THE CANNIBALIZATION EFFECT OF WIND AND SOLAR IN THE CALIFORNIA WHOLESALE ELECTRICITY MARKET

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Overview

Wind and solar technologies have the highest technical and sustainable potential (Jacobson and Delucchi, 2011; WBGU, 2011) to achieve a decarbonized electricity system. However, increasing shares of zero marginal cost electricity pressure wholesale electricity prices downwards (Clò et al., 2015; Cludius et al., 2014; Gelabert et al., 2011; Sensfuß et al., 2008; Woo et al., 2016), harming the unit revenues of renewable generator themselves, and jeopardizing their competitivenes when the technology-specific unit revenues decrease faster than the average wholesale electricity prices.

We investigate the absolute and relative "cannibalization effect" of wind and solar by estimating how much technology-specific unit revenues (absolute cannibalization) and value factors (relative cannibalization) decline as wind and solar penetration increase. Market penetration is defined as the share of solar/wind over the total electricity demand, and the solar/wind market value factor is defined as the solar/wind-generation weighted electricity price (unit revenue of solar/wind producers) over the average wholesale electricity price (Hirth, 2015, 2013).

Methods

We build a time series econometric model for the period January 2014 - July 2017 with data from the California Independent System Operator (CAISO) and the Energy Information Administration of the USA (EIA). We calculate daily technology-specific unit revenues (UR) and value factors (VF) from hourly data of the day-ahead electricity market (eq. 1), which are then regressed on wind and solar penetration, gas price and demand, as well as a vector of daily, monthly and yearly dummies to account for seasonality (eq. 2 for the dependent solar value factor)

$$VF_t^s = \frac{UR_t^s}{\bar{p}_t} = \frac{[\sum_{h=1}^{24}(S_h * p_h)]/\sum_{h=1}^{24} S_h}{\sum_{h=1}^{24} p_h/24} \quad (1)$$

$$VF_t^s = \alpha + \beta_1\, Solar\_sh_t + \beta_2\, Wind\_sh_t + \beta_3\, Gas\_price_t + \beta_4\, Demand_t + \gamma D_t + \varepsilon_t \quad (2)$$

This simple model allows us to estimate not only the effect of solar and wind penetration on their own unit revenues and value factors, but also the cross-effects between technologies. We estimate the model first with data from centralized installations from CAISO. However, since distributed solar generation accounts for about a third of total solar generation, we interpolate daily solar distributed generation from monthly EIA generation data and then run the model again including not only centralized but also distributed solar generation. We find that omitting distributed generation (as usually done in the literature) cause bias and overestimation of the effect of solar penetration. Once we have estimated the parameters for the whole dataset, we investigate how the effect of solar/wind penetration changes depending on demand and penetration level to explore potential non-linearities.

Results

Our results confirm the absolute cannibalization effect of wind and solar (i.e. increasing their penetration lowers their respective unit revenues). This effect is stronger for solar than for wind. Regarding cross-effects between both technologies, wind causes the decrease of solar unit revenues, but we cannot confirm that solar affects the wind unit revenues. In general, the absolute cannibalization effect is just a reflection of the aforementioned merit-order effect.

The relative cannibalization effect (i.e. decreasing value factor (eq. 1) as penetration increases, see Fig. 1) is more relevant since it determines the value of variable renewables in comparison with dispatchable technologies. We find that solar penetration causes the decline of the solar value factor. This effect, contrary to suggested by previous literature, increases with penetration. The wind relative cannibalization effect is only significant when demand is low and penetration high. Regarding cross-cannibalization, while wind penetration causes the decline of the solar value factor (in a lower extend than solar penetration itself), solar seems to increase the wind value factor when penetration is high and demand low, or be insignificant otherwise. This would explain the increase of the wind value factor despite the increase in wind penetration, and is probably caused by the price "duck curve" oberved in the day ahead

hourly electricity market, through which electricity prices plummet at noon due to high solar penetration, but spike after sunset due to the demand ramp up.

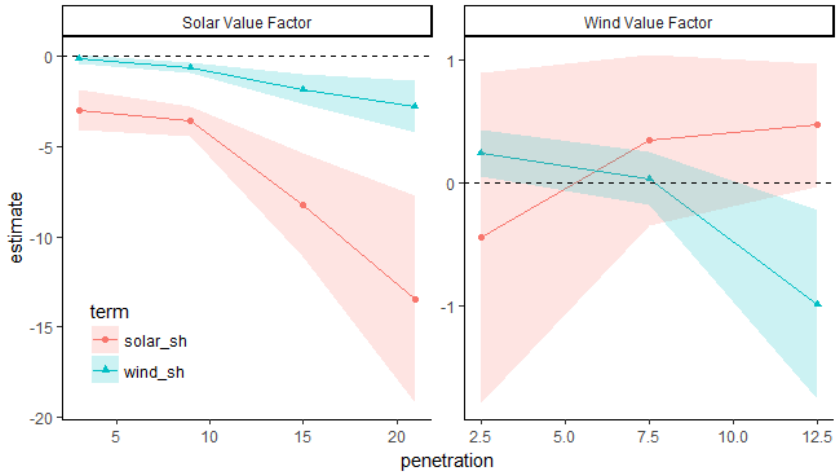

Figure 1. Relative cannibalization effect: marginal effect of solar and wind penetration (solar_sh and wind_sh respectively), at different penetration levels, on their respective value factors. Regression results (eq. 2) at 95% confidence.

Conclusions

This study confirms the absolute and relative cannibalization effect of solar and (in a lower extent) wind in the wholesale electricity market. Wind is more resilient than solar in this sense, because its cannibalization is lower (probably due to the lower concentration of its generation pattern), and because solar penetration has a positive effect on the wind value factor. This results are useful to shed light on the value of variable renewables and on the inadecuacy of the current marginal wholesale electricity market to incorporate large shares of variable renewables. Besides, the value factor is necessary to calculate the value-adjusted LCOE in order to make fair comparisons between conventional and renewable technologies.

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