refinitiv (LSEG) workspace for 2019 to 2022. For causal discovery, we apply the LPCMCI algorithm, which detects and quantifies causal relationships in multivariate time series while accounting for unobserved common causes (latent confounders) [6]. Available through the open-source package Tigramite [9], LPCMCI identifies both lagged and contemporaneous links. The final output of the algorithm includes the direction of the causal relationships and a matrix of p-values that allows an assessment of the strength of the causal effects. To test how the causal relationships may have changed with growing RES deployment (and other developments in Texas) over time, we apply a rolling-window procedure. Specifically, we track the evolution of causal relationships over 2-year periods (namely, 2019-2020, 2020-2021, 2021-2022). We analyze the causal graphs depicting the contemporaneous and lagged causal links found by LPCMCI, and compare the results across periods and against prior literature.

Results

In Fig. 1 we show the resulting causal graphs for the three periods under study. We first make the important conclusion that hub average electricity prices are causally driven by natural gas prices throughout the analyzed period despite the increase in the share of renewable energy production. This is because of the continued reliance of the power system on natural gas generation to meet system load. We do not find a causal link from electricity prices back to natural gas prices, indicating that, for now, the causal direction continues to flow from natural gas to electricity prices. Noteworthy, however, is the change in the gas hubs driving electricity price dynamics over time. As shown in Fig. 1, our results indicate that the HH prices causally influenced hub average electricity prices in the 2019-2020 and 2020-2021 periods but not in the period afterward. Similarly, the HSC prices are causally linked to the electricity prices in two of the three analyzed periods, while the (day-before) prices in the Katy hub appear to become causally relevant only starting from the 2020 period onwards.

With regard to the oil prices, we do not find any direct or indirect causal links between the WTI index and electricity prices. Similarly, we do not detect a link between WTI and natural gas prices— except for the Waha hub in the 2020-2021 period— consistent with previous findings on oil-gas price decoupling [11]. Finally, our analysis indicates the variant temporal dynamics in the causal relationships among major US natural gas hubs: the Katy price hub appears to be increasingly causally linked to the other major hubs, which aligns with the reported increase in liquidity in this hub [12].

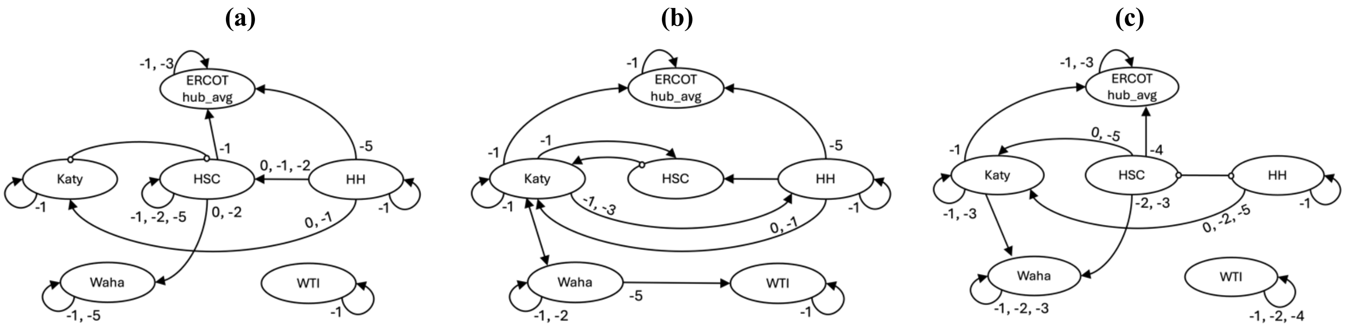

Figure 1. Causal graphs for periods of (a) 2019-2020, (b) 2020-2021, and (c) 2021-2022 at a significance level of 5%. The arrows depict the direction of causality, and the numbers next to the arrows represent the time lag. For example, {0, -1} indicates a contemporaneous causal link as well as a causal link with lag 1. This means that today's price of one variable has a direct causal effect on today's price of the other variable and on tomorrow's price of the other variable.

Conclusions

The ongoing energy transition in Texas, characterized by the increased share of RES in power generation, puts a question on the future relationships between electricity and fossil energy prices. In this study, we provide new insights into the evolution of price relationships in Texas by integrating advanced causal discovery methods. We find that the HH, HSC, and Katy natural gas prices continue to influence the hub average electricity prices in ERCOT. However, when moving the time window, we observe that the relative importance and influence of different natural gas price hubs on one another and electricity prices change. Our findings offer lessons for other markets and suggest that, in the future, the power market dynamics may be more influenced by factors critical for RES than fossil energy prices.

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