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The market value of variable renewables☆,☆☆
The effect of solar wind power variability on their relative price

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ABSTRACT

This paper provides a comprehensive discussion of the market value of variable renewable energy (VRE). The inherent variability of wind speeds and solar radiation affects the price that VRE generators receive on the market (market value). During windy and sunny times the additional electricity supply reduces the prices. Because the drop is larger with more installed capacity, the market value of VRE falls with higher penetration rate. This study aims to develop a better understanding on how the market value with penetration, and how policies and prices affect the market value. Quantitative evidence is derived from a review of published studies, regression analysis of market data, and the calibrated model of the European electricity market EMMA. We find the value of wind power to fall from 110% of the average power price to 50–80% as wind penetration increases from zero to 30% of total electricity consumption. For solar power, similarly low value levels are reached already at 15% penetration. Hence, competitive large-scale renewable deployment will be more difficult to accomplish than as many anticipate.

1. Introduction

Electricity generation from renewables has been growing rapidly during the last years, driven by technological progress, economies of scale, and deployment subsidies. Renewables are one of the major options to mitigate greenhouse gas emissions and are expected to grow significantly in importance throughout the coming decades (IEA, 2012; IPCC, 2011). According to official targets, the share of renewables in EU electricity consumption shall reach 35% by 2020 and 60–80% in 2050, up from 17% in 2008.[1] As hydropower potentials are largely exploited in many regions, and biomass growth is limited by supply constraints and sustainability concerns, much of the growth will need to come from wind and solar power. Wind and solar are variable[2] renewable energy sources (VREs) in the sense that their output is determined by weather, in contrast to "dispatchable" generators that adjust output as a reaction to economic incentives. Following Joskow (2011), we define the market value of VRE as the revenue that generators can earn on markets, without income from

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[1] National targets for 2020 are formulated in the National Renewable Energy Action Plans. Beurskens et al. (2011), Eurelectric (2011a), PointCarbon (2011) and ENDS (2010) provide comprehensive summaries. The EU targets for 2050 have been formulated in the European Commission (2011). Historical data are provided by Eurostat (2011).

[2] Variable renewables have been also termed intermittent, fluctuating, or non-dispatchable.

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subsidies. The market value of VRE is affected by three intrinsic technological properties:

- The supply of VRE is variable. Due to storage constraints and supply and demand variability, electricity is a time-heterogeneous good. Thus the value of electricity depends on when it is produced. In the case of VRE, the time of generation is determined by weather conditions. Variability affects the market value because it determines when electricity is generated.
- The output of VRE is uncertain until realization. Electricity trading takes place, production decisions are made, and power plants are committed the day before delivery. Forecast errors of VRE generation need to be balanced at short notice, which is costly. These costs reduce the market value.
- The primary resource is bound to certain locations. Transmission constraints cause electricity to be a heterogeneous good across space. Hence, the value of electricity depends on where it is generated. Since good wind sites are often located far from load centers, this reduces the value of wind power.[3]

We use a framework introduced in Hirth (2012a) and compare the market income of a VRE generator to the system base price. The system base price is the time-weighted average wholesale electricity price in a market. The effect of variability is called "profile costs", the effect of uncertainty "balancing costs" and the effect of locations "grid-related costs" (Fig. 1). We label these components "cost" for simplicity, even though they might appear as a discount on revenues and not as costs in a bookkeeping sense.

Profile, balancing, and grid-related costs are not market failures, but represent the intrinsic lower value of electricity during times of high supply, at remote sites, and the economic costs of uncertainty.

In this paper, we focus on the impact of variability on the market value of VRE, leaving uncertainty and location for further research. The reason for doing so is that in a broad literature review we have identified profile costs as the largest cost component and found this topic under-researched relative to balancing costs (Hirth, 2012a).

The market value of VRE will be measured as its relative price compared to the base price. We call this relative price "value factor"[4] and define it more rigorously in Section 3. The value factor is calculated as the ratio of the hourly wind-weighted average wholesale electricity price and its time-weighted average (base price). Hence the value factor is a metric for the valence of electricity with a certain time profile relative to a flat profile (Stephenson, 1973). The wind value factor compares the value of actual wind power with varying winds with its value if winds were invariant (Fripp and Wiser, 2008). In economic terms, it is a relative price where the numeraire good is the base price. A decreasing value factor of wind implies that wind power becomes less valuable as a generation technology compared to a constant source of electricity.

There are two mechanisms through which variability affects the market value of renewables in thermal[5] power systems. We label them "correlation effect" and "merit-order effect". If a VRE generation profile is positively correlated with demand or other exogenous parameters that increase the price, it receives a higher price than a constant source of electricity (correlation effect) — as long as its

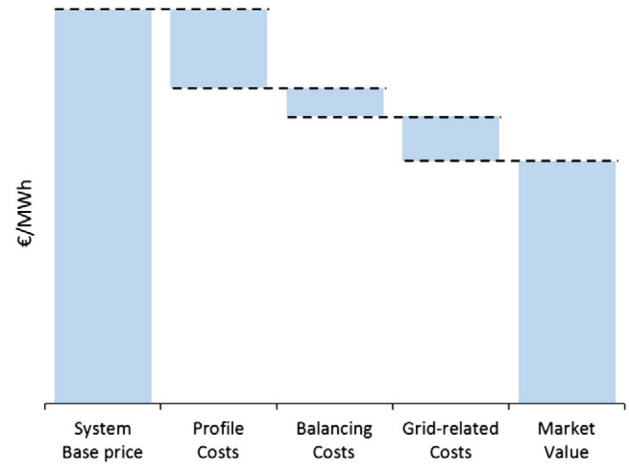

Fig. 1. The system base price and the market value of wind power. The difference between those two can be decomposed into profile, balancing, and grid-related costs.

capacity remains small. For example, while the 2011 base price in Germany was 51 €/MWh, solar power received an average price of 56 €/MWh (a value factor of 1.1) on the market, because it is typically generated when demand is high. In Europe, there is a positive correlation effect for solar due to diurnal correlation with demand, and for wind because of seasonal correlation.

However, if installed VRE capacity is non-marginal, VRE supply itself reduces the price during windy and sunny hours by shifting the residual load curve to the left (merit-order effect, Fig. 2). The more capacity is installed, the larger the price drop will be. This implies that the market value of VRE falls with higher penetration. The figure also suggests that the price drop will be larger if the merit-order curve becomes steeper in the relevant region. The fundamental reason for the merit-order effect is that the short-term supply function is upward sloping because a) there exists a set of generation technologies that differ in their variable-to-fix costs ratio and b) electricity storage is costly.

More generally, it is of course a well-known economic result that the price of a good decreases as supply is increased.

Profile costs have important implications for policy makers, investors, and energy system modelers alike. In a market environment, investors

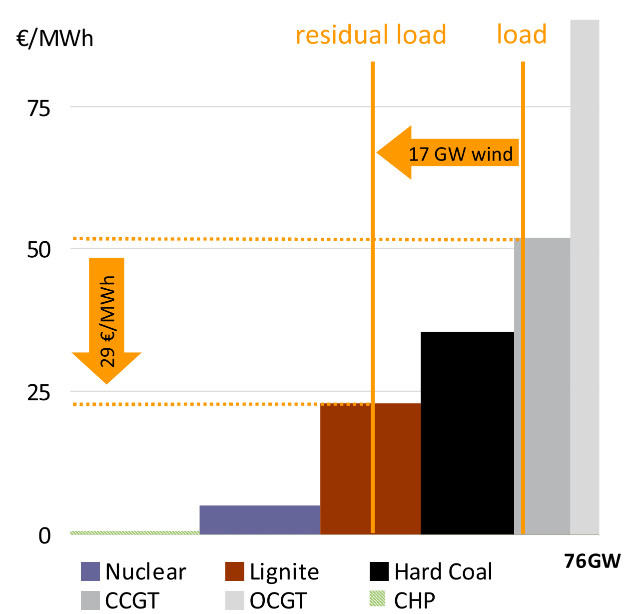

Fig. 2. Merit-order effect during a windy hour: VRE in-feed reduces the equilibrium price. Numbers are illustrative.

[3] Of course all types of generation are to some extent subject to expected and unexpected outages and are bound to certain sites, but VRE generation is much more uncertain, location-specific, and variable than thermal generation. Also, while weather conditions limit the generation of wind and solar power, they can be always downward adjusted and are in this sense partially dispatchable. The fourth typical property of VRE that is sometimes mentioned (Milligan et al., 2009), low variable costs, does not impact the value of electricity.

[4] In the German literature known as "Profilfaktor" or "Wertigkeitsfaktor."

[5] "Thermal" (capacity-constrained) power systems are systems with predominantly thermal generators. These systems offer limited possibility to store energy. In contrast (energy-constrained) "hydro" systems have significant amounts of hydro reservoirs that allow storing energy in the form of water.