The impact of the coal-gas relative price on the CO_2 marginal abatement effect of renewable electricity in the US.

Félix Michelet, CERNA, Mines ParisTech - PSL, +33635266103, felix.michelet@mines-paristech.fr

Overview

Renewable electricity like photovoltaic (PV) and wind emits close to zero CO_2 per MWh of generated electricity. A short-term effect of their deployment on CO_2 emissions is that less thermal generation is needed, and therefore the associated emissions are abated. Indeed, for a constant level of electricity demand, generating an additional MWh of renewable electricity would offset one MWh of electricity produced most of the time with coal or gas, depending on gas and coal prices. The technology of the plant that is offset (called the marginal plant) is of importance, because coal-powered plants emit on average twice as much CO_2 as gas-powered plants. Therefore, offsetting electricity produced with coal would offset twice more CO_2 per MWh than electricity produced with gas.

Historically in the U.S., coal-powered plants were used for baseload and had lower marginal cost than gas-powered plants used for peakload. In this case, renewable electricity deployment offset mainly gas-powered plants. However, due to the shale-gas revolution led by the discovery of hydraulic fracturing extraction techniques, a dramatic decrease in natural gas prices has happened in the US the last decade. As a consequence, fuel switching between coal and gas happen and we expect the marginal plant to be more often powered with gas. In addition to this fuel switching, wind and solar generation have increased during the last two decades, driven by state-level renewable portfolio standards and investment tax credit. Understanding the environmental implications of this fuel switching phenomenon coupled with the increase of renewables capacity is important because electricity generation accounts for about a third of annual greenhouse gas emissions in the U.S. due to the use of coal and natural gas. According to Wilson and Staffel (2018), fuel switching in the power sector from coal to natural gas generation could be a game changer by delivering rapid carbon savings on the order of 1 $GtCO_2$ per year globally. This magnitude of potential savings leads us to wonder how renewables generation and fuel prices affect marginal CO_2 emissions on the short-run.

In our paper, we assess empirically the impact of the relative prices of coal and gas on the coal and gas-powered electricity generation, and on the CO_2 emissions from electricity production offset due to renewable electricity increase. In other words, we want to measure how the impact on CO_2 emissions of an additional MWh of renewable electricity vary with the coal and gas cost ratio.

We contribute to a recent literature on the effects of the Shale Gas Boom and of renewables capacity increase on electricity markets. Related work includes Holladay and LaRivier (2017), Fell and Kaffine (2018), Coglianese et al. (2020) and Gugler et al. (2020). Holladay and LaRivier (2017) find that the reductions in CO_2 emissions due to renewables deployment can be smaller with low gas prices. Fell and Kaffine show that the marginal CO_2 response to fuel prices is larger at higher levels of wind generation. Coglianese et al. estimate that the declining price of natural gas is responsible for 92 percent of the decline in coal production over the 2008-2016 period. Finally, Gugler et al. compare the electric generation sectors in Germany and in the UK as their mix are comparable but follow different carbon abatement policies. They find that high carbon prices (which is equivalent to low natural gas prices relative to coal) and renewable subsidization can be complementary in abating CO_2 emissions if the technology that is replaced at the margin by renewables deployment is coal. Our approach expands the literature by disentangling the effects of the relative prices of gas and coal and of wind generation, by taking into account capacity modifications, and by using more recent data.

Method

We use exogenous monthly variations in wind/solar electricity and coal/gas prices to estimate their impacts, individually and jointly, on coal/gas generation and emissions. We employ detailed monthly unit-level data from several sources. Thermal power plants generation data, PV/wind production data and electricity demand are extracted from the EIA-923 monthly survey. Capacity and vintage data are retrived from the EIA-860 survey and are displayed at the generator level. Thus, we aggregate the capacities at the plant level to merge them with the generation data, and we compute the capacity weighted average of the generators' vintage. Capacity considered is the nameplate capacity in megawatt. Coal and gas prices are extracted from the "Average cost of fossil fuels for electricity generation (per Btu)" EIA dataset and the EIA short-term energy outlook data browser.

CO_2 emissions data are collected from the EPA's Emissions & Generation Resource Integrated Database (eGRID). With this database, we compute the total CO_2 emissions for each plant on each month measured in tons as the generation weighted emissions.

It should be noted that over the period we study, new power plants are built and start operate, while others are temporally inactive for maintenance reasons, or definitely retired. Without taking these capacity modifications into consideration, we would find biased estimates. Therefore, we need to estimate both the extensive margin, i.e. the on/off decision, and the intensive margin which is our dependant variable variations conditional on the plant being operational. To do so, we estimate a Heckman two-steps model that delivers the full effect of our control variables which is composed of both the extensive margin and the intensive margin. This model first captures the decision to operate the plant or not, then it measures the effect of our control variables on the outcome variable conditional on operating. We run this procedure for the dependent variable being gas and coal-powered plants generation as well as CO_2 emissions.

Results and conclusion

We find two main insights. First, the main contributor of coal-based production decrease is the relative price of coal and gas and not renewables generation increase. In most regions, the decrease of coal generation is mainly compensated by gas production increase. We find that on average, an increase of the coal/gas cost ratio by 0.1 decreases total monthly coal-fired plants generation in a given CENSUS by 1.6 TWh and increases total monthly gas fired-plants generation by 1.5 TWh. We also find that wind and PV production decrease coal generation, and wind decreases gas generation in all CENSUS, meaning thermal production is indeed offset by renewables. However, PV is found to increase gas generation. A possible explanation is that gas plants that are quick to start are needed as a back up for PV production that is intermittent.
The second insight is that emissions decrease at an increasing rate with the cost ratio, and that wind and solar generation decrease also CO_2 emissions. As an exemple, in West South Central, increasing the cost ratio from 0.2 to 0.3 decreases the emissions of the marginal plant by 200tCO_2 monthly, while increasing the cost ratio from 0.5 to 0.6 decreases the emissions by 500tCO_2.
We also find that the interaction effect between relative fuel prices and renewables generation is negative and significant in regions with high wind or solar penetration. This interaction effect implies that cheaper natural gas relative to coal and greater wind or solar generation levels together lead to a greater reduction in emissions than either factor in isolation. Again in West South Central for an exemple, adding 1GWh of wind generation reduces the CO_2 emissions of the marginal plant by 350tCO_2 with a cost ratio of 0.2, and by 580 tCO_2 with a cost ratio of 0.5.
Our results have implications for other countries that do not experience such a decrease in gas prices but which have gas and coal-powered plants. Indeed, it means that a carbon price could have a greater effect on curbing emissions with additional renewable electricity production than without.

References

Coglianese, J., Gerarden, T. D., and Stock, J. H. (2020). The Effects of Fuel Prices, Environmental Regluations, and Other Factors on U.S. Coal Production, 2008-2016. The Energy Journal, 41(1)

Fell, H. and Kaffine, D. T. (2018). The Fall of Coal: Joint Impacts of Fuel Prices and Renewables on Generation and Emissions. American Economic Journal: Economic Policy, 10(2):90–116.

Gugler, K., Haxhimusa, A., and Liebensteiner, M. (2021). Effectiveness of climate policies: Carbon pricing vs. subsidizing renewables. Journal of Environmental Economics and Management, 106:102405.

Holladay, J. S. and LaRiviere, J. (2017). The impact of cheap natural gas on marginal emissions from electricity generation and implications for energy policy. Journal of Environmental Economics and Management, 85:205–227.

Wilson, I. A. G. and Staffell, I. (2018). Rapid fuel switching from coal to natural gas through effective carbon pricing. Nature Energy, 3(5):365–372.