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The effect of feed-in tariffs on the production cost and the landscape externalities of wind power generation in West Saxony, Germany

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Key words: feed-in tariff, spatial allocation, wind power.

Abstract

Although wind power is currently the most efficient source of renewable energy, the cost of wind electricity still exceeds the market price. Subsidies in the form of feed-in tariffs (FIT) have been introduced in many countries to support the expansion of wind power. These tariffs are highly debated. Proponents say they are necessary to pave the way for decarbonising energy production. Opponents argue they prevent a welfare-optimal energy supply. Thus, in a case study we try to shed light on the welfare economic aspect of FIT by combining spatial modelling and economic valuation of landscape externalities of wind turbines. We show for the planning region West Saxony, Germany, that setting FIT in a welfare optimal manner is a challenging task. If set too high the production costs are overly increased, lowering social welfare. If set too low energy production targets may not be reached and/or external costs are overly increased, again lowering social welfare. Taking a closer look at the tariffs offered by the German Renewable Sources Energy Act we find for West Saxony that the tariffs quite well meet economic welfare considerations. One should note, however, that this finding might apply only to the present data set.

1. Introduction

Wind power is the world's fastest growing energy source (Saidur et al., 2010) and constitutes an important component of the energy mix in many countries (REN 21, 2010). In future, it's further expansion is expected to help meeting ambitious energy and climate policy goals. In Germany, for instance, the share of onshore wind power to electricity production is expected to increase from an installed capacity of 27.5 GW in 2010 to 37.8 GW in 2030 (Nitsch et al., 2010). Since the cost of wind power still exceeds the market price for electricity from conventional energy sources, many countries have introduced feed-in tariffs (FIT) using them as a key instrument of their energy policy for more than a decade (Saidur et al., 2010). These include Denmark and Germany, which implemented them in the mid90s (Lipp, 2007), and Spain, which implemented them in 1998 (González, 2008). Overall, more than 50 countries are said to be experimenting with implementing FIT (Bull et al., 2011). A common feature of all FIT implementations is that they generally guarantee producers of renewable electricity the feed of their electricity into the grid at a guaranteed price above the market price.

FIT are seen as a crucial instrument to develop renewable deployment and are suggested as an appropriate instrument to drive, among others, the extension (Saidur et al., 2010) as well as the repowering of wind energy (del Rio et al., 2011). However, the design of FIT can strongly influence the efficiency of electricity generation. The design of FIT programmes is thus constantly debated (del Rio and Gual, 2007; Lipp 2007; Ayoub and Yuij, 2012; Dong, 2012; Schallenberg-Rodriguez; Hass, 2012). In Germany, for instance, it has been updated a couple of times. One reason for changing and adapting the design of the FIT is that there are various trade-offs. For instance, there can be trade-offs between long-term goals (technical innovation) and short-term goals (fast expansion of renewables): high tariffs ensure the latter but may hinder the former (Lesser and Su, 2008). Furthermore, if tariffs are set too low political targets for the production of electricity from renewables may not be met. In contrast, if tariffs are set too high, electricity is produced inefficiently (Lesser and Su, 2008). What has been overlooked so far in these debates are the negative externalities of renewables induced by FIT. The presence of these externalities can have important implications for policy makers because they can negatively affect political acceptance of extending renewable energy (Mabee et al., 2012). To our knowledge the negative externalities caused by FIT have so far not been considered when FIT programmes were initially set up or updated.

Considering the example of Germany which has a fairly long tradition with FIT, tariffs for wind electricity have been coupled to certain requirements that restrict the installation of wind turbines (WT) to locations where wind power production is economically efficient. According to the German Renewable Energy Sources Act (BGBl 2011), the tariff is guaranteed only if the annual energy yield exceeds 60 percent of a certain reference value. Such a reference yield is specified for each WT technology and represents the wind power output of that WT technology at a location with average wind conditions (BGBl 2011, p. 46). This ensures that WT are not erected at locations with very poor wind conditions and reduces the average cost per unit of wind electricity. However, it implies a critical side effect: the area where WT can be erected and operated in a profitable manner is restricted since WT operators will choose a spatial location only if operation of the WT at least yields the reference value such that feed-in and payment of price (the tariff) are guaranteed. Regarding the spatial allocation of WT, we thus face a problem of space scarcity given the total land amount available in a given region. This scarcity can have two consequences: less wind power can be produced in the region and/or WT may have to be erected at sites that may be disadvantageous with regard to other policy objectives like protection of human health and nature conservation. For instance, to reach a particular energy target, WT may need to be erected closer to settlement areas or nature conservation zones. In other words, while restrictions to FIT may reduce the production cost of wind power, they may increase external costs that comprise all the adverse effects of wind power on the environment. For the policy makers who are responsible for setting the FIT the question is now, what levels of tariff and restrictions minimise the sum of both, production and external costs, and hence maximise social welfare?[1]

A prerequisite for answering this question is to identify and monetise the above-mentioned external effects of wind power supply in order to consider them as part of the total cost of wind energy production. With regard to human health, most often noise and shade effects are mentioned (Hau, 2006; Rogers et al., 2006). Visual impacts on the landscape (Möller 2006, Moran and Sherrington 2007) and impacts on birds and bats (Bright et al., 2008; Hötker et al., 2006) are most prominently cited as adverse impacts on nature. These effects represent externalities that need to be measured in monetary units in order to quantify their impact on social welfare (e.g., Álvarez-Farizo and Hanley, 2002; Ek, 2006; Dimitropoulos and Kontoleon, 2008); Meyerhoff et al., 2010).

Drechsler et al. (2011) used choice experiments for the economic valuation of the most important externalities of wind power generation in a particular study region in Germany and integrated the empirical results into a spatial modelling framework that allows determining the welfare-optimal spatial allocation of WT in a region. The design of the hypothetical market and the choice experiment are described in detail in Meyerhoff et al (2010). These authors interviewed a randomly drawn sample of the population of their study region West Saxony, Germany, and presented them a series of choice sets regarding the future shape of wind power generation in West Saxony. The present paper builds on both studies, Meyerhoff

1 Other, comparable modelling approaches such as the one presented by Delzeit et al. (2012) do not take into account negative externalities but focus on competing facility locations. Thus, their analysis relies on decentralised decision makers. The contribution of the present paper, in contrast, is to investigate the externalities that would be caused by wrongly set FITs. As the landscape externalities that are subject of the present analysis are not visible on markets this evaluation requires the view point of the policy maker.

et al. (2010) and Drechsler et al. (2011), using the data gathered in the population survey and the modelling framework to determine a spatially efficient allocation of the turbines in the study region. Using both studies allows us to investigate the two-folded effect of FIT in Germany: the effect on wind energy production costs on the one hand and the effect on land scarcity and the level of external costs on the other. In particular we will explore the impacts of different levels of FIT and different levels of the above-mentioned reference energy yield.

The paper is structured as follows. In section 2 we outline the modelling approach and present the study region. In section 3 we apply the modelling approach to the study region and present the results in section 4. Section 5 discusses the results and draws conclusions for policy design.

2. Outline of the modelling approach

As outlined in the Introduction, we consider the welfare-optimal allocation of WT such that a given level of electricity $E_{\min}$ is produced per year at minimal total cost C.[2] The total cost C of wind power supply is composed of the production costs C_p and the external costs C_e. To determine the external costs a valuation survey with a choice experiment was conducted in the study region. The attributes defined to capture relevant externalities were identified through stakeholder interviews and focus groups with people from the study region[3]. They include the size of wind farms, height of WT, effect on the endangered Red Kite (*Milvus milvus*)

[2] The determination of the welfare-optimal energy target $E_{\min}$ itself would require the consideration of the effects of wind power production on the climate and the impacts of climate change. This, however, is beyond the scope of this study. The energy target $E_{\min}$ is an exogenous parameter which we assume to be optimally set by the political decision maker.

[3] The study region comprises the area of the Planning Region West Saxony which is a part of the Free State of Saxony, Germany, with about 1,000,000 residents (2005) and an area of around 4.300km². Due to its topography the region is fairly suited for wind power production but at the same time belongs to the core distributional area of an endangered bird species: the Red Kite (*Milvus milvus*).

population in the region and the distance of WT to residential areas. The results show (Meyerhoff et al., 2010) that on average respondents have a preference for moving WT further away from residential areas and for lowering the impact on the Red Kite population. In contrast, preferences for the size of wind farms are very heterogeneous with one subgroup preferring small wind farms while another subgroup preferred large wind farms. The preferences toward the height of turbines were heterogeneous, too. In the optimisation presented in Drechsler et al. (2011), for the purpose of simplification therefore only the attributes loss rate (*L*) of the Red Kite in the study region and the minimum distance of WT to settlements ("settlement distance" *D*) are taken into account. The attribute *D* considers the impact of WT on the landscape and ultimately the human inhabitants. The production costs and the loss of Red Kites depend on the time frame. We consider a time frame of 20 years, which is about the life time of a WT, so C_p measures production costs over 20 years and *L* measures species decline within 20 years.

The analysis starts by constructing the total cost function

$$C = C_p + C_e(L, D) \tag{1}$$

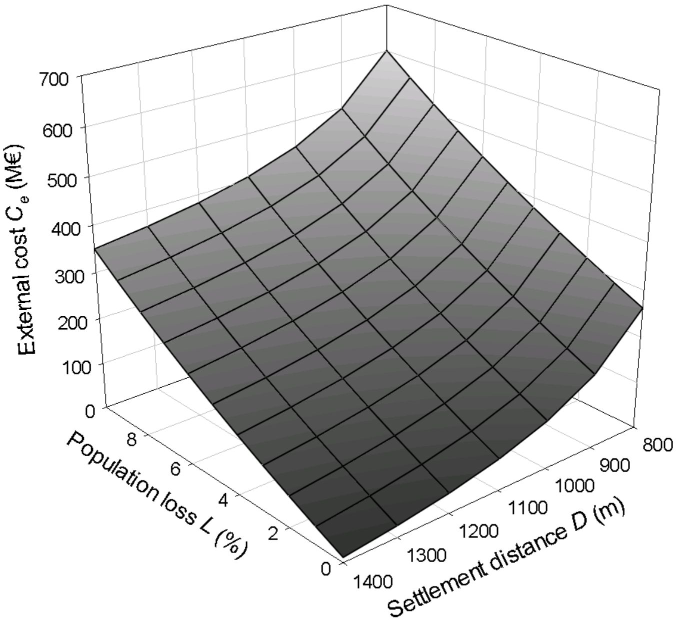
where C_e are the external costs associated with the attributes *L* and *D*. We further identify the sites that are physically and legally suitable for the installation of a WT (cf. Ohl and Eichhorn, 2010). Given these potential sites, WT allocation strategies are formed by deciding for each site whether it should contain a WT or not. For each allocation strategy we determine the associated attributes C_p, *L* and *D* and determine the total cost *C* via eq. (1). For given energy target $E_{\min}$, the welfare-optimal allocation of WT, i.e. the allocation that minimises *C*, is determined through numerical optimisation (cf. Drechsler et al. 2011).

We consider that WT are erected only at sites where they can be installed and operated profitably, i.e. where the benefits from the FIT exceed the production cost for the operator. According to the German Renewable Energy Sources Act (BGBl, 2011), an “initial” tariff of IT = 9.7 cent/kWh is paid during the first years of operation of a new installed WT (see eq. 3), which is followed by payment of a “basic” tariff of 5.02 cent/kWh for the following years. The tariffs are paid only if the annual energy output of the WT exceeds λ=0.6 times a certain reference yield (see section 3). The chosen magnitudes of IT and λ affect the set of profitable sites. Through this constraint, the choice of IT and λ determines the welfare-optimal allocation of WT in the region and the associated level of total cost C. We systematically vary these two parameters of the Renewable Energy Sources Act (BGBl 2011) and explore the effects on the production and external costs, C_p and C_e, and the total cost C.

3. Application of the modelling approach

The construction of the external cost function is based on choice experiments (Louviere et al. 2000) and described in detail in Drechsler et al. (2011). From the responses of 353 inhabitants in the study region the marginal willingness to pay for increasing the settlement distance D as well as the marginal willingness to pay for decreasing the Red Kite loss rate L are calculated. A non-linear function is fitted to the calculated values to obtain the external cost C_e as a function of the attributes D and L. Figure 1 shows that the external costs increase with increasing L and decreasing D.

Figure 1: External cost $C_e=C_L+C_D$ for the study region as a function of Red Kite loss rate L and settlement distance D for the time frame of 20 years, discounted at annual rate r=3%.



For the welfare-optimal allocation we assume that WT are erected only in open areas which comprise arable land but exclude, e.g., forests. Two state-of-the-art technologies are considered: a WT with hub height of 78m and rotor diameter of 82m, yielding a nominal power of 2 megawatts (MW), and a WT with hub height of 105m and a rotor diameter of 90m, yielding a nominal power of 3MW. For each potential site i (i=1,…,1043) the energy yield E_{ik} for each of the two WT technologies (k=1,2) is calculated by WT power curves (which tell how much power is produced at given wind speed) and wind speed distributions (number of hours in a year over which a certain wind speed is observed) available on a 1 by 1 km^2 raster. The total energy E_{tot} produced per year in the region is obtained by summing E_{ik} over all installed WT.

The production cost C_p of eq. (1) is the sum of the construction and operating costs of all erected WT. The construction and annual operating costs depend on the WT type k. We base the construction cost on the sales prices p_k from the companies' price lists (own survey) plus a

10-percent mark-up to cover on-site construction costs, including grid connection. Annual operating costs are typically estimated at five percent of the construction costs (information provided by interviewed WT operators). Considering a time frame of T=20 years, total operating costs per WT are obtained by discounting the annual costs at rate r (Table 1) for each year and summing up over all years within time frame T.

Table 1: Overview on the relevant model parameters.

Parameter / Variable	Meaning	Value / Range
$E_{\min}$	Energy target for the region	345 GWh per year
IT	Initial tariff	(5, 5.5, 6,…, 15) cent per kWh
BT	Basic tariff	5.02 cent per kWh
R_k	Reference yield	5.68 GWh/year for WT k=1 6.90 GWh/year for WT k=2
λ	Minimum ratio of energy yield and reference yield	0.5, 0.525, 0.55, …, 1.0
p_k	WT sales price	2.648 million € for WT k=1 3.489 million € for WT k=2
r	Discount rate[1]	0.05 per year (private costs and benefits) 0.03 per year (public costs and benefits)
T	Time frame of analysis	20 years

[1] The private discount rate applies in the assessment of whether a WT can be operated profitably at a particular site. For this, private revenues (V_{ik} in eq. (8)) and annual operating costs are discounted at r=5 percent. Societies generally discount at smaller rates than private actors. To calculate the production costs C_p as part of the total cost C (eq. 1) we therefore consider a smaller social discount rate of 3 percent. That means all the numerical estimates of C_p and C in the results section are based on that social discount rate.

The private revenues from WT operation are determined by the produced energy E_{ik} and the regulations of the German Renewable Energy Sources Act (BGBl, 2011). These tell that in the first 5 years after construction an “initial tariff” (“Anfangsvergütung”) of IT=9.2 cent is paid per kWh, given E_{ik} is at least λ=0.6 times the reference yield R_k. The reference yield represents the amount of energy that can be produced by WT type k at a site with average wind conditions (considering typical WT sites in Germany). An additional "system services bonus" ("Systemdienstleistungsbonus") of SSB=0.5 cent is paid on top of IT if the WT starts operating before 2014 and fulfils the requirements of an electrical engineering ordinance. The initial tariff IT is paid beyond those five years if E_{ik} is less than 1.5R_k. In particular it is paid for another

$$z = \frac{(1.5R_k - E_{ik})}{6 \cdot 0.075 R_k} \tag{2}$$

years. After 5+z years a "basic tariff" ("Grundvergütung") of BT=5.02 cent is paid per cent/kWh. Altogether, the present value revenue of a WT of type k at site i over T years is

$$V_{ik} = E_{ik}\left((IT + SSB)\sum_{t=1}^{5}(1+r)^{-t} + IT\sum_{t=6}^{z}(1+r)^{-t} + BT\sum_{t=z+1}^{T}(1+r)^{-t} \right) \tag{3}$$

if the amount of energy exceeds λ times the reference yield ($E_{ik} \geq \lambda R_k$), and V_{ik}=0 otherwise. We assume that a WT of type k is erected at site i only if the revenue V_{ik} exceeds the total of construction and operating costs.

Ecological externalities are partly taken into account by prohibiting the erection of WT in areas protected by nature conservation laws. However, many protected species occur outside protected areas as well. In the present study the Red Kite (*Milvus milvus*) is most relevant, since the study region belongs to the core area of the world-wide distribution of the species

(BirdLife International 2009) and Red Kites rather frequently collide with WT (Dürr 2008). The Red Kite loss is modelled on the basis of the distances of WT to nests of the species (Drechsler et al. 2011) and therefore depends on the spatial allocation of WT in the region.

The assumed policy objective in the study region is to produce an energy amount of $E_{\min}$=345 GWh per year, which is the amount of what is currently produced. This number assumes that WT may be reallocated but there is no net expansion of wind power production. With the model at hand we seek for the optimal spatial allocation of WT which allows reaching that energy target at minimum total cost C.

Mathematically, the task is to minimize the social cost C (eq. (1)) as a function of the spatial allocation of the WT. The spatial allocation of the WT is represented by a vector $\mathbf{x}=(x_1,x_2,\ldots,x_N)$ where element x_i (i=1,…,N) of this vector is x_i=0 if there is no WT at site i, and $x_i=k$ if a WT of type k is installed, and N is the total number of sites. The solution of the minimization problem is presented in Appendix C of Drechsler et al. (2011). Next to the optimal spatial allocation of the WT ($\mathbf{x}$*) the analysis delivers the associated optimal levels of the production cost (C_p*) and the externalities (L*) and (D*). We are interested in how the magnitude of the initial tariff (IT) and the minimum ratio of energy yield and reference yield (λ) affect C_p*, L* and D*. For this we systematically vary IT and λ within the ranges given in Table 1.

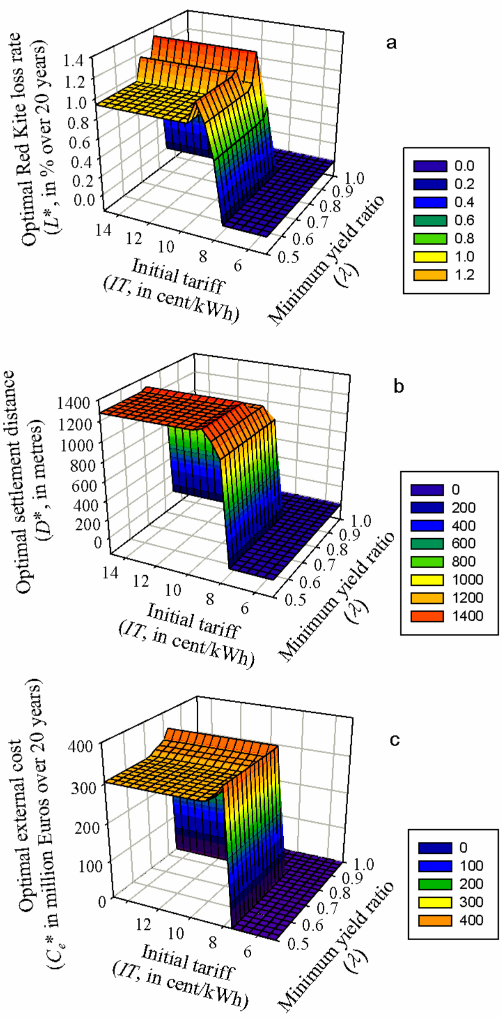
4 Results

Numerical optimisation (for details, see Drechsler 2011) delivers the welfare-optimal allocation of WT that minimises the total cost C of reaching the energy target $E_{\min}$=345 GWh/year The associated optimal Red Kite loss rate is L*=0.94 percent within 20 years, the optimal settlement distance is D*=1,257m and the optimal production cost in the landscape amounts to C_p*=352 Mio Euros (sum over 20 years, present value, discounted at 3% per year).

The level of the initial tariff (*IT*) and the minimum yield ratio (λ) affect the welfare-optimal allocation of WT in the region as well as the associated optimal levels of *L**, *D** and C_p*. We systematically vary *IT* and λ within the ranges specified in Table 1 and plot *L**, *D** and C_p* as functions of *IT* and λ (Fig. 2).

Starting from a high *IT* and low λ in Fig. 2a (left axis), the optimal level of the Red Kite loss rate (*L**) first remains constant at 0.94 as *IT* is decreased and/or λ is increased. Below a certain level of $IT \approx 9$ cent/kWh or above $\lambda \approx 0.7$, the optimal Red Kite loss rate starts to increase for a short while, until it rapidly drops to zero when *IT* is further decreased below 8 cent/kWh or λ is increased beyond 0.8. The reason for the temporary increase of *L** in the interval 8 cent/kWh $\leq IT \leq$ 9 cent/kWh and $0.7 \leq \lambda \leq 0.8$ is that by reducing *IT* or increasing λ, some WT sites with poor wind conditions but low impact on the Red Kite are not profitable any more and – since the energy target $E_{\min}$ must be met – need to be substituted by other WT sites with better wind conditions but higher impact on the Red Kite. The rapid drop of *L** to zero at too low *IT* or too high λ reflects that it is not possible to find enough profitable sites to reach the energy target $E_{\min}$ so that the cost minimisation problem has no solution.

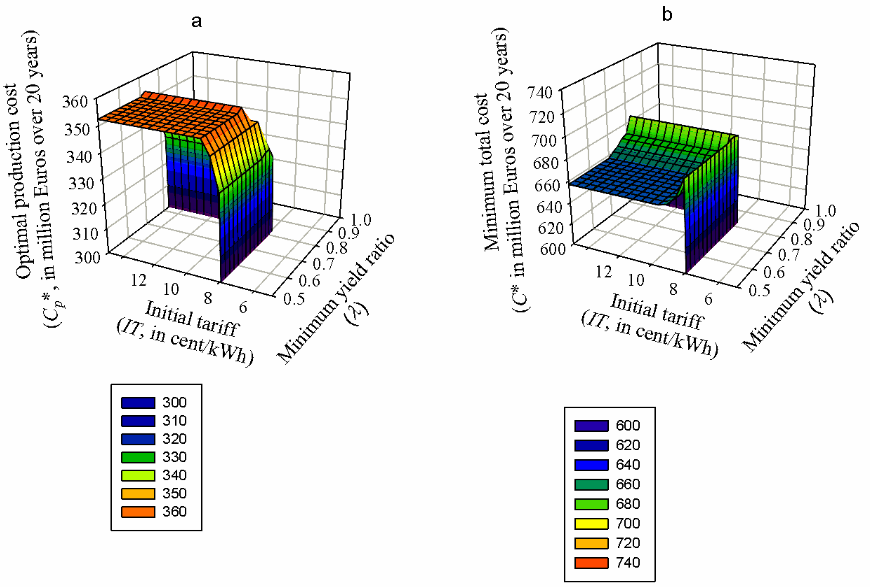
Figure 2: Optimal Red Kite loss rate L^* (panel a), optimal settlement distance D^* (panel b) and optimal external cost $C_e^*=C_L(L^*)+C_D(D^*)$ (panel c) as functions of the initial tariff (*IT*) and the minimum yield ratio λ.



An analogous picture is observed in Fig. 2b. Again, until a certain level of *IT* and λ, the optimal settlement distance remains constant at 1,275 m, then slowly declines at values just below $IT \approx 9$ cent/kWh or above $\lambda \approx 0.7$, and finally drops to zero as *IT* is further reduced below 8 cent/kWh or λ increased beyond 0.8. Similar to the case of the Red Kite loss rate, the reason for the moderate decrease of the optimal settlement distance is that reducing *IT* or increasing λ eliminates WT sites at poor wind conditions but far away from settlements, which must be substituted by sites with better wind conditions but closer to settlements. And further, if *IT* is reduced too much or λ increased too much, the energy target cannot be reached so that the cost minimisation problem has no solution.

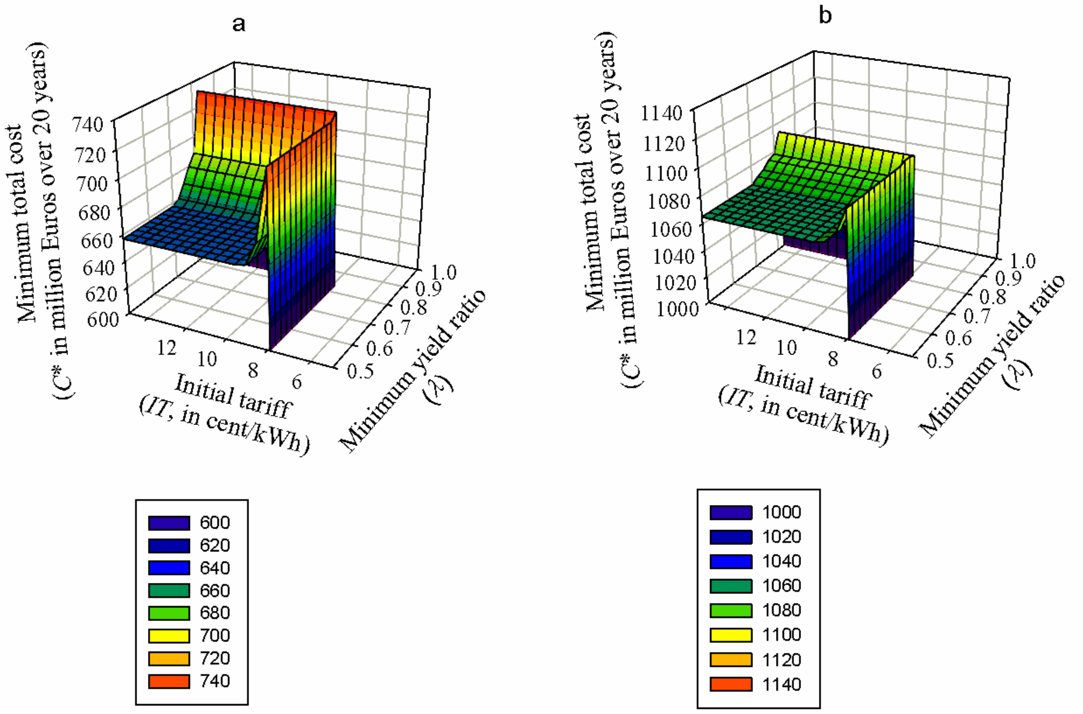
Altogether, both externalities increase if *IT* is reduced or λ is increased beyond a certain threshold, which reflects in higher external costs $C_e*=C_L(L*)+C_D(D*)$ (Fig. 2c). And if *IT* is even further reduced or λ further increased the energy target $E_{\min}$ cannot be achieved. On the other hand decreasing *IT* or increasing λ reduces the optimal production cost (Fig. 3a), because sites at poor wind conditions where the production cost per unit of electricity is high are substituted by sites with better wind conditions and low production cost per unit of electricity. The question is, which effect prevails: the increase in optimal external costs C_e* or the decrease in optimal production costs C_p*? Figure 3b shows that if *IT* is reduced below 9 cent/kWh and/or λ is increased above 0.7, optimal external costs rise faster than optimal production costs decline so that the minimum total cost $C*$ (achieved under optimal allocation of the WT) increases from 660 to 690 million Euros – before it drops to zero at about $IT \leq 8$ cent/kWh and/or $\lambda \geq 0.8$ when the energy target cannot be met. That means that by decreasing IT below 9 cnt/kWh or increasing λ above 0.7, the increase in external costs dominates the decrease in production costs!

Figure 3: Optimal level of production cost C_p* (panel a) and minimum level of total cost $C^*=C_p^*+C_e^*$ (panel b) as functions of the initial tariff (*IT*) and the minimum yield ratio λ.



A question is now how the results depend on society's preferences. In Fig. 4a the marginal willingness to pay for a decrease in the Red Kite loss rate *L* and the marginal willingness to pay for an increase in the settlement distance *D* are doubled, i.e. society values the external effects of wind power production more strongly. Like in Fig. 3b the minimum total cost increases when *IT* is decreased below 9 cnt/kWh or when λ is increased beyond 0.7. The difference is that the increase is stronger than in Fig. 3b (from 660 to 740 million Euros in Fig. 4a compared to an increase from 660 to 690 million Euros in Fig. 3b).

Figure 4: Minimum level of optimal total cost $C^*=C_p^*+C_e^*$ as function of the initial tariff (*IT*) and the minimum yield ratio λ. Panel a: the marginal willingness to pay is doubled compared to Fig. 3b; panel b: the energy target $E_{\min}$ is doubled compared to Fig. 3b.



Another parameter of interest is the energy target $E_{\min}$. Doubling $E_{\min}$ has no effect (compare Fig. 4b with Fig. 3b) except that the level of the minimum total costs *C* is shifted upwards by ca. 400 million Euros for all values of *IT* and λ.

Altogether, the threshold values of *IT* and λ beyond which the minimum total cost increases (*IT*δ9 cent/kWh and λτ0.7) and the threshold values beyond which the cost minimisation problem has no solution (ITδ8 cent/kWh and λτ0.8) do not depend on society's preferences nor on the energy target $E_{\min}$.

5. Summary and Conclusions

Wind power is one of the most promising options for producing energy in a climate-friendly manner. However, the cost of electricity from WT still exceeds the market price and so additional subsidies (feed-in tariffs (FIT)) have been introduced in many countries to support the expansion of wind power. Setting the levels of the tariffs and the restrictions under which they are granted is challenging. On the one hand the financial burden for society should be kept as low as possible, implying that tariffs should not be higher than necessary to deliver the desired amount of renewable energy supply. On the other hand, if the tariffs are set too low or the restrictions under which they are granted are set too tight the energy production targets may not be met (see also Lesser and Su 2008).

Another aspect that has so far not been analysed in detail is that the level of the FIT also influences the level of negative externalities caused by renewables such as wind power. Several studies using non-market valuation techniques have shown that renewables can cause substantial externalities through their impact on the landscape or biodiversity (for an overview see Meyerhoff et al. 2010). In the present study we consider that wind power production may negatively affect humans and the quality of landscapes and biodiversity. On the example of the planning region West Saxony in Germany we show that even if a regional energy production target is met, too low tariffs or too tight restrictions may overly increase these external costs of wind power production because WT have to be installed at sensitive sites to meet that target.

According to the German Renewable Energy Sources Act (BGBl, 2011), an initial tariff of IT=9.7 cent/kWh (for the first years after construction) and a basic tariff of BT=5.02 cent/kWh (for the following years; cf. section 3.2) are guaranteed if the annual energy yield exceeds λ=0.6 times a certain reference value. Such a reference yield exists for each WT technology and represents the wind power output of that WT technology at a spatial location with average wind conditions. We systematically vary IT and λ from their above values specified by BGBl (2011) and determine the welfare-optimal allocation of WT sites under the restriction that every year an amount of 345 GWh of wind electricity is produced in the region. This energy target equals the current level in the region and assumes that there is no net expansion of wind power production. We find that as long as certain threshold levels are not crossed (IT>9 cent/kWh and λ<0.7), the level of the FIT (IT) and the associated restriction (λ) have no effect on the welfare-optimal allocation in the region and the associated production and external costs. Since higher tariffs imply additional burdens to society, IT should not be chosen much higher than 9 cent/kWh and the minimum yield ratio λ not much lower than 0.7.

If IT is reduced below 9 cent/kWh and/or λ increased above 0.7 production costs decrease but external costs increase. The latter effect dominates the former, so that the total cost in the region increases by roughly 30 million Euros over 20 years (present value) if IT is reduced from 9 to 8 cent/kWh and/or λ is increased from 0.7 to 0.8. If further thresholds are crossed (IT reduced to values below 8 cent/kWh or λ increased beyond 0.8) the energy target cannot be met, because there are not enough profitable sites in the study region to meet the target. Given the model at hand we are able to conclude that with regard to the local conditions found in the study region the initial tariff IT should not be much smaller than 9 cent/kWh and the minimum yield ratio λ not much larger than 0.7. Altogether, IT≈9cent/kWh and λ≈0.7 are the optimal choices – figures which quite well resemble the actual ones offered in the German

Renewable Energy Sources Act (BGBl, 2011). We find that threshold values of $IT \approx 9$ cent/kWh and $\lambda \approx 0.7$ beyond which the minimum total cost increases and the threshold values $IT \approx 8$ cent/kWh and $\lambda \approx 0.8$ beyond which the energy target cannot be met do not depend on the size of the energy target nor on society's valuation of the external effects of wind power. We can therefore conclude that the above considerations about the optimal levels of $IT \approx 9$ cent/kWh and $\lambda \approx 0.7$ are quite robust with regard to changes in society's preferences and the size of the energy target. For policy makers this indicates first of all that there is no need to adjust the present FIT levels with respect to negative externalities in the study region.

However, one should note that our analysis is limited to some extent and results should be interpreted with caution. Firstly, we did not take all externalities determined in the choice experiment into account in the optimization procedure. The reason for not considering the size of wind farms and height of turbines is that preferences toward these attributes are highly heterogeneous. As providing, for example, large and small wind farms is not possible at the same location, we used for the purpose of simplification only the preferences for distance of turbines from residential areas and the impact on the Red Kite population. For these attributes preferences show less heterogeneity and the average is statistically significant for the whole sample. A step ahead might be to conduct the analysis for sub regions with more homogenous preferences towards wind power. Secondly, our analysis assumes that WT are allocated in a welfare-optimal manner, i.e. the total (production plus external) cost of producing a given amount of electricity is minimised. This is likely to be not fully achieved in reality. Thirdly, another shortcoming is that we did not include external effects such as visual impacts and other burdens from power lines that transport the electricity from the WT to the consumers (Doukas et al. 2010; Navrud et al. 2008). In the assessment of the costs of wind power production we further ignored the cost of reserve generation which is required due to the intermittent nature of wind energy (Borenstein 2011).

In addition to considering these limitations further studies are required to show whether the values of IT and λ specified in the German Renewable Energy Sources Act are generally welfare-optimal. Data collected for the present study are case-specific and may not necessarily apply to other regions. At the coast, for instance, wind conditions and landscape externalities are probably different from our study region influencing the welfare-optimal level of the FIT. However, the present study is the first that investigates the link between the FIT level and negative externalities of renewables. It demonstrates the importance of welfare-economic considerations in the design of FIT and provides a framework that allows analysing the welfare optimal design of FIT for wind power production. One can conclude from our study that countries which want to newly set up FIT programmes should take externalities into account in order to avoid inappropriate FIT levels that lead to excessively high negative externalities.

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