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ORIGINAL PAPER

Influence of onshore wind turbines on land values

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Abstract The economic consequences of wind turbines on property prices and land values are a widely discussed political and social issue. In this study, in addition to the previous research on the impact of wind turbines on property prices, the influence of wind turbines on standard land values was examined for the first time. The study thus provides new insights, particularly with regard to the debate on distance areas and financial compensation payments for residents.

The chosen investigated area is located in Northern Germany and comprises three coastal districts in the state Schleswig-Holstein with a total of 1382 land zones and a high density of wind turbines. Using ordinary least squares models, the significant influence of wind turbines on the standard land values could be shown within a radius of up to 9 km. Using an exemplary municipality for the study area, an average change in the standard land value of 7.33% per 1000 m distance could be determined. Overall, the standard land values of less densely populated areas were affected more than urban areas.

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Einfluss von Onshore-Windenergieanlagen auf den Grundstückswert

Zusammenfassung Die wirtschaftlichen Auswirkungen von Windenergieanlagen auf Immobilienpreise und Bodenwerte sind ein viel diskutiertes politisches und gesellschaftliches Thema. In dieser Studie wurde, neben den bisherigen Untersuchungen zu den Auswirkungen von Windenergieanlagen auf die Immobilienpreise, erstmals auch der Einfluss von Windenergieanlagen auf Bodenrichtwerte untersucht. Damit liefert die Studie neue Erkenntnisse, insbesondere im Hinblick auf die Diskussion um Abstandsflächen und finanzielle Ausgleichszahlungen für Anwohner.

Das gewählte Untersuchungsgebiet liegt in Norddeutschland, umfasst drei küstennahe Kreise im Bundesland Schleswig-Holstein mit insgesamt 1382 Bodenrichtwertzonen und weist eine hohe Dichte an Windenergieanlagen auf. Mit Hilfe von Regressionsmodellen (OLS) konnte der signifikante Einfluss von Windenergieanlagen auf die Bodenrichtwerte in einem Radius von bis zu 9 km nachgewiesen werden. Anhand einer Beispielgemeinde für das Untersuchungsgebiet konnte eine durchschnittliche Bodenrichtwertänderung von 7,33 % pro 1000 m Entfernung ermittelt werden. Insgesamt waren die Bodenrichtwerte von weniger dicht besiedelten Gebieten stärker betroffen als die von urbaneren Gebieten.

1 Introduction

Based on the serious consequences of the advancing global climate change, almost all countries have set themselves the task of limiting the increase in global warming and reducing greenhouse gas emissions in the long term. The energy sector in particular, which is the largest emitter of greenhouse gases in Germany (Umweltbundesamt 2020), has been assigned a central role in this context. A decisive component of global climate protection measures relates to energy system transformation, with the aim of minimising energy production from fossil fuels and expanding regenerative methods.

The Federal Republic of Germany is internationally regarded as one of the pioneers in the implementation of climate protection measures. In 2018, renewable energies accounted for 37.8% of Germany's total gross electricity consumption. With 17.0% of total electricity generation, wind energy is by far the most important renewable energy source in Germany. 89.1% of the 58.9 gigawatts generated by wind turbines in 2018 were generated on land, the remaining 10.9% at sea (BMWi 2020).

With the climate protection targets for the years 2030 and 2050 and the Erneuerbare-Energien-Gesetz (EEG 2014), which was last revised in 2017, the German government has defined precise goals to meet the agreed climate protection targets. With regard to wind energy, the Federal Government intends to further expand offshore wind farms in particular and to repower onshore plants (Umweltbundesamt

2016)[1,2]. One of the reasons for this approach is the massive opposition from parts of the inhabitants to the large-scale expansion of onshore wind farms. Aspects of nature and species protection are particularly much discussed; residents also point out possible health risks and disturbing visual and acoustic effects on humans and animals. In addition, broad sections of the inhabitants assume that wind turbines in the vicinity can have negative effects on real estate prices and the value development of land (Eichenauer 2018), as can be the case with motorways and airports (Allen et al. 2015; Levkovich et al. 2016; Mense and Kholodilin 2012). The federal and state governments are therefore trying to increase acceptance in the affected areas by stipulating distance regulations and financial compensation. The extent to which these measures can compensate for possible long-term losses in value is currently subject of much debate.

Previous studies with a focus on the real estate sector have mainly dealt with the influence of wind turbines on offer and/or sales prices. In addition to these findings, this study analysed the influence of wind turbines on standard land values in Germany. Standard land values serve as comparative values and can be used to determine the land value within the framework of property valuation. In contrast to previous studies, only undeveloped land and objective values, i.e. no developed land and subjectively influenced prices, were considered. This also allows conclusions to be drawn as to whether people's subjective opinion regarding the relationship between wind turbines and standard land values can be substantiated by means of purely objective values.

The study area chosen for the analysis covers the districts of North Frisia, Schleswig-Flensburg and Steinburg, which together account for about one third of the area of the federal state of Schleswig-Holstein. The statistical evaluation of the data is carried out using the Ordinary Least Squares Method (hereinafter referred to as OLS), which has also proved its worth in studies already carried out on this subject area.

This paper is structured as follows: In the second section, the current state of research is reviewed. Subsequently, the data basis for the investigation carried out is presented and evaluated. This is followed by a description of the analysis procedure, which was carried out with the statistical program R.[3] The empirical results are summarised in section five and finally discussed in the last part.

2 State of research

Climate change is a recurrent topic of controversial discussions and contributions in the media due to its far-reaching consequences. As a result, the energy system

[1] "Onshore installations are located on land, offshore installations in deeper waters." FIS (2019).

[2] The term "repowering" stands for the replacement of old plants by new plants. As a rule, the number of wind turbines is reduced, while at the same time the yield is increased by more modern plant technology (BWE 2017).

[3] "R" is a freely accessible programming language for statistical and graphical calculations. The R Studio user interface was also used in this analysis (Kohn and Öztürk 2017).

transformation and wind energy are also attracting ever greater interest in society, with the result that in recent years there have been an increasing number of studies on the ecological and economic advantages and disadvantages of wind energy. The influence of wind turbines on property prices has been the subject of several international and national studies.

The studies carried out in America were mostly unable to show a significant influence of wind turbines on real estate prices. Lang et al. (2014) analysed more than 48,000 single-family homes in the state of Rhode Island using a difference-in-difference approach. No correlation was found with properties located less than half a mile from the nearest wind turbine. The same results were obtained in an updated study by Hoen et al. (2015) in which, using a hedonic valuation method, more than 50,000 nationwide sales were examined at different distances from wind turbines. Hoen and Atkinson-Palombo (2016) confirmed these findings with their analysis of over 122,000 real estate transactions over a 14-year period in densely populated areas of Massachusetts. A study by Heintzelman and Tuttle (2012), using a fixed-effects model to examine over 11,000 real estate sales in New York State, provided partially contradictory findings. A hedonic analysis conducted by Castleberry and Greene (2018) revealed no price changes related to wind turbines, neither for populated nor unpopulated properties.

In Europe the observed influences on real estate prices from wind turbines remain ambiguous. Jensen et al. (2018) examined around 40% of Denmark's total area in their study and found that, within a radius of 3km around a wind turbine, property prices are negatively influenced. In addition, they demonstrated a correlation between the number of wind turbines and the amount of price decrease. Studies from the Netherlands and England also found that the visibility of the plant has a decisive influence (Gibbons 2015; Dröes and Koster 2014). Gibbons (2015) found that properties with visible wind turbines within a radius of 2km have a 5–6% decrease in value. This effect depended largely on the height of the wind turbines. For Greece, Skenteris et al. (2019) applied various hedonic pricing models to evaluate the visual impact of wind farms on dwelling prices. Depending on their modelling setup, they found either no significant effects or a negative correlation within 2km radius. Westlund and Wilhelmsson (2021) found reductions in the value of Swedish properties in vicinity to wind turbines, which exponentially decrease in distance. Moreover, their results indicate that not only the sheer existence of such turbines but also their number and their height impacts value changes.

For Germany, there are local case studies available which could either identify corresponding impacts or not. The city of Aachen investigated the influence of the "Vetschauer Berg" wind farm on a nearby development area. Contrary to the assumptions of critics, a price increase was found here, which the authors attributed to the good residential location, despite the visible wind farm (Stadt Aachen 2011). A study by the Aurich expert committee in Lower Saxony came to the conclusion that wind turbines do not have a significant influence on the purchase prices of single-family homes (Gutachterausschuss für Grundstückswerte Aurich 2020). Langer et al. (2018) used multinomial logit regressions to assess the acceptance of wind energy by the German population. They found no significant general influence of the distance to wind turbines on the acceptance, but rather identified different groups within the population and highlighted the importance of procedural and distributive justice. In contrast to the studies rejecting a clear impact of wind turbines on land values, several other studies indicate such a connection. Sunak and Madlener (2016) took disturbing variables into account, the authors found that their difference-in-difference approach had a significant effect of 9–14% on the offer prices when a wind turbine has a clear visual impact on the property. The most recent study is provided by Frondel et al. (2019), who have evaluated more than 2.7 million offer prices over the years 2007 to 2015 using an OLS model. An average negative influence of 7.1% was found for properties located within one kilometre of a wind turbine. The influence decreases steadily up to a distance of 8–9 km from the plant, after which no further effect could be determined. With up to 23.0%, wind turbines have a particularly high influence on the supply prices of old and rural properties, whereas no significant effect was observed in urban areas. The results of Sunak and Madlener (2016), who applied augmented spatial models on German data, imply that sheer distance to wind turbines is of less importance than the actual visual impact on a specific dwelling or property. They found no devaluation of properties with a minor or marginal view on proximate wind turbines.

3 Data basis

The investigations carried out are based on the above-mentioned findings and methods of previous studies but are clearly differentiated in fundamental aspects.

In contrast to Frondel et al. (2019), the data examined here came from only one federal state and not from the entire federal territory. The federal state of Schleswig-Holstein was deliberately chosen for the analysis, as it is particularly well suited for the analysis, on the one hand because of the high number of wind turbines compared to the rest of Germany, and on the other hand because of its specific topographic structures. Due to the low average height of the terrain, there are hardly any natural disturbance factors, apart from forests, which limit the visibility of wind turbines. In addition, economically induced distortions can be minimized by the homogeneous infrastructure over the whole country, the few large cities and conurbations.

The data on the investigated land zones and the associated standard land values were provided free of charge in advance by the expert committee of real estate professionals (Gutachterausschuss) of the districts of North Frisia, Schleswig-Flensburg and Steinburg. As outlined in § 192 of the Town and Country Planning Code (BauGB 2017), the expert committees for real estate values are independent authorities consisting of real estate professionals who ensure transparency on the real estate market. According to §§ 193–196 of the BauGB and the Valuation Ordinance (ImmoWertV), the expert committees of the federal states must recalculate the standard land value every two years. The basis for the calculations is the purchase price surveys, in which all actual property sales, heritable building rights and exchange transactions are recorded. The underlying data are provided by the notarising office (§ 195 BauGB). This procedure for price survey and subsequent evaluation provides a comprehensive picture of the actual market situation for the whole of Germany.

Table 1 Descriptive statistics of land zones and wind turbines

	Mean	Standard deviation	Minimum	Maximum
Standard land value in €	69.8	52.522	0.0	1250.0
Inhabitants in 1000	5.777	8.583	0.011	31.879
Commissioning date	2009	7.489	1992	2018
Hub height in m	78.17	21.01	40.0	144.0
Distance in km	2.569	1.819	0.0	8.674
Number of observations	1382			

The hub height was available for 896 and the commissioning date for 895 of the observations

The standard land value can thus be defined as the average value of one square meter of undeveloped land (BauGB § 196 (1)). Features influencing the value (§ 3 clause 2 ImmoWertV) have to be allowed for by increases, reductions or in other appropriate ways (cp. § 4 clause 1 ff VW-RL[4]). Such features include, in particular, the location of the property, rights and encumbrances dormant in it, admissible type and the extent of its development, its shape, adjacent public services nature of soil.

The use of standard land values in the analyses carried out here is thus a novelty, as the risk of distortions in the evaluation of selective sales prices is excluded as best as possible. This adds more reliability to the results as the bias which may be caused by specific circumstances of land transactions is eliminated. Since the standard land values for Germany are also available for the whole country, this procedure can be replicated for other regions without any problems. In this analysis, only land zones were examined which are also released for residential purposes. In their studies, Sunak and Madlener (2016) and Frondel et al. (2019) examined the supply and sale prices of real estate. Since people tend to behave irrationally when perceiving prices and may be influenced emotionally (Felser, 2010), this approach is susceptible to distortions. The lack of objectivity towards prices has already been observed with regard to the perception of property prices (Salzman and Zwinkels 2017). This problem can be circumvented by evaluating the standardised standard land values determined by the expert committees[5].

Since the determination of the standard land values is also based on undeveloped land, no building characteristics need to be taken into account, as is the case when evaluating offer or sales prices. The inhabitants figures for the municipalities were obtained from the websites of the respective municipality and the freely accessible statistics site Tilasto.com.

The data of the wind turbines were provided free of charge for this elaboration by the Ministry of the Interior, Rural Areas and Integration of the State of Schleswig-Holstein. The data set includes the wind turbines that are currently in operation as

[4] Comparative Valuation Guidelines as of 20 March 2014.

[5] "The market value (market value) is determined by the price that would be obtainable in the normal course of business at the time to which the determination refers, according to the legal circumstances and actual characteristics, the other nature and location of the property or other object of the valuation, without regard to unusual or personal circumstances." (BauGB § 194).

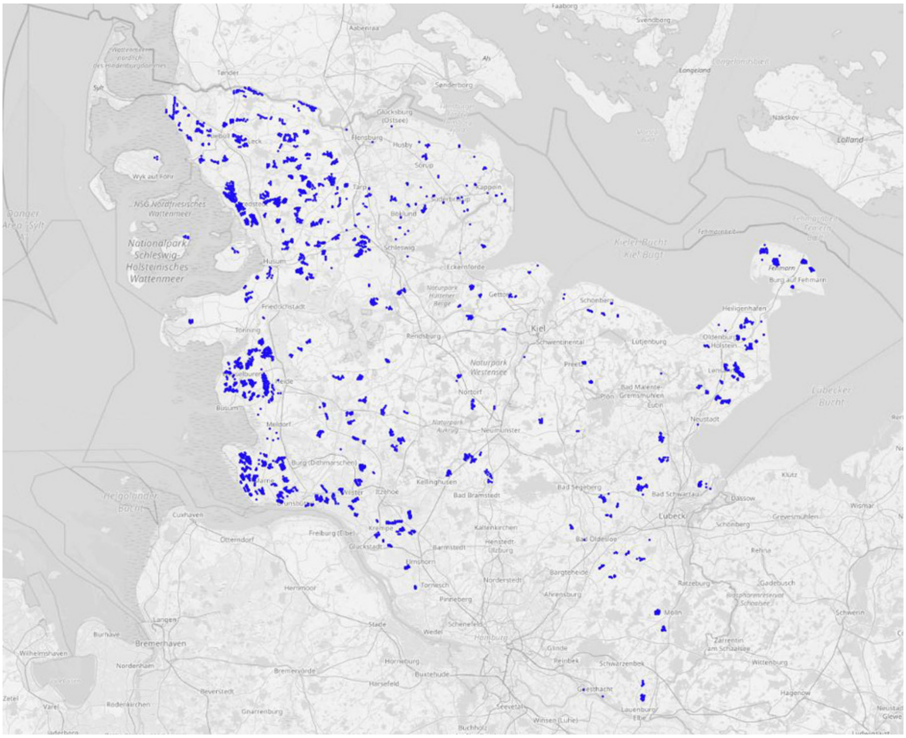

Fig. 1 Wind turbines in Schleswig-Holstein. (Source: openstreetmap.de)

well as those that are about to be put into operation. The present data set comprises a total of 3150 wind turbines located via the east and north values.

The three districts investigated are characterised by the fact that they contain about 50% of the total wind turbines of the federal state and all land zones have a wind turbine at a distance of less than 9 km. North Frisia and Steinburg border directly on the North Sea, Schleswig-Flensburg the Baltic Sea. It has to be noted, that some of the analysed land zones include wind turbines and thus the distance to the next wind turbine is defined as 0.0 m in our data set. Further, the height and commissioning date are not available for all observations which leads to some limitations in the analysis (cf. Table 1).

Table 1 shows the descriptive evaluation of the available data of the land zones and the wind turbines for the 1382 zones examined.

Figure 1 shows the distribution of wind turbines in the state, it is clearly visible that especially in the analysed north-eastern regions more wind turbinesare located.

The distance between the 1382 land zones under consideration and the nearest wind turbine in operation could be measured digitally by georeferencing the data. The influence of overlapping effects of several wind turbines was not considered.

As can be seen in Fig. 2, more than two thirds of the land zones have a wind turbine within a radius of up to 3 km. This covers in particular the area where previous studies could show the greatest influence on offer and sales prices. Due

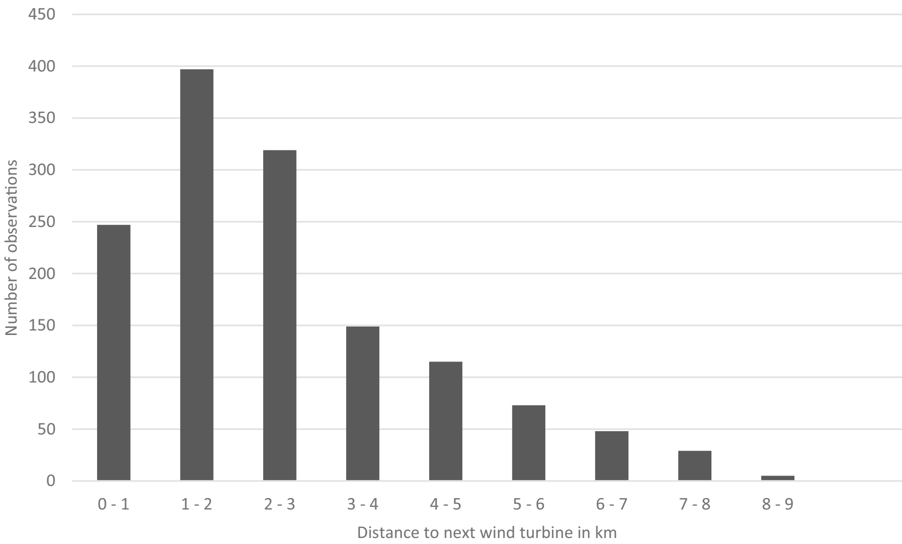

Fig. 2 Distance to next wind turbine

to the large sample, however, the distances 3–4 km and 4–5 km are also represented with over 100 observations each.

4 Methodology

Based on the social discussion and the findings of research on the relevance of the visual effects, two hypotheses were derived that specifically describe the visual influence of wind turbines. The the distance from the land zone (cf. Hypothesis 1) and height (cf. Hypothesis 2) are decisive for the visibility of the turbines. Since it can be assumed that urban areas are less susceptible for this influences, and rural areas predominate in the investigated area, this correlation was considered separately in Hypothesis 4. In order to determine whether a negative effect of the installation of new wind turbines can be detected in the chronological development of standard values we also take the date of commissioning into account (cf. Hypothesis 3).

Following these research objectives, the following hypotheses were derived:

1. The distance between the land zones and the next wind turbine influences the standard land values (H_A)
2. The hub height of the wind turbine increases the influence on the standard land values (H_A)
3. On the basis of the commissioning data of the wind turbines, a change in the temporal development of the standard land values can be detected (H_A)
4. The size of the municipality (measured in terms of inhabitants) influences the impact of the wind turbines on the standard land value (H_A)

To clarify the listed theses, the statistical correlation was determined using the OLS method. The regression model is described by the following equation:

$$y_i = \beta_0 + \beta_j * x_{j,i} + u_i$$

with:

$i =$ 1, ..., n
$ij =$ 1, ..., k

In our study, the endogenous variable y is the standard land value in €/sqm, which is explained by the exogenous variable(s) x. These variables are the distance in (1) meters, the (2) hub height of the wind turbines in meters, the (3) commissioning date and the (4) size of the municipality measured by the number of inhabitants. The parameters β_0 and β_j are estimated, u_i represents the residuals. The calculation of the parameters was carried out according to the explanations of Mittag (2012), using the corrected variance.

In the first step of the analysis, an attempt was first made to check the Hypotheses 1 and 3 with simple regressions and to demonstrate the fundamental connection between the influence of the wind turbines and the standard land values. In a subsequent model, all variables were considered in order to be able to show the interaction of the variables with each other.

In the last analysis step the grouped inhabitants and distances were evaluated in further models. In this way, specific variations in the coefficients and significance can be determined and at the same time results that are well comparable to other studies can be determined. The distances were divided from 0–9 km into classes of 1000 m each (cf. Figure 2). The class 0–1 km serves as a reference class. The inhabitants were divided into six groups (<500; ≥500; ≥1000; ≥2000; ≥5000; ≥10,000), the group <500 inhabitants serves as reference class (cf. Table 9 in Appendix).

Further, for every model we use random effects to improve the robustness and reduce the omitted variable bias. These are at first the zone ID to take local effects into account and second we consider each year to have specific effects. Note, that these random effects are estimated but not shown in the following regression tables.

5 Evaluation

The following section is divided into the description of the results of the study and the subsequent discussion with classification in the existing literature.

5.1 Research results

As shown in Table 2, the simple regression analysis provides clear results with respect to the first hypothesis. With a p-value of $< 2e^{-16}$ a very significant influence of the variable "distance" on the standard land values could be found. The coefficient of 5.117 describes that with an increase of the distance by one kilometre, the standard land value of a land zone increases by 5.117 €/sqm on average.

Table 2 OLS regression for distance

	Coefficients	Standard Errors
Distance in km	5.117***	(0.458)
Number of Observations	10,895	
Adj. R^2	0.908	

Significance codes '***' = 0.001; '**' = 0.01; '*' = 0.05; '.' = 0.1 and ' ' = 1

In contrast, the commissioning date appears to have no significant effect (cf. Table 6 in Appendix).

In order to clarify whether the height of the wind turbine increases the effect of the distance, both variables were evaluated in a multiple regression (cf. Table 7 in Appendix). It is shown that height alone does not have a significant influence on the standard land values, but it does increase the effect of distance by 0.111 for every additional meter of height. Alternatively one can state that with increasing distance between the land zone and the wind turbine, the height of the wind turbine becomes more important. In a further calculation, the population of the municipality was evaluated (cf. Table 8 in Appendix). A significant influence can also be determined here (–0.413), thus one can interpret that the larger the municipality, the less influence the wind turbines have on the standard land value.

Moreover, differentiated results were obtained by considering all variables in only one model (cf. Table 3). The significance of the variables "distance", "inhabitants" and "hub height" can be confirmed, while the effect of the "commissioning date" stays insignificant. The interaction of the first three variables is also significant at a measurement level of 0.05. This can be interpreted in many different ways, for example that the negative effect of "hub height" on the distance effect is lower the more inhabitants live in the zone. The adjusted R^2-value of 0.925 shows that the combination of the variables can still add more explanatory power to the model.

Table 4 shows the results of the evaluation of the distance classes and inhabitant groups. The coefficient represents in each case the percentage change of the standard land value in comparison to the reference group (0–1 km; 0–499 inhabitants).

Table 3 OLS regression including all variables

	Coefficients	Standard errors
Distance in km	20.825***	(2.261)
Inhabitants in 1000	7.787***	(1.739)
Hub height in m	0.289**	(0.132)
Commissioning date	0.093	(0.243)
Distance × Inhabitants	–1.083***	(0.304)
Inhabitants × Hub height	–0.038	(0.026)
Distance × Hub height	–0.165***	(0.026)
Distance × Inhabitants × Hub height	0.008*	(0.004)
Number of observations	7140	
Adj. R^2	0.925	

Table 4 OLS regression for distances and inhabitants

	Coefficients	Standard errors
1–2 km distance	6.664***	(1.662)
2–3 km distance	7.332***	(2.067)
3–4 km distance	11.838***	(2.463)
4–5 km distance	2.429	(2.587)
5–6 km distance	28.696***	(3.168)
6–7 km distance	63.015***	(3.573)
7–8 km distance	45.732***	(4.400)
8–9 km distance	31.867***	(9.359)
500–999 inhabitants	2.755	(2.706)
1000–1999 inhabitants	15.983***	(2.890)
2000–4999 inhabitants	54.293***	(3.401)
5000–9999 inhabitants	51.388***	(4.219)
10,000 and more inhabitants	64.670***	(4.187)
Number of observations	10,895	
Adj. R^2	0.915	

As already stated in model 1, it can also be seen from the distance classes that the standard land value increases with increasing distance from the wind turbine. The slightly higher explanatory power than Table 8 confirms that the splitting into categories may be meaningful. In fact, all results are very significant, except for the coefficients for the classes 4–5 km and 500–999 inhabitants. In contrast to model 1, this evaluation also shows the sometimes large differences between the individual distance classes. The existing irregularities could not be conclusively clarified, but in-depth analyses (cf. Table 9 in Appendix) and the results of Frondel et al. (2019) indicate that they can be explained by an insufficient sample. Further, it should be highlighted, that the category of 5–6 km as well as all above show a rather high increase in land values. Thus, this distance may be considered as a threshold where the effect of wind turbines strongly declines.

The evaluation of the inhabitant groups also shows that the size of the municipality has a strong influence on the standard land values. Across all distance categories, very significant effects on the standard land values can be observed. At the same time, it can be concluded from the figures Table 9 that the effect of the distance categories on the standard land value depends strongly on the size of the respective municipality.

Until now, we focused on the general values while time was included by random effects. When considering prices, it is natural that they change over time. Further, one can assume that the influence of the different observed variables changes as people care more or less about wind turbines over time. Table 5 shows how these effects change over the observed years. First, it has to be considered that the time itself has a positive impact on prices. With roughly 3.611 €/sqm price increase per year it is slightly above the inflation level. Interestingly, the effect for distance also increases over time. This indicates that people became more sensitive to the presence

Table 5 OLS regression effects over time

	Coefficients	Standard Errors
Distance in km	17.286***	(2.286)
Inhabitants in 1000	7.675***	(1.743)
Hub height in m	0.385***	(0.133)
Commissioning date	0.109	(0.241)
Year	3.611***	(0.811)
Distance × Inhabitants	–1.138***	(0.302)
Distance × Hub height	–0.166***	(0.026)
Inhabitants × Hub height	–0.031	(0.026)
Distance × Year	0.898***	(0.104)
Inhabitants × Year	–0.013	(0.029)
Hub height × Year	–0.045***	(0.010)
Distance × Inhabitants × Hub height	0.007*	(0.004)
Number of observations	7140	
Adj. R^2	0.926	

of wind turbines over the last years. However, this effect cannot be observed for the height of the turbines.

Overall, the inclusion of time as an additional variable has increased the model's accuracy very minimally compared to Table 3. Including the different years as dummy variables shows a steady and significant rise of land prices over time which approves the assumed linear relation.

Following the evaluations, the results were validated by checking the data. The examination of the residuals showed that the assumed normal distribution was present.

5.2 Discussion

The established correlations between standard land values and wind turbines favour the alternative hypotheses. We observe a significant negative influence of wind turbines on standard land values as previously expected.

Evaluations of the effect of distance on the standard land values show similar tendencies as the results of Frondel et al. (2019), with the exception of the outlier in the distance class 4–5 km. Although the visibility of the wind turbines was not explicitly checked, the effects of these important variables (Sunak and Madlener 2016; Frondel et al. 2019; Gibbons 2015; Dröes and Koster 2014) are detectable for the area under investigation. Due to the different investigation methods, the distance class 0–1 km, which is particularly meaningful in Frondel et al. (2019), cannot be compared. The changes in the standard land value with increasing distance are altogether higher than the influences on property prices described by Frondel et al. (2019). One possible explanation is that the sample includes a particularly large number of small municipalities that are strongly affected by wind turbines, as Frondel et al. (2019) have also demonstrated for rural properties.

The strong influences of wind turbines at close distances (1–3 km) were also shown in the investigations of Gibbons (2015) and Jensen et al. (2018). Both investigations indicate a price reduction up to 6%. Gibbons (2015) found a correlation with the height of the wind turbine, which could also be shown in this analysis (cf. Table 7 in Appendix). The additional overlapping effects of several turbines in the vicinity of the property, as determined by Jensen et al. (2018), have not been taken into account in this study. This factor offers great potential for further analyses, since there are many wind farms[6] installed in addition to individual wind turbines in Schleswig-Holstein.

Hoen and Atkinson-Palombo (2016) have investigated the effect of newly constructed wind farms, but without finding a significant correlation between the construction of a new wind farm and a change in the transaction prices of real estate. In contrast, Dröes and Koster (2014) found a significant negative effect on property prices even when the plant was still in the planning phase and construction was pending. The missing correlation between the commissioning date and the standard land values, as demonstrated in this study, can be compared with the results of Hoen and Atkinson-Palombo (2016) although more densely built-up areas were explicitly investigated there. Dröes and Koster (2014) as here analyse rather sparsely populated areas. Nonetheless, the estimated effects differ.

The results of this investigation represent the evaluation of the sample of the selected investigation area with a high density of wind turbines. The analysis primarily relies on the distance of a land zone to the closest wind turbine, but neglects other factors such as the number of wind turbines and the actual visibility of the installations (Sunak and Madlener 2016) closeby. Several geographical variables, such as the socio-economic structure or the rural or urban character of the study area have not been taken into account. Specific local policy practices (such as participation strategies (Musall and Kuik 2011; Langer et al. 2018)) have not been considered and should be addressed by future researchers.

Additionally, the models only show the correlation of the variables which may not necessarily mean causation in every case. Thus, for example it may be the case that lower land values may attract more investors to build wind turbines in that area.

6 Summary and conclusion

In Germany, the expansion of wind energy is regarded as a central component of the energy turnaround. Despite the growing awareness among the population of the necessity of climate protection measures, their negative economic and ecological consequences are increasingly being discussed. The effects of wind turbines on property prices have been investigated in a series of studies over the past ten years. As a supplement to previous studies, this paper is the first to determine the influence of wind turbines on standard land values, using three districts in Schleswig-Holstein as examples.

[6] A wind farm is deemed to exist "if three or more wind turbines are spatially allocated to each other in such a way that their areas of influence overlap or at least touch each other" (BVerwG, Urteil v. 30. Juni 2004—4 C 9/03—, juris.).

With the help of the OLS and mixed effects models, significant influences of wind turbines on standard land values could be determined. According to the results, the standard land value increases with increasing distance from the wind turbines. For the variable "distance" strong positive influence on the standard land value could be shown. The number of inhabitants per zone and the height of the turbine show a significant negative influence on this effect. In a model calculation in which all variables were adjusted to the area under investigation an average effect of 7.33% on the standard land value per 1000 m distance could be determined. Striking higher valuations of land zones are found for zones not closer than 5 km to the next turbine in comparison to more proximate zones. Note, that this finding might be biased by omitted variables. The results are consistent with a strain of the literature from Germany and other European countries, which have already been able to determine similar effects on offer and sales prices.

The present study gives support to those literature strains that suggest a connection between wind turbines and the loss of land values. The study estimates valuation effects on the basis of objective values determined by expert committees, which, in contrast to the property prices formed on the market, are rather robust against possible distortions caused by subjective influences. The distance areas for wind turbines, which are much discussed in politics and by experts, are intended in particular to minimize disturbing visual and acoustic effects on residents. With regard to the loss in value of land, the results show that although increasing the distance has a positive effect on the standard land value. In addition, it was shown that other factors must be considered which, in combination with the distance, have a significant influence on the change in standard land values. Considering the impact of wind turbines on land values could increase the acceptance of local population towards wind turbines.

7 Appendix

Table 6 Table OLS Regression comissioning date

	Coefficients	Standard errors
Comissioning date	0.024	(0.190)
Number of observations	7140	
Adj. R^2	0.921	

Table 7 Table OLS regression hub height

	Coefficients	Standard errors
Hub height in m	0.111	(0.092)
Distance in km	15.821***	(1.972)
Height × Distance	–0.111***	(0.023)
Number of observations	7148	
Adj. R^2	0.923	

Table 8 Table OLS regression inhabitants

	Coefficients	Standard errors
Distance in km	6.107***	(0.497)
Inhabitants	4.118***	(0.284)
Distance × inhabitants	–0.413***	(0.066)
Number of observations	10,895	
Adj. R^2	0.911	

Table 9 Table OLS regression distance and inhabitants II (1/2)

	Coefficients	Standard errors
1–2 km distance	5.476	(3.531)
2–3 km distance	–1.172	(6.024)
3–4 km distance	3.677	(5.948)
4–5 km distance	–3.844	(6.453)
5–6 km distance	3.767	(7.085)
6–7 km distance	8.952	(7.262)
7–8 km distance	34.690***	(8.407)
8–9 km distance	7.005	(25.732)
500–999 inhabitants	–0.870	(4.395)
1000–1999 inhabitants	6.551	(5.248)
2000–4999 inhabitants	21.700***	(5.354)
5000–9999 inhabitants	35.276***	(6.455)
10,000 and more inhabitants	80.164***	(7.391)
1–2 km × 500–999	2.267	(4.478)
2–3 km × 500–999	11.546	(7.218)
3–4 km × 500–999	5.201	(8.071)
4–5 km × 500–999	18.557**	(7.850)
5–6 km × 500–999	21.957**	(9.057)
6–7 km × 500–999	13.768	(9.288)
7–8 km × 500–999	–14.383	(10.216)
8–9 km × 500–999	6.524	(28.491)
1–2 km × 1000–1999	3.154	(5.420)
2–3 km × 1000–1999	9.032	(7.622)
3–4 km × 1000–1999	5.740	(8.327)
4–5 km × 1000–1999	15.187*	(8.469)
5–6 km × 1000–1999	6.709	(10.090)

Table 9 (Continued)

	Coefficients	Standard errors
6–7 km × 1000–1999	7.643	(10.780)
7–8 km × 1000–1999	–9.807	(17.969)
8–9 km × 1000–1999	18.782	(30.291)
1–2 km × 2000–4999	–1.122	(4.981)
2–3 km × 2000–4999	9.469	(7.642)
3–4 km × 2000–4999	8.379	(8.001)
4–5 km × 2000–4999	7.069	(8.774)
5–6 km × 2000–4999	119.737***	(9.909)
6–7 km × 2000–4999	300.563***	(11.207)
7–8 km × 2000–4999	NA	NA
8–9 km × 2000–4999	NA	NA
1–2 km × 5000–9999	2.013	(6.170)
2–3 km × 5000–9999	6.010	(8.364)

Table 10 OLS Regression distance and inhabitants II (2/2)

	Coefficients	Standard errors
3–4 km × 5000–9999	57.124***	(10.485)
4–5 km × 5000–9999	16.561	(19.971)
5–6 km × 5000–9999	106.579***	(14.627)
6–7 km × 5000–9999	NA	NA
7–8 km × 5000–9999	NA	NA
8–9 km × 5000–9999	NA	NA
1–2 km × 10,000 and more	–15.398**	(6.840)
2–3 km × 10,000 and more	–11.001	(8.602)
3–4 km × 10,000 and more	–18.848**	(8.903)
4–5 km × 10,000 and more	–50.760***	(10.362)
5–6 km × 10,000 and more	–29.749**	(12.117)
6–7 km × 10,000 and more	–22.431*	(13.242)
7–8 km × 10,000 and more	–12.524	(15.657)
8–9 km × 10,000 and more	NA	NA
Number of observations	10,895	
Adj. R^2	0.927	

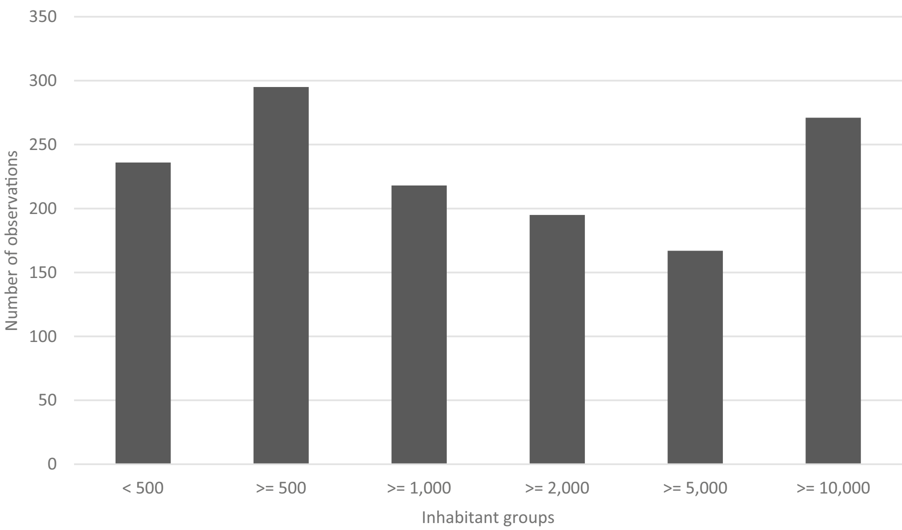

Fig. 3 Descriptive analysis Inhabitant groups

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