How to cope with externalities of wind power development? - Combining *Ecological-Economic Modelling* and *Choice Experiments* in a German case study

Preliminary draft (do not cite)

Ohl, C. [a], Drechsler, M. [b], Eichhorn, M. [b], Meyerhoff, J. [c], Monsees, J. [a], Johst, K. [b]

[a] Helmholtz Centre for Environmental Research - UFZ, Department of Economics, Permoserstr. 15, 04318 Leipzig, Germany.

[b] Helmholtz Centre for Environmental Research - UFZ, Department of Ecological Systems Analysis, Permoserstr. 15, 04318 Leipzig, Germany.

[c] TU Berlin, Chair in Environmental and Land Economics, Sekr. EB 4-2, Straße des 17. Juni 145, 10623 Berlin, Germany.

Contact:

Cornelia Ohl, Department of Economics, Permoserstrasse 15, 04318 Leipzig, Germany, cornelia.ohl@ufz.de.

How to cope with externalities of wind power development? - Combining *Ecological-Economic Modelling* and *Choice Experiments* in a German case study

1. Introduction

In future, wind power is to contribute decisively toward achieving energy and climate policy goals. In Germany wind power onshore should be raised from 5% (2006) to 10% (2030) (BMU 2006: 4). On the level of local residents, however, the building of new turbines or the replacement of older ones by modern turbines (Repowering) is often disapproved. Residents dislike the impacts on human health due to shadow and noise effects of the turbines (e.g., Hau, 2006; Rogers et al. 2006), the visual impact on the landscape (e.g., Krause, 2001; Möller, 2006) and on biodiversity, especially on birds and bats (e.g., Bright et al., 2008; Hötker et al., 2006). From an economic point of view, these effects are externalities that show impact on social welfare. The quality and the extend of these externalities critically depend on the characteristics of the sites selected for wind power development – for example, the distance of selected areas to settlement districts and bird habitats. The site-specific externalities are frequently hard to determine because they are not covered by markets and therefore have no price. Consequently, policy makers lack guidelines for a proper placement of sites for wind power development. In turn, the externalities are usually not minimised and the policy makers fail to maximize the social welfare. This may also be the reason why wind power development – even if generally supported by society (e.g., Kuckartz and Rheingans-Heintze, 2006; Zoellner et al., 2008) – is resisted at the local level. In order to increase the quota of renewable energy supply decisively in future by wind power development it is therefore important to gather information on the significance, respectively, the extent of its negative impacts on humans and nature in a spatially explicit context. Studies on this issue are for example provided by Álvarez-Farizo and Hanley (2002), Dimitropoulos and Kontoleon (2008), Ek (2006), Groothius et al. (2008). These studies, inter alia, clearly show that wind power development poses social cost. However, so far, none of these studies aims to incorporate their empirical results in a modelling framework that delivers concrete recommendations for the selection of welfare maximising sites. In this paper we make a first attempt in this direction and present an ecological-economic modelling framework that makes use of empirical knowledge on site-specific externalities of wind power development. This framework should support the identification of welfare optimising sites and thus deliver guidance for policy makers in search of local areas for deployment of the wind resource.

The paper is structured as follows: In section 2 we will introduce our study region and the modelling framework. The framework consists of a GIS-based evaluation of relevant externalities, the monetary valuation of these externalities, a ranking of the sites with regard to their contribution to welfare and a selection of the welfare maximising sites. Section 3 will present the results for the various steps of the analysis and Section 4 summarises and closes with an outlook.

2. Methods

2.1 Study region and physical evaluation of externalities

The study region comprises the area of the planning region West Saxony which is a part of the Free State of Saxony with about 1,000,000 residents (2005) and an area of around 4.300km². (Fig. 1)

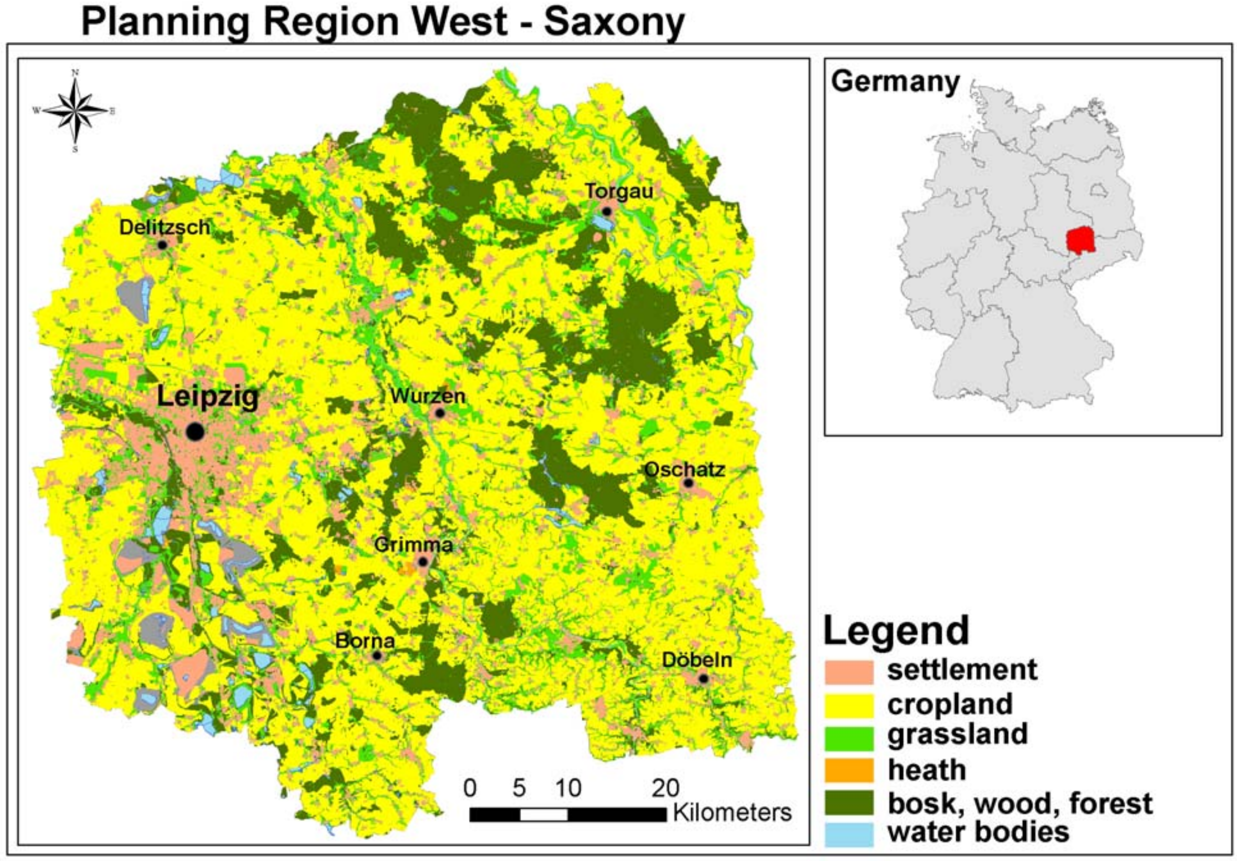

Figure 1: The planning region West-Saxony (RPV WS 2008)

Due to its topography the region is well suited for wind power production but at the same time belongs to the core distributional area of the endangered red kite (*Milvus mulvus*) (e.g., BirdLife International 2009). Red kites have been frequently observed to be killed by wind turbines (WTs). We focus on this effect in terms of an additional species population decline of magnitude *L* (measured in percent within the next 20 years) which represents one of the here considered externalities of wind turbines (WTs) (cf. Dürr 2008). The other externality we consider is the disturbance of humans, especially by noise and visual impacts. In this regard three attributes of WTs are important: The height (*H*) of the WTs, the minimum distance (*D*) of WTs to settlements, and the clustering of WTs, characterised by the typical size (*S*) of a wind park.

We start our analysis by identifying the "suitability space", which comprises those parts of the landscape that are physically and legally qualified for the allocation of WTs with the help of a geographical information system (GIS) of the region. Broadly speaking, these are open areas distant enough from infrastructure, settlements and nature conservation areas. The analysis focuses on a 2 MW WT which at present is viewed as a state-of-the-art technology. Regarding the WT in question and the German regulations on noise emissions (TA Lärm, 1998) sound emissions are within legal limits at distances above 750m. The suitability space is displayed as a grid of points. Each point in the grid represents a potential site for the allocation of a WT, taking technical minimum distances between individual WTs into account. Land-use scenarios are defined by deciding for each potential WT site within the suitability space whether it should contain a WT or not. With 1020 potential sites in West Saxony, the number of land-use scenarios is 2^{1020}.

Having specified the suitability space we determine the externalities of regional wind power development by focusing on a given energy output, *E*, depending on the parameter *H* which is given by the choice of the WT technology. The energy output *E* is calculated by summing the annual energy outputs of all installed WTs in the region. For each WT the energy output E_{WT} is calculated using the technical parameters of the WT in question (2 MW WT with a hub height of 80m and a total height of H=121m) and the relevant frequency distribution of wind speeds $f(v)$ observed at the location and altitude of the WT (for further details, see Eichhorn and Drechsler in prep.):

$$E_{\mathrm{WT}} = t\int f(v)P(v)dv \qquad (1)$$

where $P(v)$ is the power generated by the WT in question at wind speed v and

$$t = 8760 \int_{v_{\min}}^{v_{\max}} f(v) dv \qquad (2)$$

is the number of operating hours of the WT per year ($v_{\min}$ and $v_{\max}$ are the wind speed bounds between which the WT operates).

No we turn to the externality L. In the study region, by mid-2007, 221 WTs produced approximately 345 GWh electricity per year[1] which will serve as a baseline. Although the construction of WTs in conservation areas is excluded from the analysis, some species may be disturbed outside these areas. In the study region the most strongly affected species is the endangered red kite (*Milvus milvus*) whose world wide density centre is located near the study region. The impact of a WT on the red kite is based on the estimated probability of red kites colliding with WTs (Eichhorn and Drechsler in prep.). This probability $\pi(r)$ declines with increasing distance r between the WT and the bird's aerie. We assume $\pi(r)$ to have a Gaussian shape with parameters chosen to match field observations (e.g., Nachtigall 2008). Since red kites are rarely encountered at distances above 3 km from their aeries) we model $\pi(r)$ as:

$$\pi(r) = e^{-(r/3\text{km})^2} . \qquad (3)$$

The probability of a red kite colliding with any of the potential WTs in the study region is obtained by summing the probabilities of the individual WTs. We denote the distance between the i-th WT and the j-th aerie as r_{ij}. If there are N WTs and M aeries in the region the collision probability for the study region amounts to:

$$\pi_{tot} = \sum_{i=1}^{N} \sum_{j=1}^{M} \pi(r_{ij}) \qquad (4)$$

For the evaluations below we need to translate the probability π into a population loss rate L. Expert's observations according to Hötker (2006) suggest that the population loss caused by all WTs currently installed in the study region amounts to about 0.25 percent per year which corresponds to L=5. Evaluation of eq. (4) for the currently installed WTs in the region

---

[1] The information on existing turbines is based on H. J. Schlegel. Energy Efficiency Centre in the Saxony Office for the Environment and Geology. Information given personally, 11 February 2008.

delivers a value of about π_{tot}=400. Assuming a linear relationship between *L* and π_{tot} we write

$$L = 5\pi_{tot} / 400 = \pi_{tot} / 80 \tag{5}$$

Using multi-criteria analysis we determine the set of non-dominated land-use scenarios with regard to the criteria *E*, *L* and *D* (see section 2.2.)[2]. A scenario is termed non-dominated if no other scenario exists that outperforms the considered scenario in at least one attribute without underperforming in at least one other. The set of non-dominated scenarios is also termed efficiency frontier (e.g., Polasky et al. 2008). In this study we assume that the amount of energy to be produced is fixed by the policy maker at 690 GWh (status quo: 345 GWh) and focus on the efficiency frontier with regard to the two attributes, *L* and *D*.

2.2 Economic valuation of the externalities

In this paper we use choice experiments (CE) to assess the externalities of wind power development in monetaty terms. CE belong to the group of stated preference methods. They establish hypothetical markets through using surveys for valuing environmental changes (Kanninen, 2007). It is assumed that the utility to consumers of any good (i.e., also public goods such as a landscape) is derived from its attributes or characteristics. Therefore, in a choice experiment respondents are asked to make comparisons among environmental alternatives characterised by a variety of attributes and the levels of these. Typically, respondents are offered multiple choices during the survey each presenting alternative designs of the environmental change in question and the option to choose neither, i.e., to choose for instance a status quo option. The record of choices is used to estimate the respondents' willingness to pay (WTP) by modelling the probability of an alternative being chosen. Due to their focus on the attributes of a good CE are particularly useful for valuing multidimensional changes.

In a random utility model (RUM) the utility an individual *n* receives from choosing an alternative *i* (U_{ni}) consists of a systematic component (V_{ni}) and a random error component (ε_{ni}) resulting in the following utility function:

$$U_{ni} = V_{ni} + \varepsilon_{ni} \tag{6}$$

---

[2] The wind park size *S* turns out to have insignificant influence of the economic valuation of the externalities (see section 3.2) and thus is not considered any further.

Individual *n* will select an alternative *i* from the choice set C if the utility of alternative *i* is greater than the utility of any other alternative *j*:

$$P_{ni} = Pr\,\mathrm{ob}(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj}), \forall i, j \in C, j \neq i\,. \qquad (7)$$

Assuming that the error components are distributed independently and identically (IID) and follow the Gumbel distribution, the probability that alternative *i* is chosen is calculated in the *conditional logit* (CL) model as follows:

$$P_{ni} = \frac{exp[\,\mu\beta_k X_{ki}\,]}{\sum_{j\in C} exp[\,\mu\beta_k X_{kj}\,]}, \qquad (8)$$

where the scale parameter μ of the error distribution is normalized to one, and omitted, β_k is the vector of preference parameters associated with attribute k, X_{ki} is attribute *k* of alternative *i*. The estimates from the CL are contrasted with estimates from an error component logit (ECL) (Scarpa et al., 2005). This is motivated by the expectation that the Programmes B and C share an extra error component because both programmes describe tighter regulations reducing potential externalities from wind power generation. Thus, correlations between the stochastic portions of utility form these programmes may be present. Due to the additional error component there is no independence of irrelevant alternatives. The ECL therefore can also take into account that a sequence of choices was undertaken be the same individual (panel data setting).

Changes in welfare due to a marginal change in a given attribute are calculated using the marginal willingness to pay (MWTP) measure. It is defined as the maximum amount of income a person will pay in exchange for an improvement in the level of a given attribute provided. The measure can be calculated by dividing the coefficient of the attribute of interest $\beta_{attribute}$ by the coefficient of the price attribute β_{money}, representing the marginal utility of income.

In order to gather knowledge on the local preferences for future wind power development choice experiments were conducted in May and June 2008. All interviews were conducted via telephone, i.e., interviewees were contacted by random digit dialling and asked whether they are willing to participate in the survey. If they agreed, a date for the main interview was arranged and they were mailed the information about the objective of the survey, detailed descriptions of the attributes and the choice sets. Table 1 reports the attributes and their levels used to design the choice sets. A D-optimal fractional factorial design consisting of 40 choice sets was identified. The sets were blocked into 8 subgroups with 5 choice sets and each block was presented to 44 respondents at least. A first version of the questionnaire and the choice sets were discussed with residents of West-Saxony during the three focus group meetings with altogether 25 participants. Before the main survey was conducted a pilot study was carried out in both regions. Overall, 353 interviews were completed. In the course of the interview respondents were first presented the choice sets (Table 2) and were subsequently asked a couple of questions concerning their experience with wind power and their attitudes toward it. Finally, some socio-demographics were requested.

Table 1: Attributes and levels used in the choice experiment

Attributes	Information given*	Levels
Size of wind farms (*S*)	Larger wind farms generally lower the costs of electricity production but the bigger they are the bigger could be their influence on the landscape; when farms are larger in total fewer farms are needed to produce the same amount of electricity.	**Large (16 to 18 mills)** medium (10 to 12 mills) small (4 to 6 mills)
Maximum height of turbines (*H*)	The higher turbines are the more electricity can be generated because winds are stronger and more constant at higher altitudes. On the other hand visibility increases with height.	110 meter 150 meter **200 meter**
Effect on red kite; population loss (*L*)	Turbines would not be installed in conservation areas but also outside these areas conflicts may arise. For example, negative impacts on birds such as the red kite would further decrease populations. The levels indicate the loss of the population until 2020 in West Saxony.	5% **10%** 15%
Minimum distance to town (*D*)	Due to regulation turbines have to keep a minimum distance to towns and villages in order to avoid adverse effects through, e.g., noise or shading. Programme A with a minimum distance of 750 metres complies with these regulations. Visibility would diminish with higher distances.	**750 meter** 1.100 meter 1.500 meter
Monthly surcharge to power bill (PR)	Programme A presents today’s state of technology and enables to produce electricity from wind at low-costs. Programmes B and C would lead to higher costs, e.g., for infrastructure such as longer power cables, and thus require a surcharge to the monthly power bill.	**€0** €1 €2.5 €4 €6

Avoided carbon dioxide emissions	All three programmes would avoid the same amount of CO_2; in West Saxony 570,000 t per year.	Not included in choice sets

Note: Bold levels are those of the no-buy alternative (Programme A); * Compared to the German version presented to interviewees' information is presented in a condensed way.

Table 2: Example of a choice set

Wind power in West Saxony until 2020	**Programme A**	**Programme B**	**Programme C**
Size of wind farms	large farms	small farms	large farms
Maximum height of turbines	200 meter	110 meter	110 meter
Effect on red kite population	10%	5%	10%
Minimum distance to town	750 meter	1.100 meter	1.500 meter
Monthly surcharge to power bill	€ 0	€ 6,-	€ 1,-
I choose	☐	☐	☐

3. Results

3.1 The physical evaluation of the externalities: the efficiency frontier

Figure 2 shows the efficiency frontier with regard to the two attributes *L* and *D*. The efficiency frontier contains the non-dominated land-use scenarios (cf. section 2.1) and shows for a given level of *L* the maximum (most preferred by residents) level of *D* that can be achieved. As can be seen, for a given level of energy production there is a trade-off between *L* and *D*, i.e., an increase in the settlement distance *D* implies an increase in population loss *L*. Interestingly, the , slope of the efficiency frontier increases with increasing energy production (compare the upper and the lower curve in Fig. 2).

It is further important to note that there is a maximum to the settlement distance *D* (i.e., a maximum of the minimum distance that a WT may have to settlements) For instance, the energy production level of 345 GWh per year (lower line) can only be produced if the WTs to be erected are allowed to have distances to settlements of 1100m or smaller. If we demand WTs to have distances to settlements larger than 1100m, then, the energy production level of

345 GWh cannot be reached. If more energy is to be produced (upper line) the maximum settlement distance is even smaller – society must accept WTs at distances of 1000m or less.

Figure 2 also shows the baseline in the study region (termed as current situation) in comparison to the efficiency frontier. An amount of 345 GWh is produced at a population loss rate of *L*=5 and at a minimum settlement distance of *D*=800. Regarding the baseline it turns out that, at the same time, it is possible to reduce population loss *L* and to increase the settlement distance *D* by a different placement of the WTs, keeping the energy production at the current level of 345 GWh (compare the current situation with the values for L and D along the 345 GWh-line).

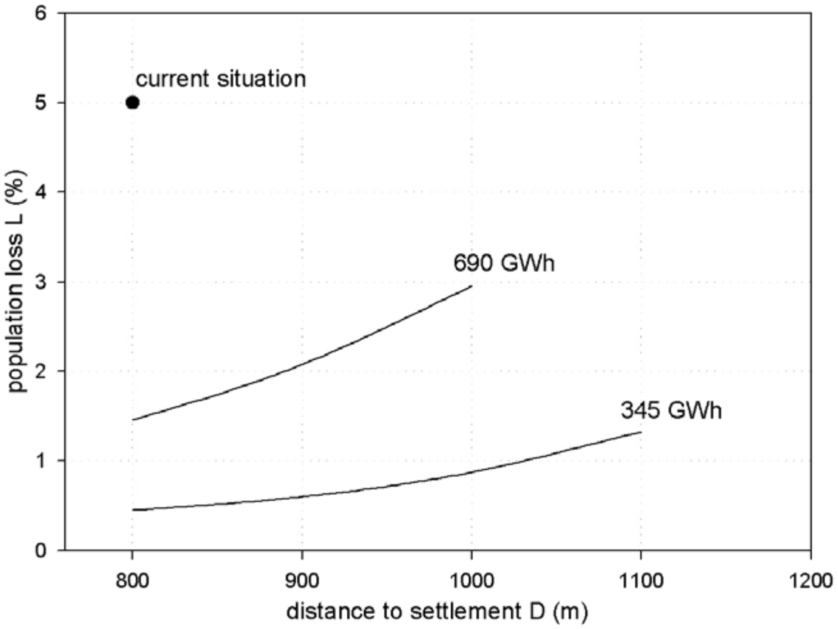

Figure 2: Efficiency frontier: the population loss *L* with regard to the red kite population in the study region as a function of the chosen settlement distance *D*. Upper and lower lines represent annual energy production levels in the region of 345 GWh and 690 GWh, respectively. The analysis is based on the assumptions that throughout the study region energy is produced by a 2MW WT.

3.2 The economic valuation of the externalities

Table 3 shows the estimates from the conditional logit model (CL) and the error component logit model (ECL); both show a similar pattern. The coefficients for the price variables are significant with the expected negative sign. Increasing prices lower the likelihood that a certain alternative is chosen. The positively significant ASC_{ProA} relating to Programme A indicates that ceteris paribus respondents would experience positive utility from Programme

A. Both times the parameters for red kite and minimum distance are significant showing that individuals prefer to reduce the impact of turbines on the red kite population and prefer to move turbines further away from villages compared to the baseline of 750 metres distance. On the other hand, the parameters for wind farm size and turbine height are not significant. Whether wind power generation would take place with large or small turbines, for instance, does not influence choices systematically. The reason for this could be preference heterogeneity, i.e., respondents preferences might be strongly opposed and thus cancel each other out.[3] The error component that introduces correlation between Programme B and Programme C is highly significant and indicates heterogeneity across individuals with their preferences for the two alternatives that would reduce externalities from wind power generation. Overall, the fit of the CL is rather low while the ECL taking the panel character of the data into account performs much better.

Table 3: Estimation results

Attribute	**CL**		**ECL**	
	Parameter (t-value)	MWTP in € per month	Parameter (t-value)	MWTP in € per month
ASC_{ProA}	0.683 (4.778)		0.873 (2.95)	
Wind farm: medium	0.088 (1.525)	n.s.	0.092 (1.36)	n.s.
Wind farm small	-0.022 (-0.384)	n.s.	-0.001 (-0.01)	n.s.
Max. Height turbine: 110	0.023 (0.414)	n.s.	0.06 (0.99)	n.s.
Max. Height turbine: 150	-0.016 (-0.297)	n.s.	-0.039 (-0.63)	n.s.
Red kite: 5%	0.417 (7.453)	2.23 (1.02 — 3.44)	0.583 (9.82)	2.13 (1.24 — 3.01)
Red kite: 15%	-0.462 (-7.534)	-3.03 (-4.50 — -1.55)	-0.639 (-9.46)	-2.81 (-4.01 — -1.61)
Minimum distance: 1100	0.142 (2.556)	3.18 (1.72 — 4.63)	0.199 (3.00)	3.18 (2.12 — 4.24)
Minimum distance: 1500	0.248 (4.528)	3.81 (2.28 — 5.34)	0.388 (6.58)	3.94 (2.82 — 5.07)
Price	-0.168 (-7.109)		-0.247 (-10.10)	
$EC_{ProBProC}$			3.658 (11.66)	
No. of observations	1765		1765	
(S)Log-L	-1742.13		-1371.86	
Pseudo R^2	0.03		0.29	

Note: 95% confidence intervals were calculated using the Krinsky-Robb method; **MWTP = marginal willingness to pay; CL = conditional logit model; ECL = error component logit model**

---

[3] An application of the latent class model reveals that preference heterogeneity is indeed present. For example, respondents in one segment prefer smaller wind farms as in Programme A (Meyerhoff et al., 2009).

The results from the CE clearly indicate that substantial efficiency gains are expected to result if wind power production takes place by a reallocation of WTs such that the current situation is shifted to a point on the efficiency frontier. The optimal point to choose depends on the marginal WTP for the significant attributes (MWTP) as also reported in Table 3. For example, based on the estimations from the CL respondents would pay € 2.2 per month to reduce the impacts on the red kite population from 10% to 5%. The MWTP for moving turbines to a distance of 1100 metres amounts to € 3.18 and for moving them to 1500 metres to € 3.81. The MWTP based on the ECL is in the same order of magnitude for both attributes but the confidence intervals are smaller. Thus, in the following we use the estimates from the ECL as an input for the modelling of the optimal WT allocation.

Starting from the baseline: 10% red kite population loss, 750m distance to settlement areas, the monthly willingness to pay of respondents

a) is positive if *L* is reduced from 10% to 5% red kite population loss (MWTP = 2.13 Euros),
b) is negative if *L* is increased from 10% to 15% (MWTP=- 2.81 Euros),
c) is positive if the settlement distance *D* is increased from 750m to 1100m (MWTP=3.18 Euros), and
d) is also positive if *D* increases from 750m to 1500m (MWTP=3.94 Euros).

These results can be used to determine the parameters *a*, *b*, *A* and *B* of eqs. (9) and (10), leading to the iso-utility lines shown in Fig. 3. One can se that utility increases with increasing settlement distance *D* and decreasing population loss *L*.

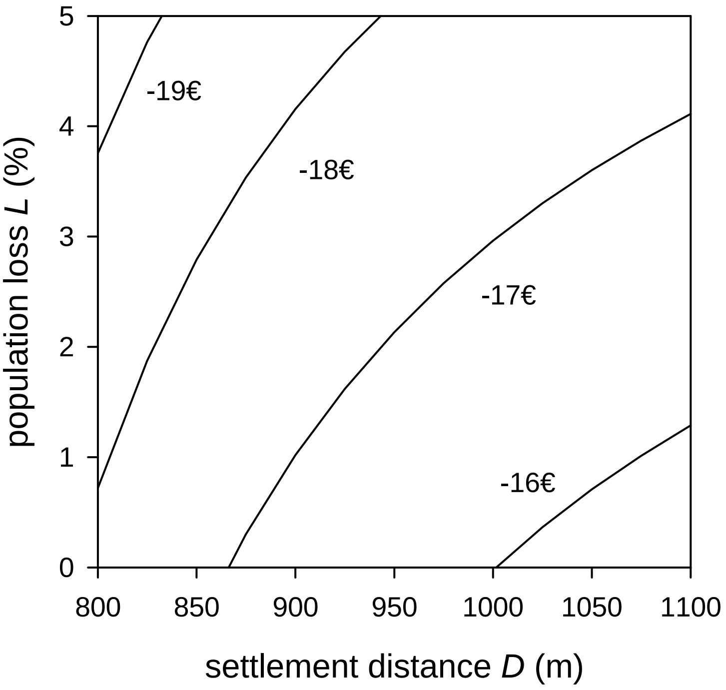

Figure 3: Iso-utility lines (utility is measured in Euros per person per month).

3.3 Identification of optimal sites for future wind power development

The evaluation of the choice experiments delivers the marginal willingness to pay (MWTP, measured in € per person per month) for the different levels of the attributes *L* and *D* (the other attributes (*H* and *S*) analysed in the choice experiments turned out to affect the MWTP only insignificantly. Therefore we only use the results for *L* and *D* in order to construct a utility function that describes the demand for the two attributes. We assume that the utility function is composed additively from the partial utilities,

$$U(L,D) = U_1(L) + U_2(D) \tag{9}$$

where $U_1(L)$ is the partial utility derived from red kite loss, $U_2(D)$ the partial utility of the settlement distance. Assuming that marginal utility is declining in the attributes *L* and *D*, we choose the following functional forms for U_1 and U_2:

$$U_1(L) \equiv \frac{a}{L-A} \text{ and } U_2(D) \equiv \frac{b}{D-B} \tag{10}$$

with *a*, *b*, *A* and *B* some constants.

In order to determine the welfare optimal settlement distance *D**, the iso-utility lines of Fig. 3 need to be overlaid with the efficiency frontiers of Fig. 2, as shown in Fig. 4. In order to identify the optimal settlement distance *D** for the current annual energy production level of 345 GWh, we have to identify the point on the lower dashed line (Fig. 4) that intersects or touches the solid line with the highest possible utility. That point is found on the iso-utility line associated with utility -16€. The optimal settlement distance *D** is the end point of the lower dashed line (star in Fig. 4) – which is the maximum possible value for settlement distance allowing to produce the amount of 345 GWh per year and identified in Fig. 2 at point *D**=1100m. Similarly, to identify the optimal settlement distance for the energy production level of 690 GWh, we have to identify the point on the upper dashed line (Fig. 4) that intersects or touches the solid line with the highest possible utility. That point is found on the line associated with utility -17€ and the optimal settlement distance is again the maximum possible value for settlement distance allowing to produce the amount of 690 GWh per year and identified in Fig. 2 at point *D**=1000m. The utility here is 1 Euro smaller than the one associated with the welfare optimising WT allocation for 345 GWh. This decrease in the utility indicates that within the scope of our example, an increased level of wind energy production from currently 345 GWh to 690 GWh in future is expected to reduce social welfare. However, comparting the optimal WT allocation allowing to produce 690 GWh with the current (inefficient) situation (compare the dot in the upper left corner with the star on the 690GWh line), the welfare optimising allocation of WT involves both an increase in the settlement distance *D* and a reduction of the red kite population loss rate *L* and would consequently lead to an improvement in social welfare.

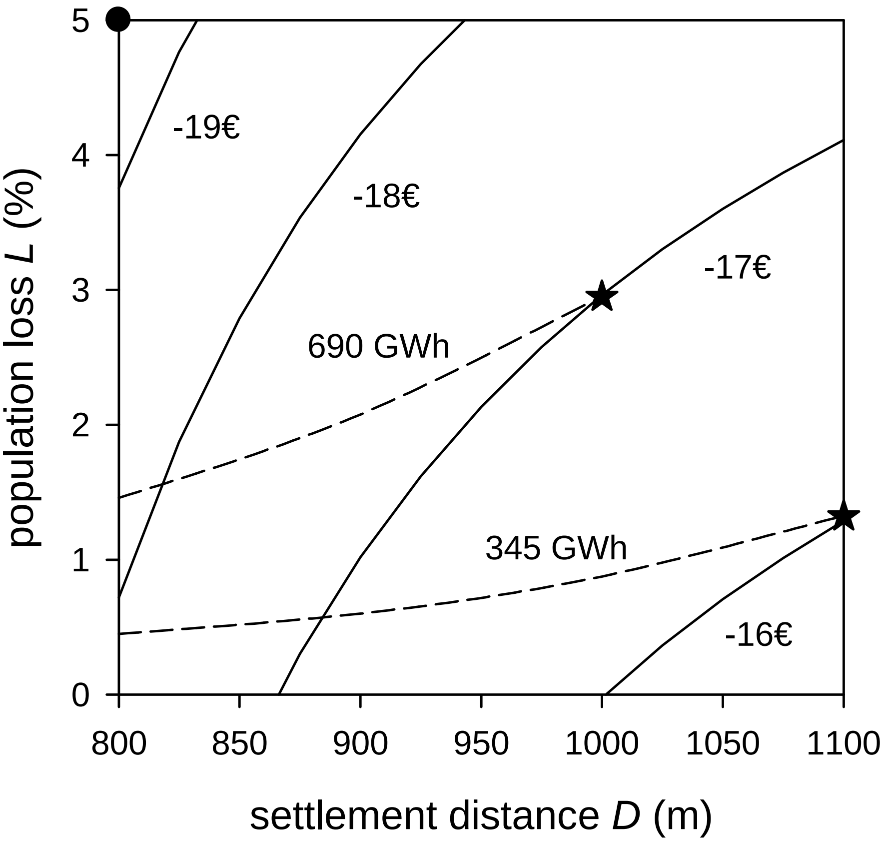

Figure 4: The trade-off between population loss and settlement distance. Solid lines: iso-utility curves (cf. Fig. 3), dashed lines: efficiency frontier for the two considered energy production levels. The welfare optimal settlement distance (and corresponding population loss rate) is given by the point on the efficiency frontier that leads to the maximum possible utility (shown by stars). The current situation in the region is represented by the dot in the upper left corner of the panel..

4. Discusssion

The results of our study indicate that an increased level of wind energy production (from 345 GWh to 690 GWh) is expected to reduce social welfare if both levels are produced efficiently. The current situation in West Saxony however is inefficient with regard to the externalities and land use options in questions here. Therefore the shift from the inefficient supply of 345 GWh to an efficient supply of 690 GWh is able to result in lower externalities and thus a welfare improvement. The results of the CE motivate this by the expected decrease in red kite population loss as well as an increasing distance between WTs and settlement areas in the case of optimal WT allocation. With regard to an efficient WT allocation in the baseline scenario this would not hold because an increase in the energy production level would lead to lower optimal settlement distances. If more energy is produced more WTs need to be installed in the region. The amount of regional land area suitable for WT erection however is given and the distance between this land area and the settlements usually not altered within the time horizon of the analysis (in general a reallocation of settlements would be feasible but most often it is only due to long term demographic changes). In addition an increase of wind energy supply requires more land area for WT erection within the suitability space. Consequently, more areas are occupied by WTs which in the study area implies that more land area needs to be taken up with a distance closer to the settlements. In other words, if not enough land area with maximum distance to settlements is found for producing the politically set energy target, land area closer to settlements will be needed for WT erection. In the study region this also increases the impact on the red kite which is as disliked by the respondents as is the decrease in the distance to the settlements. This leads to a decrease of social welfare if the number of WTs increases for a doubling of the quota of wind energy supply in case of efficient energy production in the baseline scenario. Regarding the current situation which supplies wind energy inefficiently, this negative effect on social welfare can be compensated by an optimal design of WT allocation. Against this background it is crucial to note that the impact on social welfare depends on the height of the turbines, even though in the CE the height turned out to be insignificant. The reason is that taller WTs are more efficient in terms of energy production because wind blows more strongly and constantly at higher altitudes. A politically set target for wind power development could thus be produced with a lower number of erected WTs if their height increases. As reported in e.g., dena (2005), Ohl and Eichhorn (2008) taller WTs show positive effects regarding the uptake of land area such that a fixed energy target can frequently be produced by lower number of turbines and a lower demand for land area compared to smaller turbine types. As a result this effect might also counterbalance the expected welfare loss in the study region if wind energy would be produced efficiently in the current situation and, compared to the currently inefficient situation; it might further increase social welfare. In future the deployment of the wind resource by means of repowering seems thus to be advantageous.

5. Summary and outlook

"The paper introduces an integrative approach for determining the landscape related externalities from onshore wind power in order to draw conclusion for a sustainable and socially optimal wind power development until 2020 and beyond. We applied an ecological-economic modelling framework (EEMF) which considers that wind energy can be supplied by different modes of production. Among others these depend on technical turbine parameters and the spatial distribution of turbines in the landscape. Five such characteristics of wind power generation were defined as attributes of environmental changes and presented for valuation in a choice experiment (CE) in summer 2008 to the public in our study region West Saxony. The results from the choice experiments delivered monetary values for the landscape related externalities from local wind power generation and were integrated in the EEMF. In a first step the EEMF used a geographic information system (GIS) in order to identify potential sites for the generation of wind power in the study region, i.e. the suitability space. In step 2 each location was assessed in terms of its wind energy yield and the value it delivers for nature protection, the latter being indicated by an expected red kite population loss due to the operation of wind turbines. This procedure delivered the supply side for regional wind power development. In step 3 we turned to the demand side and evaluated the societal preferences for wind power development at the considered regional level. In step 4 we used the results of the CE for constructing a utility function that delivers information on the socially optimal placement of wind turbines in West Saxony. The goal was to provide quantitative measures of the trade-offs between the attributes in order to integrate them in the EEMF and to assess the potential sites for wind power development in terms of their social costs. In the final step 5 we identified those sites at which a certain quota of wind energy could be produced with a minimum of negative externalities. This procedure provides guidance for the process of pre-selecting sites for a controlled development of regional wind power generation as currently followed in Germany and other regions of the world. For the study region it showed that substantial improvements in social welfare are feasible by the reallocation of the wind turbines erected in the region and that efficient wind energy supply in future, even if the regional wind energy quota is expected to double, may lead to improvements in social welfare. The rationale behind is that the externalities from inefficient wind energy supply are outweighed by lower externalities of an efficient supply, even if wind energy is to double from currently annually 345 GWh to 690 GWH in future. In order to further elaborate on this result it is a scope for future research to aim at further extensions of the approach presented here, especially, the integration of further variables in the EEMF, e.g. a cost component and an alternative technology choice"

Acknowledgement

The authors wish to thank the Ministry for Education and Research for funding the research project “Conflicts of interest over wind power” [Nachhaltige Landnutzung im Spannungsfeld umweltpolitisch konfligierender Zielsetzungen am Beispiel der Windenergiegewinnung] (Grant No. 01UN0601A,B) as a part of the fona Programme “Economics for Sustainability [Wirtschaftswissenschaften für Nachhaltigkeit] (WIN)”. We also wish to thank the West Saxony Regional Planning Office for the constructive cooperation and commentary.

Literature

Alvarez-Farizo, B., Hanley, N., 2002. Using Conjoint Analysis to Quantify Public Preferences over the Environmental Impacts of Wind Farms. An Example from Spain. Energy Policy 30, 107-116.

Bright, J., Langston, R., Bullman, R., Evans, R., Gardener, S., Pearce-Higgins, J., 2008. Map of bird sensitivities to wind farms in Scotland: A tool to aid planning and conservation. Biological Conservation 141 (9), 2342-2356.

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Ministry for the Environment, Protection of Nature and Reactor Safety) (BMU) (2008a). Den Herausforderungen der Energie- und Klimapolitik erfolgreich begegnen - Hintergrundpapier zur Verabschiedung des zweiten Maßnahmenpaketes des integrierten Energie- und Klimaprogramms der Bundesregierung. (Successfully Coming to Terms with the Challenges of Energy and Climate Policies – background article on the adoption of the second measure package of the federal integrated energy and climate programme). http://www.erneuerbare-energien.de/inhalt/41818/ (10 September 2008).

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Ministry for the Environment, Protection of Nature and Reactor Safety) (BMU) (2008b). Erneuerbaren Energien in Zahlen – Nationale und internationale Entwicklungen. Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat). Redaktion: Referat KI III 1, Allgemeine und grundsätzliche Angelegenheiten der Erneuerbaren Energien. (Renewable Energies in Figures – National and international Developments. Workgroup Renewable Energies Statistics (AGEE-Stat). Eds. Work Group KI III 1, General and Basic Matters of Renewable Energies).

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Ministry for the Environment, Protection of Nature and Reactor Safety) (BMU) (2006). Themenpapier: Windenergie (Position paper: Wind energy). Artikel-Nr. 2123; Redaktion: KI III 3.

Deutsche Energie-Agentur (German Energy Agency) (dena) 2005. Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020 (Energy Planning for the Grid Feed-in of Wind Power on Land and Offshore in Germany up to 2020). Study on behalf of DENA by the consortium DEWI, E-ON/Netz, EWI, RWE Transportnetz Strom, and Vattenfall Europe Transmission. Cologne. URL: http://www.dena.de/fileadmin/user_upload/Download/Dokumente/Projekte/kraftwerke_netze/netzstudie1/dena-netzstudie_1_haupttext.pdf.

Dimitropoulos, A., Kontoleon, A., 2008. Assessing the Determinants of Local Acceptability of Wind Farm Investment: A Choice Experiment in the Greek Islands. Cambridge, UK.

Dürr T. 2008. Vogelverluste an Windenergieanlagen in Deutschland, Daten aus der zentralen Fundkartei der Staatlichen Vogelschutzwarte im Landesumweltamt Brandenburg Stand September 2008. (transl. Bird's losses on wind power engines in Germany, data from the central finding card index of the state ornithological station in the environmental authority of Brandenburg. state September, 2008). [online] URL: http://www.mluv.brandenburg.de/cms/media.php/2334/wka_vogel.pdf

Ek, K., 2006. Quantifying the Environmental Impacts of Renewable Energy: The Case of Swedish Wind Power. In: D. Pearce (Ed.), Environmental Valuation in Developed Countries: Case Studies. Edward Elgar, Cheltenham, pp. 181-210.

Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act) (EEG) 2009.

Hau, E. 2006. Wind Turbines. Fundamentals, Technology, Application, Economics. Springer, Berlin/Heidelberg.

Hötker H., Thomsen K. M. Jeromin H. 2006. Impacts on biodiversity of exploitation of renewable energy sources: the example of birds and bats – facts, gaps in knowledge, demands for further research, and ornithological guidelines for the development of renewable energy exploitation. Michael-Otto-Institut im NABU, Bergenhusen. [online] URL:http://www.batsandwind.org/pdf/impacts%20on%20biodiversity%20of%20renewable%20energy.pdf .

Kanninen, B. (ed.) 2006. Valuing Environmental Amenities Using Stated Choice Studies. Dordrecht.

Krause, C. L., 2001. Our visual landscape: Managing the landscape under special consideration of visual aspects. Landscape and Urban Planning 54, 239-254.

Kuckartz, U., Rheingans-Heintze, A., 2006. Trends im Umweltbewusstsein. Umweltgerechtigkeit, Lebensqualität und persönliches Engagement. Wiesbaden.

Menegaki, A. 2008. Valuation for Renewable Energy: A Comparative Review. Renewable and Sustainable Energy Reviews 12, 2422-2437.

Meyerhoff, J., Ohl, C., Hartje, V. (2009). Landscape externalities from onshore wind power. Berlin (unpublished manuscript)

Möller, B., 2006. Changing wind-power landscapes: regional assessment of visual impact on land use and population in Northern Jutland, Denmark. Applied Energy 83, 477-494.

Nachtigall W. 2008. Der Rotmilan (*Milvus milvus*, L. 1758) in Sachsen und Südbrandenburg – Untersuchungen zu Verbreitung und Ökologie. Dissertation, Martin-Luther-Universität Halle –Wittenberg. [online] URL: http://sundoc.bibliothek.uni-halle.de/diss-online/08/08H218/index.htm .

Ohl, C., M. Eichhorn 2008. Nachhaltige Landnutzung im Kontext der Windenergie – Rationierung von Flächen als Antwort auf die energiepolitischen Ziele der Klimapolitik. (Sustainable Land Use: Example Wind Power – Rationing Sites as an Answer to the Energy Policy Goals of Climate Policy). Journal of Environmental Law and Policy 4, 517-540.

Pearce, D., 2006. Introduction: Valuing Environments in the Rich World. In: Pearce, D. (Ed.), Environmental Valuation in Developed Countries. Edward Elgar, Cheltenham.

Polasky S., Nelson E., Camm J., Csuti B., Fackler P., Lonsdorf E., Montgomery C., White D., Arthur J., Graber-Yonts B., Haight R., Kagan J., Starfield A., Tobalske C. 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. Biological Conservation 141: 1505-1524.

Rogers, A.L., Manwell, J. F., Wright, S. 2002, amended 2006. Wind Turbine Acoustic Noise – A White Paper. Renewable Energy Research Laboratory Department of Mechanical and

Industrial Engineering University of Massachusetts at Amherst Amherst, MA 01003 413-545-4359. www.ceere.org/rerl. URL: http://www.wind-watch.org/documents/wp-content/uploads/rogers-windturbinenoise_rev2006.pdf .

Scarpa, R., Ferrini, S., Willis, K. (2005). Performance of Error Component Models for Status-Quo Effects in Choice Experiments. In: R. Scarpa and A. Alberini (eds.), Applications of Simulation Methods in Environmental and Resource Economics. Dordrecht, 247-273.

Zoellner, J., Schweizer-Ries, P., Wemheuer, C., 2008. Public Acceptance of Renewable Energies: Results from Case Studies in Germany. *Energy Policy* 36, 4136-4141.