How flexible electricity demand stabilizes wind and solar market values: The case of hydrogen electrolyzers

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Link to published working paper

Overview

Wind and solar energy are often expected to fall victim to their own success: the higher their share in electricity production, the more their revenue on electricity markets (their "market value") declines (e.g. Grubb, 1991; Joskow, 2011; Hirth, 2013). This "self-cannibalization" effect is substantial. At an assumed 30% market share, the market value of wind energy is estimated to decline by 20-50%; the value of solar energy may decline even more (Hirth, 2013). As a result, it has often been thought that renewable investors cannot recover their costs on the market alone and that renewable support schemes will need to continue indefinitely (Clò and D'Adamo, 2015; Green and Léautier, 2015; Blazquez et al., 2018; Chyong et al., 2019).

Meanwhile, using renewable electricity in electrolyzers to produce hydrogen without the emission of carbon has recently become increasingly popular, and the investment cost of electrolyzers is expected to decrease (International Energy Agency, 2019). Not only could electrolytic hydrogen substitute fossil fuels in non-electric applications, but also could a flexible operation of electrolyzers help the market integration of variable renewables by absorbing wind and solar energy when and where it is abundant (Ruhnau et al., 2019; Roach and Meeus, 2020). Previous studies have investigated the competitiveness of green hydrogen versus hydrogen produced from fossil fuels, but electrolyzers have not yet been the focus of the literature on mitigating the decline in the value of renewable energy.

In this study, I argue that hydrogen electrolysis – as an ideal type of flexible electricity demand – can effectively and permanently halt the decline in the market value of renewables. This is because low wholesale electricity prices caused by renewables trigger merchant investment in electrolyzers, which produce hydrogen whenever electricity prices are low, and because the electrolyzers' additional electricity demand in turn stabilizes market prices and with them the value of renewables. More generally, this study contributes to the literature on how flexible electricity demand can help integrating variable renewable supply. This study on hydrogen complements and contrasts with previous results on flexible demand for heating and transport (Ruhnau et al., 2020; Bernath et al., 2021)

Methods

First, I introduce an analytical framework for market-based dispatch of and investment in hydrogen electrolyzers. Within this framework, I derive a simple formula for the minimum market value of renewables based on equilibrium conditions between renewable energy supply and electrolyzer dispatch and investment decisions.

Second, I use Monte Carlo simulations to quantify the minimum market value for a wide range of assumptions on renewable profiles, hydrogen prices, and electrolyzer investment cost, inter alia. Sensitivity analyses are carried out to identify key influencing factors on the hydrogen-induced minimum market value of renewables.

Third, a more detailed electricity market model is employed to put the simplistic estimates of the minimum market value into perspective. The model is parametrized to the Northwesten European power system and calculates renewable market values for different market shares – with and without hydrogen electrolyzers.

Results

The Monte Carlo simulation reveals that – due to flexible hydrogen production alone – market values across Europe likely converge above €19 ± 9 MWh^{-1} for solar energy and above €27 ± 8 MWh^{-1} for wind energy in 2050 (annual mean estimate ± standard deviation). This is a lower boundary in the sense that other options for integrating variable renewables, including other types of flexible electricity demand, may further increase the market value.

The numerical market model confirms this estimate: with perfectly flexible electrolyzers, market values converge above the analytically derived minimum (Fig. 1, H2 flex); without electrolyzers, the decline continues (no H2). When accounting for the cost of hydrogen storage, the positive effect of electrolyzers decreases (H2 storage), but it is still substantial when compared to the case without or with inflexible electrolyzers (H2 inflex).

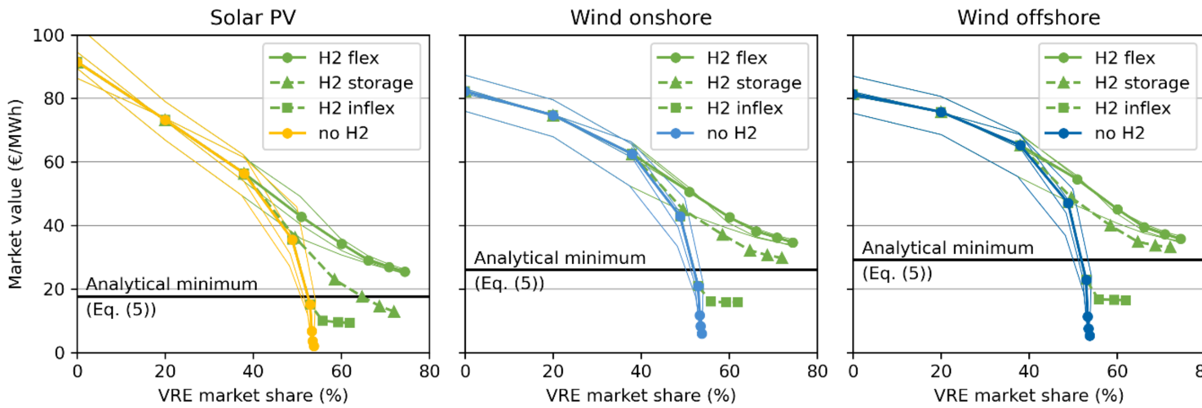

Figure 1: The impact of flexible electricity demand from hydrogen electrolyzers on the market values of variable renewable energy sources (VRE).

Conclusions

This study demonstrates that, even in electricity systems with very high shares of variable generation at zero marginal cost, the market value of VRE (and market prices in general) will not necessarily fall to zero. Instead, hydrogen electrolyzers can stabilize market values in the range of projected levelized cost (International Renewable Energy Agency, 2019a, 2019b). This finding has profound implications: by 2050, investment in renewables may be less in need of guaranteed state support than often thought.

At the same time, electrolytic hydrogen becomes more economical at higher renewable market shares. However, hydrogen production is only one example of flexible electricity demand, and the presented framework may be extended and adapted to other applications, including electric heating, transport, and industry. Eventually, different applications will compete for using renewable electricity when electricity prices are low, jointly contributing to stabilizing the market value of renewables.

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