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The market value of renewable electricity – Which factors really matter?

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HIGHLIGHTS

- The market value measures the revenues of renewable electricity.
- The relative importance of different factors for its development is analyzed.
- The market value is mainly influenced by generation mix, fuel and CO_2 prices.
- Flexibility options become relevant at high shares of renewable electricity.

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ABSTRACT

The development of renewable energy technologies, their future market integration, and support scheme design depends crucially on the market value of electricity from renewable sources. The literature shows that there are many factors that potentially influence these market values. However, existing studies are limited in mostly just analyzing the influence of these factors individually or at most the combined effects of only two factors. In this study, a large number of scenarios for possible future electricity systems and the resulting market values are calculated. Results are assessed using descriptive statistics and regression analysis to identify the most important factors influencing market values. Therefore, we are able to quantitatively analyze the individual impacts of a complex combination of flexibility options, which can facilitate more informed strategies by policy markers, regulators, and market participants regarding system flexibility options. We show here that the development of CO_2 and gas prices, as well as the conventional capacity mix is crucial for the development of renewable electricity market values. System flexibility including must-run requirements, heat grids and electric mobility become relevant at higher technology-specific market shares for both photovoltaics and onshore wind. Storage only influences photovoltaics market values even though assumed storage capacities and volume are high.

1. Introduction

Shares of electricity generated from renewable energy (RE) sources are increasing globally. The most important renewable technologies, wind and solar, have close to zero marginal costs and are variable in nature. As a consequence, their revenue depends on the covariance of market price developments and weather patterns. The market revenues of variable renewable sources tend to be lower than the average market prices, at least at rising renewable shares, due to their low marginal costs and the price reducing effect at electricity markets – on account of the so-called merit-order-effect [1,2].

Absolute and relative market values are used to determine the market revenues of renewables. The average revenue per unit of energy is defined as the 'market value' or 'absolute market value' of renewables. Its percentage deviation from the overall average electricity price is defined as the 'relative market value' or 'market value factor'. The mathematical formulas for both types of market values are shown in Eqs. (1) and (2):

Absolute market value

$$MV_{abs} = \frac{\sum_{h=1}^{n} p_h \times f_h}{f_m} \quad (1)$$

MV_{abs}: absolute market value
h: hour
n: number of hours in respective month
m: month
p: electricity market price
f: feed-in/generation of renewable plant

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Relative market value

$$MV_{rel} = \frac{\sum_{h=1}^{\infty} p_h \times f_h}{\bar{p}_m \times f_m} \quad (2)$$

MV_{rel}: relative market value

This study focuses on the development of absolute market values since the absolute market value compared to generation costs indicates in how far renewables will be able to pay for themselves at regular electricity markets. The question is whether renewables will be profitable at regular electricity markets without additional support in the medium to long term. However, even if renewables are able to pay for themselves at regular electricity markets on average, this might not lead to high deployment rates without support due to higher risks involved when investing in RE as shown by Tietjen et al. [3]. Bunn and Yusupov [4] argue that the risk return profile of renewables becomes even less attractive over time as the merit order effect decreases market incomes. A number of authors therefore argue that electricity markets need to adapt to the requirements of renewables in order to enable profitability [5]. For instance, RE revenues at current electricity markets could possibly be increased by allowing for their participation in balancing markets and other market segments (see for example [6]). All these considerations are however not implemented in the modeling for this paper.

A number of studies analyze the development of market values of variable renewables. As different input data and methodologies are used, the absolute figures regarding market values in the different studies vary considerably. All authors agree however that all else equal market values decrease when technology-specific market shares increase [7–9,45].

In addition, some authors identify and analyze additional influencing factors for the development of market values.

Some of these influencing factors can be summarized under market design elements. First, Brown and Rowlands [10] find that nodal pricing can increase renewable market values. Second, market power increases market values of renewables but reduces market value factors.[1] renewables profit from peak prices to a lesser extent than conventional plants due to their generation pattern [11–13]. Also, capacity-based rather than generation-based support schemes imply higher market values with feed-in premiums outperforming fixed feed-in tariffs in that regard [14–16].

Technical characteristics also influence the market value of renewables. Hirth and Müller [17] found that system-friendly wind turbines, i.e. turbines reaching higher full load hours and capacity factors, with higher full load hours have higher market values than other wind turbines. The same is true for offshore wind market value factors [18]. Photovoltaic (PV) market value factors are found to be above wind value factors at low penetration rates due to higher covariance to demand patterns but decrease more sharply as renewable shares increase [19,20]. Tilt angles of PV are also found to have an effect on market values but the effect is estimated to be small (<1%) [21]. Capellaro [22] stresses that wind market values are site-specific and average values measured at the macroeconomic level are not sufficient for assessing specific investments.

Another group of influencing factors form part of system flexibility. Reducing the must-run requirements and ramping times of conventional capacities is found to increase market values [12,14,17,23–25]. Demand side flexibility is also supporting the market values of renewables especially at higher penetration levels [12,26,27]. Storage increases market values of PV and, to a much lesser extent, those of wind power [12,14,19,23,25,28,29]. Khatib and Difiglio [30] also mention that CO_2 pricing and large storage facilities increase the attractiveness of renewables but without quantifying the effect. The influence of interconnector capacities on the market value of wind power depends on the correlation of wind power output between countries. According to Obersteiner [31] and Hirth [23], wind market values increase with higher interconnection capacities but not necessarily in all countries involved. The effect for solar market values is much less pronounced according to Hirth [19]. Höfling [12] and Nicolosi [14] assume lower renewable shares in neighboring countries, and in this case, interconnection capacity increases market values substantially. Winkler et al. [25] found that increasing interconnection capacity has a positive impact on market values in Germany, even if other European countries also have high renewable shares. Tveten et al. [32] showed that interconnecting thermal and hydro power regions increases absolute market values in all regions involved with relative market values decreasing in hydro power regions. Steen et al. [33] showed for the Nordic power system that a link to the heating sector increases or decreases market values depending on the market zone where the plant is located. Winkler et al. [25] however found a very important positive impact of a link to the heating sector for wind market values and a lower positive effect for PV market values. The access of PV and wind plants to flexible demand assets also has a positive effect on market values according to Garnier and Madlener [34]. However, additional revenues might not be sufficient to incentivize demand side flexibility.

Market values are also impacted by fuel and CO_2 price. CO_2 prices are identified as a driver for market values by many authors [12,19,23,24,30,35]. The level of their effect is however not clear. While some authors find a very large positive impact, others only find a small effect. In some cases, there is even a negative effect of rising CO_2 prices due to resulting adaptations of the conventional energy system (specifically lignite with CCS). The effect of fuel prices is also not clear. Hirth [19] finds that an increase in coal prices implies a higher market value factor while an increase in gas prices reduces the market value factor. According to Höfling [12], an increase in fuel prices has no clear effect on market value factors.

Interactions between various influencing factors are mentioned by only a few scholars. Hirth and Müller [17] found that when an electricity system is flexible – including storage, high interconnection capacity, and flexible plant operation – the additional increase in market value by installing system-friendly wind turbines is reduced from 11% to 5%. Winkler et al. [25] compared the effect of increased interconnection with those of increased storage and conclude that interconnection cannot be adequately replaced by storage even if extremely high storage capacities are assumed. These first analyses show the benefits of investigating these interactions, as this allows for increased understanding of the importance of individual influencing factors.

However, so far there exists no structural assessment of the relative importance of a bigger number of influencing factors, nor comparison of the extent of their influence. The relative importance of influencing factors for the absolute market value is important for both policy makers and practitioners as a better understanding of these factors will lead to adequate support and implementation of regulations that maximize the profitability of renewable generation technologies. This efficiency in turn can mitigate policy costs for renewable energy deployment. For practitioners i.e. industry or other providers of system flexibility, the knowledge of the relative importance of different influencing factors helps to derive better strategies in that the full complexity of their investment and operation decisions can be more clearly understood and considered. Simplistic and isolated approaches

[1] Plants with market power are able to increase prices above general costs when they are online and price-setting. This happens mostly in hours with scarcity. Renewables profit from the resulting high prices but to a lesser extent than conventional power plants as typically the generation from varable renewable is low in hours with scarcity. As a consequence, the revenue of renewable (absolute market value) increases while their revenue relative to the revenue of conventional power plants (relative market value) decreases.