The Impact of Wind Power Support Schemes on Technology Choices

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1 Introduction

Since 2000, global deployment of renewable energies such as wind and solar power has grown strongly. Germany has been at the forefront of this development, undergoing the *Energiewende*, which is facilitating the country's transition to renewable energy. These provided about 32.5 % of Germany's gross electricity consumption in 2015 (AG Energiebilanzen, 2015). The official national goal is a renewable share of at least 80 % by 2050. To achieve this, the German government targets an annual capacity increase in the order of 2.8-2.9 GW in onshore wind (Bundestag, 2016).

However, the volatile power generation of solar and wind power poses new challenges and costs to an energy system built for thermal power plants. In times of little sunshine and generally low wind speeds, back-up capacity, storage and demand side response measures can be required in order to meet the - rather inelastic - demand for electricity.

Yet, there is also the option to directly address the volatile generation from renewables. For solar, alternative orientations facing east and west are discussed in this context, so that the power is supplied more smoothly throughout the day, cp. Fraunhofer-Institut für Solare Energiesysteme ISE (2014). For wind power, where the vast majority of electricity is currently produced in high wind, recently debated *system-friendly* turbines can serve this purpose. These have a larger share of their production in low and medium wind, i.e. when less wind power is in the system. *Ceteris paribus*, a lower supply of wind power means a lower supply of electricity, such that the price-setting power plant has a higher marginal cost. Additionally, such system-friendly turbines make better use of existing infrastructure, since their

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maximum output is *ceteris paribus* lower, so that there is less need for grid expansion and lower integration costs accrue. For the purpose of this study, only the increase in achievable market prices is analyzed, as avoided costs for grid expansion, integration, storage, back-up capacity and demand side responses are hardly quantifiable. These benefits would persist if all new installations shifted to system-friendly turbines. If these benefits could also be captured in this analysis, the *optimally*-deployed turbines would be more system-friendly than what is identified here.

Whether investors choose system-friendly turbines depends on the policy scheme. Originally, fixed *Feed-In-Tariffs* (FIT) were the method of choice for increasing capacity of solar and wind power. Through the Renewable Energy Sources Act, a German FIT policy was introduced in 2000. Under the FIT, investors receive a specific remuneration per produced kWh. Thus, the more electricity they produce, the higher the absolute amount of remuneration received.[1] As this remuneration is the only source of revenues, investors are indifferent to the actual electricity wholesale prices. Yet, the wholesale price reflects, to a certain degree, if supply is low and demand is high. In times of a relatively low power supply, prices will *ceteris paribus* be higher, and vice versa prices are lower in relatively high supply. Summarized, fixed FITs provide investors with a high degree of certainty, but little incentives to install system-friendly wind turbines.

The *floating Market Premium Scheme* (MPS) aims to bring the wind power supply closer to demand. Germany first introduced the MPS on a voluntary basis in 2012, and made it obligatory in August 2014, thus abolishing the fixed FIT except for very small installations. The floating MPS exposes operators to the wholesale electricity price and in addition to a premium (Gawel and Purkus, 2013). The overall payment is based on how strongly a turbine's generation correlates with overall wind power production, and whether deviations from it occur in hours of lower or higher electricity prices. Therefore, the covariance between a turbine's electricity generation with the overall German wind power feed-in plays an important role in determining an investor's revenues (Schmidt et al., 2013).

This covariance with the overall German wind power feed-in is potentially influenced by the location. Grothe and Müsgens (2013) find that under the MPS, locations in Germany gain or lose to different degrees, depending on their correlation with the overall German feed-in. Schmidt et al. (2013) analyze

[1]Due to the adjustments of the production volume-based benchmark approach, this does not exactly hold true in Germany. Higher generation can lead to a shorter extension of the higher FIT, and thus can also partially lower remuneration, see May (2015)

the covariance between the generation at Austrian sites with overall generation, and find that under an MPS, the optimal allocation of turbines differs compared to the optimal allocation under a FIT.

Tisdale et al. (2014) analyze how MPS influence the reliance on project finance for investors. They find that the MPS incurs additional risks to investors. The remuneration is potentially lower compared to FITs. Therefore investors' return on investment requirement is higher under MPSs than under FITs. In order to have access to such cheap debt, investors are bound to conservative estimates of their future cash flows, as these are usually the only source from which creditors are paid (Tisdale et al., 2014). Bürer and Wüstenhagen (2009) find that especially European investors prefer the secure revenue streams from FITs over MPS.

The prevailing policy regime also potentially affects the turbine technology deployed, yet the consequences of the shift towards the MPS are not clear. Öko-Institut (2014) assume perfect foresight on the investors' side, yet find a minimal impact. However, they enable investors to only choose between two turbine models, so that no gradual changes are observable.

In 2015, installed turbines in Germany were more system-friendly compared to previous years (Deutsche WindGuard, 2015). This development can be driven by several reasons: A generally different investment environment, the (initially voluntary) introduction of a floating market premium scheme in 2012, and the supply-side availability of more system-friendly turbines. Fraunhofer IWES (2013b) states that there is no clear evidence that turbine technologies in wind-rich regions have changed, but primarily became more specialized at low wind speeds at low-wind sites. In contrast, Fraunhofer IWES (2015) find that also at sites with intermediate wind conditions, more system-friendly turbines have gained in popularity. Among others, Deutsche WindGuard (2014), Molly (2011, 2012, 2014), Fraunhofer IWES (2013a,b) and Hirth and Müller (2016) argue that more system-friendly turbines than the current standard would benefit the energy system as a whole.

One so-far neglected aspect is the question of how the *system-optimal* turbine should be defined. The aforementioned authors primarily state generally that more system-friendly turbines benefit the system. Only Molly (2012) defines an optimality criterion: The costs for a turbine which is combined with a storage, in order to perfectly smoothen the power generation over the year. However, this introduces excessive costs since the power production of any individual turbine need not necessarily be smooth. Alternatively, I define the system-optimal turbine to minimize the discounted difference between costs per kWh and the expected electricity value, i.e. price, per kWh.[2] This difference sets the subsidy level, such that the required subsidy is minimized. The turbine which optimizes this criterion is considered *system-optimal*.

This study assesses the impact of different policy measures such as the MPS on investors' technology choices. By applying the optimality criterion, I scrutinize how close these technologies get to this system-optimum. Knowing about the effects on risk and locational choices, I analyze the effect of the MPS on investors' technology choices and the channels through which such effects can be induced. This is conducted by modeling investors' investment optimization problem. As in Schmidt et al. (2013) and Grothe and Müsgens (2013), investors are assumed to maximize the net present value (NPV) of their investment, treating the prevailing policy scheme as exogenously given. Yet, since investors depend on risk-averse project-finance, I assume they cannot integrate long-term expected power market changes into their investment decision and thus base it on the current power price profile. Furthermore, unlike Grothe and Müsgens (2013), Schmidt et al. (2013) and Öko-Institut (2014), who take only one to two turbine types into account, I analyze investors who are free to choose from more than 140 turbine configurations. Importantly, I extend the analysis of Schmidt et al. (2013), who find that the covariance between turbines' production and the overall wind power supply affects the NPV. I allow for this difference in covariances not only to occur between turbine locations, but also between turbine technologies.

Furthermore, I suggest and model a new alternative policy, the *production value-based benchmark approach*. Based on a model of the future energy system, it *a priori* adjusts a turbine's remuneration level depending on its production's future market value. Thus, it replicates the cost-covering nature of the existing production *volume*-based benchmark approach (where remuneration is adjusted to the location, see (May, 2015)) and applies it to the turbine configuration and thus system-friendliness of turbines. Investors fully receive the average production value their turbines are forecast to obtain in the future. Hence, turbines that in the future will provide a greater market value are eligible to a higher remuneration level. This way, the system-optimal turbine is also most attractive to investors.[3]

The remainder of this paper is structured as follows: In section 2, I present the investment model.

[2] As Joskow (2011) points out, it is not sufficient to merely compare the levelized cost of electricity and opt for the volatile technology that comes at the least costs per kWh because the production values can vary between technologies.

[3] Öko-Institut (2014) suggest a different remuneration scheme where the remuneration depends on a turbine's production characteristics. This approach can support the development of system-friendly turbines. However, it does so explicitly, generally assuming their deployment to be advantageous for the system.

Then, I give an overview of the calculations for the FIT, the MPS, and the production value-based benchmark approach. I describe the data and wind turbine technologies in section 3. The results are discussed in section 4. Section 5 draws conclusions and identifies policy implications.

2 Methodology

Investors optimize their discounted future revenues and costs, taking the prevailing renewable support scheme as exogenously given. I analyze one scenario per policy, and investigate the differences between these. I outline the fixed feed-in tariff and the floating market premium scheme in sections 2.2 and 2.3, indicating how they are implemented in the investment decision model. Finally, the production value-based benchmark approach is a policy explicitly granting remuneration depending on the turbine's future system-friendliness, as laid out in section 2.4.

2.1 Wind power investment

The investor maximizes their net present value (NPV) with respect to turbine technology i. Three technology characteristics are important determinants of output: hub height, generator nominal power and rotor blade length (cp. section 3.1). In its general form, turbine i's NPV N_i is defined as

$$N_i = -\alpha_i + \sum_t \delta_t \omega_{i,t} (\pi_{policy_{i,t}} - \beta_t) \tag{1}$$

α_i represents the turbine's fixed costs. Its generated electricity at time t is $\omega_{i,t}$. It is discounted with the discount factor δ_t. The policy-specific remuneration per kWh is captured in $\pi_{policy_{i,t}}$. The variable operations and maintenance costs are β_t.[4]

2.2 Fixed Feed-in Tariff

Fixed feed-in tariffs compensate investors with a fixed payment per generated kWh. Even though the rate is fixed, in the German implementation, a turbine receives either the initial high payment F_{high} or a lower, subsequent payment F_{low}. The initial period lasts at least 5 years, and can be extended to cover

[4]The operations and maintenance costs do not change the qualitative analysis in the following and are thus omitted from the theoretical analysis.