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Where the wind blows: Assessing the effect of fixed and premium based feed-in tariffs on the spatial diversification of wind turbines

J. Schmidt *, G. Lehecka, V. Gass, E. Schmid

Institute for Sustainable Economic Development, University of Natural Resources and Life Sciences, Vienna, Feistmantelstraße 4, 1180 Vienna, Austria

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ABSTRACT

Feed-in tariffs (FIT) are among the most important policy instruments to promote renewable electricity production. The fixed-price FIT (FFIT), which guarantee a fixed price for every unit of produced electricity and the premium based FIT (PFIT), which pay a premium on top of the market price are commonly implemented in the EU. Costs for balancing intermittent electricity production may be significantly higher with FFIT than with PFIT, and FFIT do not provide any incentive to produce electricity when marginal production costs are high. In contrast, PFIT do provide strong incentives to better match renewable power output with marginal production costs in the system. The purpose of this article is to assess the effects of the two tariff schemes on the choice of wind turbine locations. In an analytical model, we show that both the covariance between wind power supply and demand as well as between the different wind power locations matter for investors in a PFIT scheme. High covariance with other intermittent producers causes a decrease in market prices and consequently in revenues for wind power investors. They are therefore incentivized to diversify the locations of wind turbines to decrease the covariance between different wind power production locations. In an empirical optimization model, we analyze the effects of these two different schemes in a policy experiment for Austria. The numerical results show that under a PFIT scheme, (1) spatial diversification is incentivized, (2) the covariance of wind power production with marginal electricity production costs increases, and (3) the variances of the wind power output and of residual load decrease if wind power deployment attains 10% of total national electricity consumption.

Nomenclature

Symbol	Description	Unit
Model parameters		
NPV_i^{FFIT}, NPV_i^{PFIT}	Net present value (NPV) under the FFIT and PFIT scheme for location *i*	€
$w_{i,t}$	Wind power production at location *i*, and hour *t*	MWh
NPV^{FFIT}, NPV^{PFIT}	Net present value (NPV) of the optimal solution under the FFIT and PFIT scheme	€
f^{FFIT}, f^{PFIT}	Fixed-price and premium-price feed in tariffs	€ MWh^{-1}
c_i^{dis}	Sum of discounted cash-outflows (investment, and operation and maintenance costs) at location *i*	€
dr_t	Discount factor from time *t* back to time 0	
$f_t^{dis}(w_{j,t};l_j)$	Discounted compensation for investors in a PFIT scheme consisting of market price plus premium	€ MWh^{-1}
p_t	Marginal production costs in system without additional wind power production	€ MWh^{-1}
$f_t^{mo}(w_{j,t};l_j)$	Function that determines the price decreasing effect of wind power production (i.e. the merit order effect)	€ MWh^{-1}
$w_{i,t}^s$	Simulated wind power production at location *i* and hour *t*	MWh
c_i^{sdis}	Simulated sum of cash out flows resulting from investment, operation and maintenance costs at location *i*	€
p_t^h	Historical electricity price at Austrian energy exchange in hour *t*	€ MWh^{-1}
d_t^h	Historical electricity demand in Austria at hour *t*	MWh
w_t^h	Historical measured wind power production in Austria at hour *t*	MWh
$dh_{t,k}$	Dummy for hours	
$wd_{t,h}$	Dummy for days	
$m_{t,u}$	Dummy for months	
ε_t	Error term	
Optimization model variables		
l_i	Decision variable in interval [0,1] on the deployment of the wind potential in location *i*	
Model indices		
i, j	Location and alias for location	
t	Time period	

1. Introduction

Feed-in tariffs (FIT) are among the most important policy instruments to promote renewable electricity production. Two types of tariff schemes are commonly implemented in the EU: fixed-price FIT (FFIT), which guarantee a fixed price for every unit of produced electricity, and premium based FIT (PFIT), which pay a premium on top of the market price. FFIT transfer price risks from investors to consumers,

* Corresponding author. Tel.: +43 1 47654 3594; fax: +43 1 47654 3692.
E-mail address: Johannes.schmidt@boku.ac.at (J. Schmidt).

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which can lead to high and stable growth rates of renewables and incentivize investments of risk-averse investors such as small municipalities and private households. However, FFIT do not provide any incentive to match electricity production with marginal costs of electricity production (Couture and Gagnon, 2010; Schallenberg-Rodriguez and Haas, 2012), and the costs for balancing intermittent electricity production may be lower with PFIT (Hiroux and Saguan, 2010; Klein, 2008). As shown by Lamont (2008), the market value of renewable electricity increases with the covariance between marginal electricity production costs and renewable electricity production. PFIT could provide an incentive to better match renewable power output with marginal production costs. Technically, there are various options to shift electricity production to times when prices are high. Fuel based renewables such as bioelectricity can directly adjust their output to market price signals. Maintenance of intermittent renewable technologies, such as wind power, can be scheduled in times of low prices to maximize output when prices are high (Schallenberg-Rodriguez and Haas, 2012). Furthermore, investors can, a priori to the investment, choose locations for intermittent production where production is correlated with marginal electricity costs.

In this article, we assess the effects of the two tariff schemes on the choice of wind turbine locations. We show that both the covariance between wind power supply and marginal production costs matter as well as the covariance between the different wind power locations. High covariance with other intermittent producers can cause a decrease in market prices and consequently a loss in revenues for the wind power investors. Spatial diversification allows decreasing the covariance between different wind power production locations. Consequently, lower covariance between different wind power production locations causes lower variance of total wind power production (Degeilh and Singh, 2011). This may decrease energy system costs caused by wind power due to less variability of the residual load, i.e. demand minus intermittent producers. In addition, spatial diversification may be beneficial to the grid operation because less transmission lines may be necessary and the visual impact of wind turbines is spread over a larger region. FFIT do not provide any incentives to diversify production locations. They lead to investments in high yielding locations that are often concentrated in one region.

Diversifying wind power production locations can reduce variability of total wind power output as shown in Degeilh and Singh (2011). Roques et al. (2010) apply portfolio optimization to analyze the potential of reducing the variance of joint output of European wind power production. Rombauts et al. (2011) also present a portfolio based approach on the optimal portfolio of wind power production locations under transmission constraints. However, both take the position of a social planner to optimally deploy wind turbines. They do not assess the effect of policies on the spatial distribution of wind power capacity. Recent assessments of FFIT and PFIT (Couture and Gagnon, 2010; Klein, 2008; Schallenberg-Rodriguez and Haas, 2012) argue that PFIT require more subsidies due to increased price risks for project developers. They also argue that incentives to match wind power production with marginal production costs are higher in PFIT than in FFIT such that wind integration costs can be reduced. However, no quantitative analysis is applied by any of the studies. Hence, we aim at assessing quantitatively the effect of the two tariff schemes on the spatial distribution of wind power deployment and associated co-benefits of reduced variance in wind power output.

This article is structured as follows. The analytical model for investors under FFIT and PFIT schemes is investigated in Section 2. Then, in Section 3, we apply the optimization models to analyze whether PFIT and FFIT lead to different location choices in the case of Austria. For this purpose, we create synthetic time series of wind power production, using data from the Austrian wind atlas and from meteorological stations, which are included in an optimization model that considers the effect of wind power production on market prices. The optimization model also employs price reducing effects of wind power derived from a regression analysis of hourly market prices from the Austrian Energy Exchange. The results are presented in Section 4 and discussed in Section 5. Finally, a summary and conclusions are given in Section 6.

2. Analytical model

We compute net present values (NPV) of investment options in the two different FIT support schemes. Investors can choose between different wind power locations that differ by their wind profile and associated investment, operation and maintenance (O&M) costs.

The NPV_i^{FFIT}, denoting the NPV of a fully deployed location i in the FFIT scheme is thus determined by

$$NPV_i^{FFIT} = f^{FFIT} \sum_t w_{i,t} dr_t - c_i^{dis} \tag{1}$$

where $w_{i,t}$ denotes the potential wind power production at location i and hour t, and f^{FFIT} is the fixed feed-in tariff. The factor dr_t is applied to discount the revenues to the present time. Also, the investor has to consider the sum of annually discounted cash outflows c_i^{dis} at location i, consisting of investment and O&M costs.

The wind power production at location i, and hour t, $w_{i,t}$, is considered to be a random variable with respect to index t, and thus, the NPV_i^{FFIT} in Eq. (1) can be rewritten in terms of the expected value in order to clarify the effect of correlations between the terms:

$$E\left(NPV_i^{FFIT}\right) = E\left(w_{i,t}\right) f^{FFIT} \sum_t dr_t - c_i^{dis}. \tag{2}$$

$E(\bullet)$ denotes the expected value of wind power production at the location. This implies that the NPV of a certain location is only determined by the expected discounted total revenue from selling wind power at the location minus the discounted total costs, assuming that the covariance between $w_{i,t}$ and dr_t is 0.

The investor under a FFIT scheme faces the following optimization problem:

$$\max_l \; NPV^{FFIT} = \sum_i NPV_i^{FFIT} l_i \tag{3}$$

$$\text{s.t.} \quad 0 \le l_i \le 1, \forall i. \tag{4}$$

The investor maximizes the net present value NPV^{FFIT} by choosing from different wind power locations i. The decision variable l_i indicates how much of a certain location is going to be built. Adding expectations to Eq. (3), and extending by Eq. (2), yields

$$E\left(NPV^{FFIT}\right) = \sum_i l_i \left(f^{FFIT} E\left(w_{i,t}\right) \sum_t dr_t - c_i^{dis} \right) \tag{5}$$

Since the net present value is independent of the covariance of locations with marginal production costs or with each other, the investor aims at investing in wind turbines at locations with high wind power production and low costs. Any location which NPV_i is greater than 0 is fully built while all other locations are not included at all in the optimal solution because covariance with other locations is not of interest (Schmidt et al., 2013).

In contrast, under a PFIT scheme, the NPV of a fully deployed location is given by

$$NPV_i^{PFIT} = \sum_t w_{i,t} f_t^{dis}\left(w_{j,t}; l_j\right) - c_i^{dis}. \tag{6}$$

At location i, the NPV consists of cash in-flows from the produced wind energy (i.e. $w_{i,t}$) times the compensation per unit $f_t^{dis}(w_{j,t}; l_j)$, which consists of the discounted market price in hour t plus the discounted feed-in premium. The market price is dependent on the deployment of