Valuating the negative externality of wind turbines: traditional hedonic and difference-in-difference approaches

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Abstract:

Local negative externalities of an establishment of wind turbines have been documented in research; often with the help of the hedonic methodology and property values. We use mixed methods including hedonic methodology, propensity score matching, and the difference-in-difference approach to estimate causal effects, using almost 600,000 real estate transactions in Sweden from 2005 to 2018. The results indicate that we can reject the hypothesis that proximity to wind turbines does not impact property values, and this impact is relatively strong and varies over time and geographic region. Difference-in-difference with matching confirms estimates in the hedonic price equation studies. Furthermore, there is no indication of pre-event differences in house price outcomes based on distance from new wind turbines. Depending on the region, the total negative capitalisation amounts to between 10 and 25 percent within 0–2 kilometres from the wind power plant. We apply these estimates to the total housing stock in three different potential future development areas. Although effects per property are relatively marginal, the total effects of a wind farm establishment will be significant if they are located in densely populated areas.

Keywords: wind turbine, capitalisation effect, regional, difference-in-difference, matching, property values

JEL-codes: C21, Q51, R30

1. Introduction

In order to mitigate climate change, politicians and business leaders across the world are implementing measures to reduce CO^2 emissions and produce fossil-free energy. Sweden has set the goal of zero net emissions of greenhouse gases by 2045. At the same time, nuclear power is being phased out, and several new industry projects for replacing fossil energy with electricity/fuel cells are being launched. Two large plants for fossil-free production of directly-reduced sponge iron and steel are planned in northern Sweden, and their total yearly use of electricity is estimated to be 82 Twh. The branch organisation *Energiföretagen* has estimated a yearly demand of 320 Twh electricity in Sweden in 2045, compared with 140 Twh in 2020. Thus, the need for new fossil-free energy is enormous.

The only possibility to substantially increase the supply of fossil-free energy within the foreseeable future is wind power, and Sweden is currently planning to build wind turbines that will produce 100 new Twh (Energimyndigheten 2020). However, these plans have caused concerns among property owners in the vicinity of the planned wind farms over reduced property values and other problems such as noise/air vibrations and changed landscape views.

The international research literature on wind turbines' possible effect on the value of nearby properties is not unanimous. A substantial number of European studies of different countries have shown adverse effects of wind turbines on the values of properties nearby (Gibbons 2015; Sunak & Madlener 2016, 2017; Jensen et al. 2014, 2018; Frondel et al. 2019; Dröes & Koster 2016, 2021). However, several North American studies have not found any effects (Hoen et al. 2009, 2011, 2015; Lang et al. 2014; Castelberry & Greene 2018), but a few have shown negative effects (Heintzelmann & Tuttle 2012) or mixed effects (Vyn 2018). Also, in the studies that found an effect, the magnitude of the effect varied considerably.

A consultancy report that analysed the period 2001–2007 found no impact of wind turbines on property values in Sweden (Svensk Vindenergi 2011). However, the only academic Swedish investigation on the topic so far, published eleven years later and covering the period 2013–2018 (Westlund & Wilhelmsson 2021), showed effects in line with the other European studies; i.e. negative effects. They also found that this effect diminished with the distance from the wind turbines and fell to zero after 7–8 kilometres. They used a hedonic model that controlled for other factors that could be expected to influence house prices (size of house and plot, type of house, year of construction, distance to an urban centre, etc.), but they did not study prices prior to construction of the wind farms.

A crucial issue for studies of cause and effect is causality. A simple finding of a negative correlation between proximity to wind turbines and house prices is not proof that the one has caused another. One way to handle this problem is to study house prices (within a certain distance from the wind farms) before and after the construction of wind farms. This method can be combined with the difference-in-difference method, which compares house prices' development between a treatment group (those within a certain distance from wind turbines) and a control group (houses outside the distance limit).

Against this background, this study aims to 1) estimate the causal relationship between wind turbines and property values in Sweden and 2) calculate the total capitalisation effect on the housing stock of three planned wind power development areas.

Our main contributions are primarily to the research question, methodology, and in our results, and we have a broader purpose related to previous research. The research question has been to estimate the capitalisation effect and calculate the expected effect on property values in the total housing stock in three planned wind power development areas in different parts of Sweden.

Methodologically, our contribution is that in addition to estimating the capitalisation effect of having a wind turbine in the vicinity using hedonic methodology, we have also analysed causality more carefully than previous studies that used Sweden as a case study, such as Westlund and Wilhelmsson (2021). To estimate a causal relationship between property values and the location of wind turbines, we have ensured that all relevant explanatory variables are included in the model. We have also used fixed geographical effects to reduce the risk of omitted variable bias. Furthermore, we have handled non-causality due to measurement errors by estimating models that take into account potential outliers more effectively. Finally, we have addressed the issue of reverse causality by estimating pre-investment effects and conducting a difference-in-difference analysis regarding wind power investments in 2015 and 2016.

Empirically, we increased knowledge of the subject by analysing data over a longer period, enabling us to estimate capitalisation effects over time and effects both before and after a wind power establishment. Furthermore, we have tested the hypothesis that there are regional differences in the capitalisation effect, which has not been analysed before. We have also shown that the capitalisation effect estimated using hedonic methodology is as good as the estimated effects from the difference-in-difference models, thus confirming our interpretation. The estimates in the hedonic models are also causal—i.e. the wind turbines impact property values—although wind turbines tend to be located in areas that would have lower values, with or without a wind turbine establishment. The causal connection is also strengthened because we could not find any pre-investment effects in the planned development areas.

The remaining article is disposed of as follows: in the next section, we intend to present the theoretical framework based on the classical welfare theory and the valuation of local negative externalities. These costs can be evaluated with a revealed or stated preference approach. We have chosen the latter as there is a market where the negative externality can be capitalised; namely the real estate market. The section will then describe our methodological approach when estimating the hedonic price equation. Emphasis will be placed on how we, through difference-in-difference methodology with matching using the method propensity score, intended to estimate the causal relationship between property prices and proximity to wind turbines. We will also present models that test the hypothesis of parameter heterogeneity. Section three presents the Swedish case study and institutional context and how these affect wind turbine location planning in Sweden. This section will also present the three separate case studies that estimate the total price impact in areas that may have wind turbines in the future.

Section four presents the empirical analysis. The starting point is the estimation of the classic hedonic price equation, where it is estimated through weighted least squares (WLS) with weights from propensity score matching. We then test the hypothesis that values have changed over time and differ between regions. In this section, we also conduct so-called pre-event studies to test whether there was capitalisation in the years before the actual wind turbine investment occurred. The lack of capitalisation confirms that the hypothesis that wind turbines do not affect property prices can be rejected. We also present the results from the difference-in-difference models. The section concludes by presenting an estimate of the price effect on total housing stock in three potential future wind power areas. The article concludes with a discussion of the results in section five. Section six presents conclusions and policy recommendations.

2. Theoretical framework and identification strategy

The research project aims to estimate the socio-economic cost of a non-marginal expansion of wind turbines. The cost of externalities can either be based on the willingness to pay to avoid a wind turbine or the willingness to accept them. Furthermore, the non-marginal willingness to pay can be based on either stated or revealed preferences. We have used a revealed preference approach, as we have an underlying market where we can assume that proximity to wind turbines impacts the poverty market. Through real estate transactions, we can expect household preferences to be reflected in prices established in the housing market. An underlying assumption is, of course, that we can identify properties that either have or do not have an impact on externality in order to be able to estimate a difference. The following section presents how we estimate willingness to pay for the non-marginal change constituted by an expansion of wind turbines.

Identification strategy

Estimating the causal relationship between property values and the investment of wind turbines in the vicinity of the properties is not an easy task. There are many reasons we can not maintain the exogeneous (zero conditional means) assumption we make when estimating the regression model. Perhaps the most important reason is the issue of reverse causality, but we can also face issues with omitted variables and selection biases. This section will first present our identification strategy for the capitalisation effects, and then we will present how we have estimated the socio-economic cost for three different planned wind power projects in Sweden.

The empirical analysis has taken place in several steps. In the first step, we have estimated a classic hedonic price equation (Rosen, 1974) as in Westlund and Wilhelmsson (2021) presented in equation 1.

$$Price_i = \alpha_j + \beta X_i + \lambda W_i + \varepsilon_i \qquad (1)$$

By including relevant underlying factors (*X*) and fixed time and municipal effects (α_j), the intention is to explain the observed price variation (*Price*). Omitted variable bias and its contribution to problems of endogeneity should be minimised (Hill et al., 2021). In addition to the fixed effects, we have also included the property's indoor and outside size, age, and distance to the nearest main town and urban area. The basic model includes the minimum distance between property and wind turbine (*W*) in the price equation as a binary variable where the variable is equal to 1 if the property is located within 10 kilometres from the wind turbine; otherwise it is equal to zero. A distance of ten kilometres has been chosen, as it has been shown in empirical research that the effect is most significant a few kilometres away from the wind turbines and then decreases until up to around 10 kilometres, where it falls to near-zero (Jensen et al., 2018).

In step 2, we have also included an interaction variable between proximity to wind power and time to test whether the capitalisation effect is constant, or increases or decreases over time.

All models have been estimated by adjusting for the fact that properties closer to and farther from wind turbines may differ in characteristics. We have done this by estimating a propensity score model (Rosenbaum and Rubin, 1983) that calculates the probability that the property is within 10 kilometres of a wind turbine. Independent variables in the propensity score model are property attributes and distance to the nearest urban area and municipality centre, as well as longitude and latitude (which are included to minimise problems of spatial dependence). The probabilities (propensity score) have then been used to calculate weights where those within 10 kilometres are assigned the weight (1/propensity score) and those outside are assigned the weight (1/(1–propensity score)) following (Cole and Hernán, 2008). These weights were then used to estimate a weighted least square model (WLS) of equation 1.

As a robustness test, we have also estimated a model to analyse whether the estimates are affected by outliers in the data material. This has been done by estimating an outlier-robust iterative weighted least square model where highly influential observations are weighted down following Rousseeuw and Leroy (2003).

In step 2, we analyse the issue of reverse causality more explicitly by first estimating a so-called pre-investment analysis and then a difference-in-difference model (Dague and Lahey, 2019). In the pre-event analysis, we more carefully analyse investments in wind turbines that were carried out in 2015–2016 by estimating models for the years before the investment (a similar approach was used in Raftopoulou and Giannakopoulos, 2022, and Boyle and Lahey, 2010). If it is the case that the wind turbines have been located in areas that had lower property values from the beginning, we expect the capitalisation effect for future wind turbines to have a negative capitalisation in previous years. If this is not the case, it indicates that it is not a question of reverse causality between wind power location and property values, but that wind power location has causally affected prices.

Difference-in-difference takes the analysis one step further by analysing the effect after the construction of the wind turbines. See, for example, Sunak and Madlener (2016) for an empirical example of the difference-in-difference of wind farms' impact on property values in Germany. The methodology involves creating a treatment variable (*Treatment*) that indicates whether the property is within 10 kilometres of a wind turbine built at a specific time. Properties 10 kilometres or more away from the turbines comprise the control group. To account for whether the property was sold before or after construction, a distance similar to the reported pre-analysis was calculated. We then created a binary variable equal to 1 if the property has been sold after construction (*Post*) and finally calculate an interaction variable between *Treatment* and *Post*. The model, including all the above variables and the parameter estimation regarding *Post*, shows that prices have generally changed in both the treatment and control areas.

$$Price_i = \alpha + \lambda_1 Post_{i,t} + \lambda_2 Treatment_i + \lambda_3 [Treatment * Post]_{i,t} + \varepsilon_i \qquad (2)$$

The parameter estimate regarding the variable [*Treatment*] shows whether the area where the wind power plant was built had lower or higher prices before construction. The parameter estimate (λ_3) regarding [*Treatment*Post*] is of primary interest to us, as it shows whether the wind power plant has impacted the property values. The expectations are that the parameter estimate should be negative and statistically significant. We have performed it separately for two years of wind power investments. It is essential to consider whether these values were already close to previously-made wind power investments. We have done this by excluding properties that were closer than 14 kilometres from a wind turbine before the aforementioned investments.

By including fixed effects, estimating WLS, examining measurement errors in variables and outliers in the data, as well as estimates of pre-investment analyses and DiD analyses with propensity score methods, we are expected to be able to reject the hypothesis that wind turbines do not have an impact on property values.

In step 3, we have estimated models where the intention is to analyse whether the capitalisation effect differs within 10 kilometres from wind turbines. This has been done by including binary variables equal to 1 if the property is within a 2-kilometre range from the wind turbines (and 0 if not). In addition, we have estimated models in different time intervals to examine whether capitalisation differs over time.

In step 4, we analyse parameter heterogeneity by examining whether the capitalisation effect differs between regions. Here we have chosen the regional division NUTS1, where Sweden is divided into North, Central, and South. We have also analysed whether the capitalisation effect varies within each region. We have done this by testing the hypothesis that capitalisation differs more in urban than rural environments.

Estimating the total effects on property values

The estimation of the total effects has also been done in several steps. The estimated capitalisation effects are an important input in these calculations, but first, we must identify properties that will be affected in future proposed development areas. We have done this by using the geocoded locations of the wind turbines and calculated the distance to all properties for residential purposes in the housing stock. Residential properties within 10 kilometres of the planned wind turbines will then, in the next step, be valued based on their location (municipality, distance to urban areas and main towns) and residential attributes (residential address, year of construction and type of dwelling), which are then summed up. Within 2-kilometre intervals from the wind turbine, the valuation will be multiplied by the capitalisation factor within the selected interval, then summed up, and the difference between the two is then calculated.

3. The case study of Sweden

We are analysing the wind power expansion in Sweden over the past 15 years. The plan for the future is that this expansion will continue, in an effort to reduce and eventually be able to phase out all energy production based on fossil fuels. This means that Sweden will need to invest in new development areas in addition to existing wind powers. We will analyse three of these planned areas in more detail. The section aims to provide a background to Sweden as a case study and the three planned areas.

After a long start-up phase, wind power expansion in Sweden took off about 2010 (see Figure 1). An important factor was a 2006 governmental bill (Prop. 2005/06:143) positing governmental support to municipal master plans that developed prerequisites for extension of wind power and lowered property taxes on wind turbines. With growing awareness of the threats of climate change, the political importance of wind power has increased, as it is currently the only available energy source that can be substantially expanded relatively rapidly.[1] In 2021, there were 4754 wind turbines in Sweden that produced 27,108 TWh, corresponding to 17% of total electricity production.

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[1] Nuclear power, which currently produces 30% of Sweden's electricity, is slowly being phased out, and the potential for increased hydroelectricity is small, since it mainly consists of replacing old turbines with newer, more efficient ones. Solar electricity production is expanding but is still on the margins.

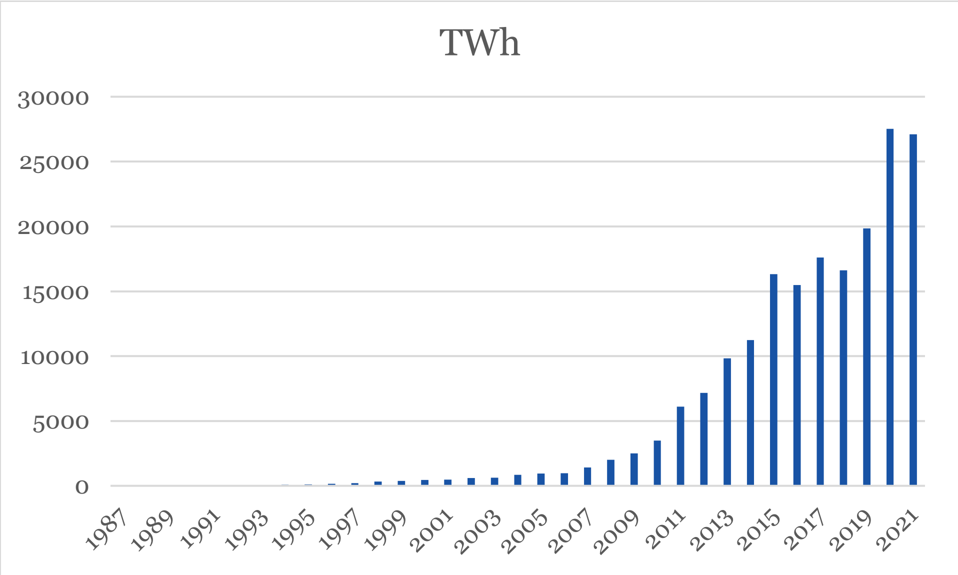


Figure 1. Production of wind power electricity in Sweden 1987–2021. Source: Swedish Energy Agency.

The conversion to CO[2] neutral energy consumption, in combination with the phasing out of nuclear power, has created pressure on the extended wind power capacity. In 2021, the Swedish Energy Agency presented a plan to build 4165 new, 6 MW land-based wind turbines that would produce 80,000 TWh, plus additional off-shore wind turbines that would produce 20,000 TWh. However, if the abovementioned plans to produce directly-reduced sponge iron and fossil-free steel are realised, the need for additional electricity will be even greater.

The expansion of wind power and the plans to multiply their capacity have caused increasing resistance. Studies at the Gothenburg University show that support for the continued expansion of wind power among rural dwellers in Sweden has decreased from over 80% in 2000 to 56% in 2018 (Hedberg 2019). Since 2021 there has also been an intense debate on wind power's effects on property values.

In Sweden, the municipality (local government) makes decisions over land use and other planning issues. Strong local opinions can influence politicians' decisions. Municipalities can veto wind power, and can withdraw their earlier acceptance of wind turbines at a particular place anytime during the planning process. This has stopped or delayed a substantial number of planned wind farms in the last decade. Therefore, a governmental inquiry has recently suggested that municipalities' decisions on location permits for wind turbines should be based on their master plans and be valid for five years (SOU 2021:53). The inquiry also noted the issue of economic compensation to municipalities and local associations for the inconveniences that wind turbines might create, as such compensation might make municipalities and local dwellers more positive to wind power, and suggested further inquiry of this issue. The inquiry did not discuss possible compensation to property owners affected by lowered property values.

Case studies

(1) Östra Göinge

Östra Göinge is a municipality in southern Sweden. It is relatively small, with only 15,000 inhabitants in the municipality, covering 452 square kilometres. This corresponds to a population density of about 33 people per square kilometre. For comparison, the general population density in Sweden is approximately 26 inhabitants per square kilometre. About 80% of the population lives in one of the larger villages in the municipality.

The planned wind power expansion consists of 16 wind turbines [Area: 1256-V-009] and two separate areas west and east of the village Knislinge. The planned expansion is only about 6 kilometres away from the villages Broby and Knislinge, both with a population of about 3100. The proximity to these communities means that many property owners will be affected by wind power investments.

What is interesting about this location is that it is close to the municipal border. A large part of the impact will be on property owners who are not residents of the municipality that decided to allow construction of the wind turbines.

(2) Finspång

Finspång is a municipality 180km southwest of Stockholm. In terms of size, there are about as many people living in Finspång as in Östra Göinge. However, the municipality is significantly larger (1200 square kilometres), which gives it a population density of approximately 18 inhabitants per square kilometre, which is lower than average in Sweden. The wind power development area is north of Norrköping, near the smaller community Simonstorp. The project area [0562-V-004] consists of 16 wind turbines with an estimated annual production of 225 GWh. Significantly fewer property owners will be affected by the development here than in Östra Göinge.

(3) Skellefteå

Skellefteå is a municipality in the northern part of Sweden. The municipality is larger than Finspång and Östra Göinge both in terms of population (with approximately 75,000 inhabitants) and area (9944 square kilometres). The population density is approximately seven inhabitants per square kilometre; i.e. significantly lower than the average in Sweden. The wind power area [2482-V-025] is located near the community Burträsk and consists of 33 wind turbines. In the immediate area, there are already former wind power areas. In the vicinity of the project area, relatively few property owners will be affected.

4. Empirical analysis

The empirical analysis consists of three parts, the first part of which is intended to estimate the capitalisation of wind turbines into property values. This is done by relating existing wind turbines to real estate transactions using the traditional hedonic price equation. We will first present the underlying secondary data used in the empirical analysis and then present the results from the econometric models. We will also present models and tests to ensure that the relationships that have been estimated are causal. The second part of the empirical analysis calculates the total socio-economic cost for three future development areas. In the second stage, we estimate a relatively simple valuation model based on transactions in the immediate area and then apply this model to the entire housing stock in the vicinity of the development areas in the third stage. We can then value all properties in the housing stock with and without wind farms, which gives us a calculation of the total socio-economic cost based on property values. Information about plans for future wind turbines comes from the Swedish Energy Agency [2].

Data and descriptive statistics

The quantitative analysis uses data from three sources: Swedish Brokerage Statistics regarding real estate transactions, Valueguard AB regarding housing registers, and the Swedish Energy Agency regarding wind turbines. All data are geographically coded with longitude and latitude. Real estate transactions refer to the period 2005–2018, the housing register refers to 2018, and the wind turbines in question are all in use. Descriptive statistics are shown in Table 1. We compare all sales with those that were within 20 kilometres from a wind turbine when they were sold.

[2] https://www.energimyndigheten.se/fornybart/vindkraft/vindlov/vindbrukskollen/

Table 1. Descriptive Statistics

PANEL A
(all observations)

Variable	Obs	Mean	Std. Dev.	Min	Max
Contract price	614,316	2,158,351	1,794,332	130000	1.100e+08
Living area	614,316	118.196	42.184	30	311
Plot area	614,316	1901.398	4157.224	132	59638
Number of rooms	614,316	4.782	1.44	1	9
Building year	598,494	1960.157	31.158	1012	2019
Detached					
Row house					
Semi-detached					
Proximity to wind turbine	613,037	18.511	15.561	.028	165.631
Distance to urban area	613,037	10.844	12.62	.009	234.913
Distance to main town	613,037	3.285	3.296	0	117.662

PANEL B
(observations within 20 kilometres from a wind turbine)

Variable	Obs	Mean	Std. Dev.	Min	Max
Contract price	388,621	2,016,450	1,472,086	130000	50000000
Living area	388,621	118.233	41.794	30	311
Plot area	388,621	1902.062	4164.855	132	59600
Number of rooms	388,621	4.764	1.418	1	9
Building year	378,836	1959.472	32.041	1012	2019
Detached					
Row house					
Semi-detached					
Proximity to wind turbine	388,621	9.08	5.384	.028	20
Distance to urban area	388,621	10.342	13.587	.009	141.283
Distance to main town	388,621	2.902	2.812	0	64.908

Note: The table shows descriptive statistics concerning the dependent variable transaction price and the independent variables. The transaction price is based on arm-lengths transactions between 2005 and 2018. The independent variables are housing attributes: living area (square meters), plot area (square metres), number of rooms, building year, and type of housing (detached, semi-detached and row house). Neighbourhood attributes are the minimum distance (in kilometres) to the main urban area in the municipality (distance to the main town) and the minimum distance (in kilometres) to any urban area with more than 200 inhabitants (distance to the urban area). Distance to the wind turbine (in kilometres) is measured as the minimum Euclidian distance from the house to the 'wind turbine. Panel A shows all transactions, and Panel B only shows transactions with 20 kilometres of an existing wind turbine. The statistics are average value (mean), standard deviation (Std. Dev.), minimum (min) and maximum (max). Source: Svenskt Mäklars Statistik AB, Energimyndigheten, Statistics Sweden and own calculations.

In total, there are more than 600,000 observations available in the empirical analysis in the total sample (Panel A in Table 1), but most estimations are based on around 390,000 transactions within 20 kilometres from the wind turbine (Panel B in Table 1). We can observe that the differences between price and the independent variables are minor, with a slightly lower average price for those closer to an existing wind turbine while size, age, and type are the same. The average distance to urban areas or main towns is the same. The big difference is, of course, the distance to a wind turbine where, within 20 kilometres of a wind turbine, for obvious reasons, they are on average closer (to wind turbines), compared to all other transactions.

Modelling the capitalisation effects

A. Hedonic price model

Here we present four models related to proximity to wind turbines at poverty prices by estimating the hedonic price equation. Column 1 in Table 2 shows estimates property attributes and distance to urban areas, as well as the distance to the main town in the municipality, together with a binary variable (treatment variable) regarding proximity to wind turbines. Model 2 also includes fixed geographical effects, and in Model 3, observations are weighted based on how likely they were to be in the vicinity of a wind turbine. Column 4 presents a model to test the hypothesis that capitalisation varies over time by including an interaction variable between proximity to wind turbines and a year variable.

Table 2. Hedonic price equation.

	Model 1	Model 2	Model 3	Model 4
Living area	0.604***	0.577***	0.566***	0.567***
	(120.69)	(191.32)	(183.49)	(183.63)
Plot area	–0.139***	0.0548***	0.0538***	0.0539***
	(–84.59)	(47.82)	(46.24)	(46.31)
Number of rooms	0.402***	0.145***	0.154***	0.153***
	(79.19)	(47.69)	(49.48)	(49.40)
Building years	8.442***	5.113***	5.111***	5.110***
	(86.74)	(76.15)	(74.90)	(74.85)
Distance to main town	–0.0241***	–0.183***	–0.183***	–0.183***
	(–24.58)	(–229.19)	(–227.22)	(–227.37)
Distance to urban area	0.101***	0.0376***	0.0377***	0.0378***
	(104.70)	(57.25)	(56.98)	(57.10)
Proximity to wind turbine	–0.0466***	–0.0356***	–0.0346***	0.0123***
	(–22.53)	(–19.39)	(–18.61)	(4.63)
Wind turbine * period				–0.00670***
				(–23.54)
R^2	0.286	0.774	0.773	0.773
Adjusted R^2	0.286	0.774	0.773	0.773
Fixed effects	No	Yes	Yes	Yes
Method	OLS	OLS	WLS	WLS
AIC	949929.30	386556.80	392062.30	391496.30
Observations	490668	490667	490667	490667

Note: The table shows the results of four hedonic price equations. The dependent variable equals the natural logarithm of the transaction price. The independent variables are indoor size, measured in square meters, the number of rooms and outside plot area, building years and distance to the primary city in the municipality, and the minimum distance to an urban settlement. All variables are expressed in natural logarithms. Proximity to a wind turbine is a binary variable equal to 1 if the property is within 10 kilometres from the wind turbine measured in Euclidian distance. Model 1 does not include fixed municipality effects, and Model 2 includes fixed municipality effects. Model 3 uses weighted least square (WLS) instead of ordinary least square (OLS), where weights are equal to the inverse probability of treatment Model 4 and include an interaction variable between the binary variable of wind turbine and time period, with 2005 equal to 1 and 2018 equal to 13. *t* statistics in parentheses. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Fixed municipal effects are essential in explaining the price variation in Sweden. The degree of explanation goes from just under 30% in Model 1 to just under 80% in models 2–4. Approximately 490,000 observations have formed the basis for the estimates in all models. The effect of housing size shows statistical significance, where an additional 1% increase in living area increases the price by approximately 0.6 percent. The effect is robust between models. The estimates regarding other value-affecting attributes are not robust, and they vary to a relatively large extent, especially in Model 1. The larger the plot area and the newer the property, the higher the price. The distance to the main town in the municipality has a negative parameter estimate, which means that if the distance to the main town increases by 1%, values fall by approximately 0.2%. However, values increase further away from the property in smaller urban areas in the municipality.

The primary variable is proximity to wind turbines. The parameter estimate decreases when fixed municipal effects are included in the model (Model 2), but correcting for differences in the properties in the treated and untreated sample (Model 3) has a relatively small effect on the estimate.

When the estimated binary parameters indicate a large change in the dependent variable, Halvorsen and Palmquist (1980) suggest that the exact percentage difference should be computed as 100*[exp(b) – 1], and Kennedy (1981) argues that the correct expression is equal to p = [exp(b – 1/2V(b)) – 1]*100, where V(b) is an estimate of the variance of b. However, the difference between the estimates is small. We are following Halvorsen and Palmquist's (1980) suggestion. The capitalisation effect amounts to approximately –3.4 percent. The confidence interval is relatively narrow and ranges from –3.75 to –3.05 percent.

In Model 4, we have included the interaction variable between period (year) and proximity to wind turbines. The parameter estimate is statistically significant at a 5% level. Estimates are higher compared to, for example, Jensen et al. (2018), who conclude that prices will go down by 3%–6% when two wind turbines are located within 1 kilometre of the property. It can be noted that the capitalisation effect has increased over time relatively markedly. In 2005, the estimate was positive, as the estimate was equal to approximately 1.2% percent. Capitalisation then increased by 0.07% per year, and in 2018 capitalisation was –8.23 percent. This may be due in part to the fact that today's wind turbines are significantly higher now than they were ten years ago, which gives a higher capitalisation effect, and partly because the location of the wind turbines takes place closer to urban areas. The wind turbines built from 2001 to 2007 had an average height of 103 meters (maximum total height: 150 meters). The average total height for built wind turbines from 2016 to 2018 is 174 meters (maximum total height: 205 meters). Of course, the fact that discussions regarding the location of wind turbines have been increased locally in the last 5–10 years, that citizens have become more aware of the issue, and that more people have been affected by their location may have had an effect.

B. Pre-event analysis

We have analysed the capitalisation effect four years before the wind power plant operates in the pre-event analysis. A significant capitalisation would show that the location of wind turbines takes place in areas with lower residential prices even before the wind turbine was in place, and a lack of capitalisation effect would show that the wind turbines have not been located in areas with lower prices. Panel A in Table 3 shows the effect in the years before the completion of the 2015 wind turbine, and Panel B shows corresponding effects for the 2016 wind turbine.

Table 3. Capitalisation pre-effect of investments in 2015 (Panel A) and 2016 (Panel B)

PANEL A				
	(1)	(2)	(3)	(4)
	d1	d2	d3	d4
Living area	0.454***	0.455***	0.428***	0.432***
	(25.56)	(25.57)	(21.31)	(24.66)
Plot area	0.0817***	0.0738***	0.0862***	0.0792***
	(10.39)	(9.68)	(11.32)	(12.06)
Number of rooms	0.187***	0.191***	0.197***	0.208***
	(9.79)	(10.44)	(9.64)	(10.99)
Building years	4.707***	4.519***	4.675***	4.319***
	(11.73)	(11.94)	(10.74)	(12.54)
Distance to main town	–0.202***	–0.200***	–0.207***	–0.196***
	(–29.19)	(–27.04)	(–26.09)	(–28.57)
Distance to urban area	0.0190***	0.0126*	0.00614	0.0254***
	(3.85)	(2.33)	(1.11)	(4.99)
Proximity to 2015 wind turbine	–0.209	–0.104	0.0178	–0.219
	(–1.23)	(–0.71)	(0.15)	(–1.29)
R^2	0.842	0.853	0.850	0.842
Adjusted R^2	0.839	0.851	0.847	0.840
Observations	10805	10276	9700	12517
PANEL B				
	(1)	(2)	(3)	(4)
	d1	d2	d3	d4
Living area	0.457***	0.425***	0.432***	0.434***
	(25.78)	(21.11)	(24.56)	(24.09)
Plot area	0.0736***	0.0865***	0.0784***	0.0915***
	(9.61)	(11.30)	(11.89)	(14.55)
Number of rooms	0.190***	0.198***	0.208***	0.217***
	(10.35)	(9.69)	(10.90)	(11.45)
Building years	4.508***	4.599***	4.232***	5.052***
	(11.89)	(10.57)	(12.30)	(14.35)
Distance to main town	–0.201***	–0.207***	–0.196***	–0.195***
	(–27.08)	(–26.08)	(–28.19)	(–27.34)
Distance to urban area	0.0109*	0.00636	0.0242***	0.0167***
	(2.02)	(1.15)	(4.83)	(3.37)
Proximity to 2016 wind turbine	–0.253	–0.0867	–0.177	–0.00331
	(–1.92)	(–0.44)	(–1.31)	(–0.02)
R^2	0.854	0.850	0.842	0.848
Adjusted R^2	0.851	0.847	0.840	0.846
Observations	10220	9624	12407	11268

Note: The tables in Panel A and B show a capitalisation effect in the areas where a wind power investment occurred in 2015 and 2016 before the investments took place. For all transactions up to 4 years before the investment, the distance to the location has been calculated, and a binary variable indicating whether the property is within 10 kilometres of the proposed wind turbine has been included in the hedonic price equation. The dependent variable is the natural logarithm of the transaction price. The independent variables consist of the natural logarithm of the living area, plot area, number of rooms and year of construction, and binary variables regarding semi-detached houses and terraced houses (default consists of the detached villa). In addition, the distance to the nearest urban area and the nearest distance to the nearest capital in the municipality are included. The model also includes fixed municipal effects and month effects. *t* statistics in parentheses, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Each column in Panels A and B consists of a cross-section of one year. Each model includes fixed municipal effects, and the degree of explanation is generally very good, as almost 85% of the variation in housing prices can be explained by included variables. The variable of primary interest is the variable that measures proximity to a wind turbine (within 10 kilometres of the wind turbine). The model in column 1 refers to 4 years before the wind turbines built in 2015 and 2016 were completed, and column 4 refers to proximity to wind turbines one year before. Since it is the effect of new wind turbines that we intend to measure, we have excluded housing transactions that were closer than 20 kilometres from an existing wind turbine built before 2015 and 2016, respectively.

The result is unambiguous as it can not be observed that any of the parameter estimates are statistically significant from zero. Hence, we can not reject the hypothesis that proximity to wind turbines impacts prices in the years before they were built, which strengthens our results from the hedonic analysis. An additional step in the analysis is to estimate a difference-in-difference model.

C. Difference-in-difference

The pre-event analysis shows that the areas where wind turbines have been built did not have lower housing prices than surrounding areas. To further analyse the causal relationship, we have also estimated difference-in-difference models. This means that we have analysed the 2015 and 2016 wind power investments and analysed housing prices in the period before and the period after, and that we have analysed housing prices in the area that has been treated against the untreated area (control area). To ensure that the houses in the treated area are approximately the same as those in the control area, we have estimated the propensity score, which is then used to weight the WLS estimate. All models include previously used value-influencing attributes and fixed municipal effects. The table illustrates the 2015 and 2016 wind power investments (columns 1 and 2), and column 3 presents the results from a combined model.

Table 4. Difference-in-difference estimates in 2015 and 2016 with propensity score matching.

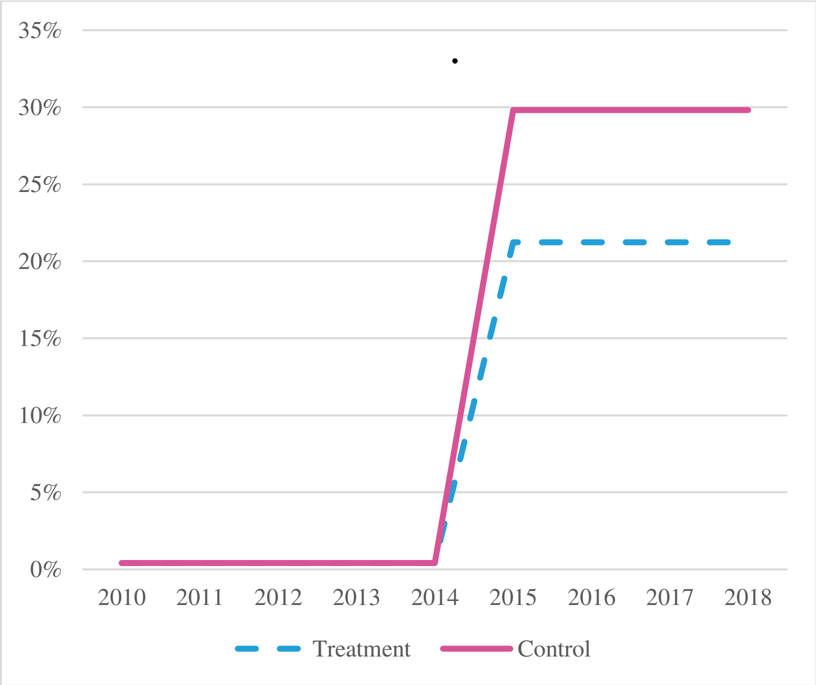
	(1) 2015	(2) 2016	(3) 2015-2016
Treatment	0.00412	-0.0626*	-0.0563***
	(0.12)	(-2.03)	(-3.55)
Post	0.294***	0.256***	0.383***
	(153.09)	(114.05)	(220.80)
Post * Treatment	–0.0858*	–0.106*	–0.0871**
	(–2.11)	(–2.02)	(–3.25)
R^2	0.804	0.796	0.802
Adjusted R^2	0.804	0.795	0.801
Observations	159,862	139,415	272,746

Note: The table shows the results from two difference-in-difference models where the 2015 (DiD 2015) and 2016 (DiD 2016) and the combined effect (DiD 2015-16) of wind power investments have been analysed. Parameter estimates regarding the variable *Near* (transactions within a radius of 10 kilometres from the wind turbines), *Post* (the years after the investment) and *Treatment* (*Near* * *Post*). The Coefficient for *Treatment* is of primary interest, as it estimates the expected capitalisation effect. The *Near* coefficient is also of interest as it shows the price level in the treatment area. The analysis period for DiD 2015 is 2011–2018, and for DiD 2016, it is 2012–2018. Only transactions that occurred before the investment was 10 kilometres from an existing wind turbine are included. The dependent variable consists of the natural logarithm of price. The independent variables consist of the natural logarithm of the living area, plot area, number of rooms and year of construction, and binary variables regarding semi-detached houses and terraced houses (default consists of the detached villa). In addition, the distance to the nearest urban area and the nearest distance to the municipality centre are both included. The model also includes fixed municipal effects and month effects. *t* statistics in parentheses, $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$

The results from the difference-in-difference models indicate a causal relationship between proximity to wind turbines and property values. As before, the models show a high degree of explanation (around 80%), and the number of transactions amounts to between 130,000 and 270,000. Of course, there are significantly more observations in the treatment group than in the control group. However, the observations are weighted, which means that the observations that are part of the control group and show similarity with those part of the treatment group will be weighted in the estimate. The result indicates that the 2015 investments did not occur in areas with lower prices than the control group (the estimate regarding the variable *Treatment* is not statistically significant), but this does not apply to the 2016 investments. The estimate is statistically significant and indicates that the wind turbine areas have 6% lower prices than the control group. The same effect estimate can be observed when we combine 2015 and 2016. The parameter estimate regarding the variable *Post* is statistically significant and positive, indicating that prices have generally risen between the pre-period and the post-period. Prices are approximately 25% percent higher during 2016–2018 compared to 2011–2014. The parameter estimation regarding the interaction variable [*Post* * *Treatment*] is of central importance. It is negative in all three models and statistically significant, indicating a negative capitalisation in property prices amounting to 8–10%. Sunak and Madlener's (2016) findings suggest that wind farms' impact on property values amounts to 9%–14% if the wind turbines visibly impact the property. Our estimates are on the lower side, but on the other hand, we do not have information about visibility as we have only the Euclidian distance between the wind turbine and the property.

Figure 2 illustrates the effect of wind power investments in 2015–2016. Before the investments took place, prices in the treatment area were lower than those in the control area, and increased after the investment. However, prices rose more in the control area than in the treatment area, which is indicated by the solid yellow line in the figure (which is higher than the dashed orange line.)

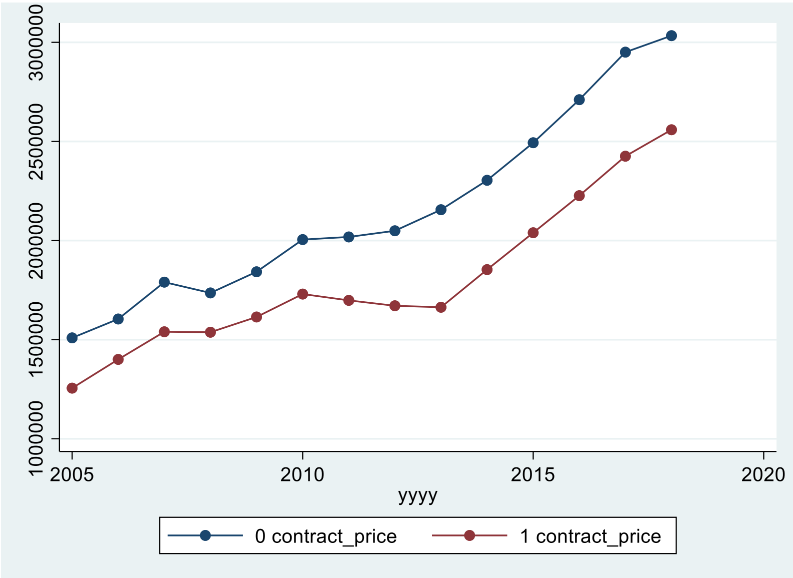
Figure 2. Difference-in-Difference estimates of the wind turbine investments in 2015.



Note: The figure illustrates the estimates regarding the Difference-in-Difference model of 2015–2016 and shows the effect of treatment versus the control effect. Treatment consists of *Near*, *Post* and *Treatment* estimates from Table 6 in column 3, and control consists of the estimates *Near* and *Post* from the same table.

Figure 3 shows the price trends before and after the wind turbines were built in 2015 and 2016. The blue line shows the price trend in areas that have not had a wind turbine located in their vicinity, while the red line shows the price trend in the areas that have received a wind turbine. We can visually observe that the trends are relatively constant over time, but the areas with wind turbines saw a decline in prices from 2011 to 2013. After that, the price trends are parallel, which is what we assume.

Figure 3. Parallel trend assumption



Note. Average house price on the y-axis and year on the x-axis.

D. Parameter heterogeneity

In the next step of the analysis, instead of one binary variable (within ten kilometres) in the model, we have included six binary variables with distance intervals to wind turbines of 2 kilometres. Sunak and Madlener (2017) used 1-kilometre intervals up to 5 kilometres, but we are using 2 kilometres up to 10 kilometres because of the lack of transactions in a 1 kilometres interval. We have previously seen that the valuation or capitalisation of wind turbines has increased over time, so we are using the period 2012–2018 for our estimation of capitalisation effects.

One of our research questions was to investigate whether capitalisation differed between regions. There can be many reasons why this is the case. One can be the availability of suitable land for wind turbines, how densely populated the region is, and how close to urban areas the wind turbines are. Therefore, we will test the hypothesis that capitalisation differs in years between regions in the subsequent analysis step. We have chosen the NUTS1 classification, which means that Sweden is divided into three regions. The results are presented in Table 5.

Table 5. Hedonic price equation; 2 kilometre intervals. Regions based on NUTS1. 2012–2018.

	(1) South	(2) Central	(3) North
Living area	0.620***	0.571***	0.493***
	(86.51)	(47.61)	(23.30)
Plot area	0.0185***	0.0454***	0.142***
	(7.03)	(10.97)	(18.69)
Number of rooms	0.136***	0.189***	0.172***
	(19.12)	(14.95)	(8.14)
Building years	4.814***	3.936***	8.095***
	(29.90)	(18.40)	(20.57)
Distance to main town	–0.142***	–0.188***	–0.237***
	(–78.21)	(–55.56)	(–35.79)
Distance to urban area	0.0375***	0.0309***	0.0468***
	(25.71)	(11.56)	(10.43)
Wind turbine 0–2 km	–0.130***	–0.112***	–0.248***
	(–17.26)	(–8.32)	(–10.66)
Wind turbine 2–4 km	–0.0889***	–0.0493***	–0.111***
	(–13.30)	(–4.75)	(–6.08)
Wind turbine 4–6 km	–0.0488***	–0.00660	–0.117***
	(–7.36)	(–0.63)	(–7.85)
Wind turbine 6–8 km	–0.0220**	–0.0250**	–0.0947***
	(–3.27)	(–2.76)	(–7.01)
Wind turbine 8–10 km	–0.0235***	–0.00611	–0.00938
	(–3.48)	(–0.67)	(–0.72)
Wind turbine 10–12 km	0.00324	–0.00404	–0.0184
	(0.47)	(–0.46)	(–1.67)
R^2	0.706	0.727	0.688
Adjusted R^2	0.706	0.726	0.686
AIC	85204.6	14506.9	14393.5
Observations	95716	24980	13925

Note: The table shows the results of three hedonic price equations. The dependent variable equals the natural logarithm of the transaction price. The independent variables are indoor size measured in square meters, the number of rooms and outside plot area, building age in years and distance to the primary city in the municipality, and the minimum distance to an urban settlement. All variables are expressed in natural logarithm. Proximity to a wind turbine is a binary variable equal to 1 if the property is within a 2 kilometres interval from the wind turbine measured in Euclidian distance. All models include fixed municipality effects and fixed time effects. Model 1 shows the results from the south region. Model 2 shows the results from the central part of Sweden, and Model 3 shows the north part of Sweden. All use weighted least square (WLS), where the weights equal the inverse probability of treatment. *t* statistics in parentheses. *t* statistics in parentheses. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

The degree of explanation is high in the regional models, and the included variables can explain around 70% of the variation in housing prices. Unlike the models that referred to different periods, the regional models show significant differences in the parameter estimates for the value-influencing attributes. For example, the marginal willingness to pay for the living area is more economically significant in the southern parts of the country than in the northern ones, which on the other hand, have a higher willingness to pay for outdoor space than the southern parts of the country. The effect of the year of construction is also of great importance, where the willingness to pay for newer properties is significantly higher in the northern parts of Sweden. The willingness to pay for proximity to urban areas is relatively constant between the regions, while the proximity to the main town is significantly greater in the northern parts; i.e. housing prices fall the further away from the main town the property happens to be located. All parameter estimates have expected signs and have a reasonable magnitude. However, it is worth noting that the number of observations is lower in the northern parts of Sweden, which may somewhat increase the uncertainty in the estimates.

The estimates regarding proximity to the wind power effect show significant differences between regions. In the interval 0–2 kilometres, the price impact in the country's southern parts is about 13% and increases to just under 25% in the northern parts of the country. Even though the percentage capitalisation is greater, the effect in SEK is minor, as housing prices are lower in the northern parts compared with southern Sweden.

The parameter estimates within other ranges follow the same pattern, with slightly higher capitalisation in the northern parts of Sweden compared with the southern and central parts of Sweden. However, it is worth noting that the capitalisation is somewhat more local in the northern parts of Sweden, as we cannot find a negative capitalisation further out than 8 kilometres from wind power turbines, while in the southern parts of Sweden there is a capitalisation up to 10 kilometres.

In addition to interregional effects, we have also analysed the intra-regional effect, where we have explicitly tested the hypothesis that the capitalisation effect is affected by the distance to urban areas. We have also divided the data into 2 kilometre intervals from urban areas. Thus, we test the hypothesis that the capitalisation effect of a property 2 kilometres from a wind turbine is affected if it is 2 kilometres from an urban area compared to 10 kilometres from an urban area. The results are presented in Table 6.

Table 6. Hedonic price equation; 2 kilometres interval. Intraregional effects, 2012–2018, WLS

	(1) 0-2	(2) 2-4	(3) 4-6	(4) 4-8	(5) 8-10
Living area	0.596***	0.590***	0.558***	0.609***	0.545***
	(74.89)	(52.78)	(35.10)	(24.49)	(12.81)
Plot area	0.0518***	0.0608***	0.0526***	0.0707***	0.113***
	(15.19)	(15.35)	(9.84)	(8.01)	(7.05)
Number of rooms	0.141***	0.134***	0.179***	0.100***	0.0975*
	(18.09)	(11.88)	(11.23)	(3.71)	(2.08)
Building year	4.859***	5.071***	4.457***	5.559***	3.823***
	(29.87)	(15.58)	(16.69)	(14.65)	(5.70)
Distance to main town	–0.148***	–0.195***	–0.220***	–0.352***	–0.413***
	(–78.59)	(–39.92)	(–19.94)	(–13.07)	(–7.39)
Distance to urban area	0.0508***	–0.00578	0.0157	–0.0517	–0.0284
	(24.41)	(–0.54)	(0.52)	(–0.71)	(–0.17)
Wind turbine 0–2 km	–0.107***	–0.173***	–0.203***	–0.111**	0.00320
	(–12.31)	(–13.91)	(–11.91)	(–3.20)	(0.05)
Wind turbine 2–4 km	–0.0795***	–0.104***	–0.147***	–0.0992**	0.0338
	(–10.77)	(–10.53)	(–9.47)	(–3.10)	(0.57)
Wind turbine 4–6 km	–0.0152*	–0.0584***	–0.101***	–0.0271	0.00637
	(–2.07)	(–6.03)	(–6.85)	(–0.89)	(0.11)
Wind turbine 6–8 km	0.00462	–0.0589***	–0.0547***	–0.0224	0.0429
	(0.62)	(–6.74)	(–4.10)	(–0.74)	(0.81)
Wind turbine 8–10 km	0.0157*	–0.0395***	–0.0799***	0.0113	0.0108
	(2.05)	(–4.53)	(–6.25)	(0.38)	(0.21)
Wind turbine 10–12 km	0.0234**	–0.0157	–0.0247*	0.0192	–0.0228
	(3.18)	(–1.89)	(–1.98)	(0.68)	(–0.44)
R^2	0.734	0.733	0.730	0.669	0.640
Adjusted R^2	0.733	0.731	0.727	0.659	0.617
AIC	55533.2	27086.0	16322.3	7614.1	3249.6
Observations	71321	37177	19324	7418	2830

Note: *t* statistics in parentheses. $^{*}p$ <0.05, $^{**}p$ 0.01, $^{***}p$ <0.001.

We note that there is a significant intraregional variation in the capitalisation rates. If the property is close to an urban area, the capitalisation rate is generally lower than if the poverty is a little further out. However, the degree of capitalisation will be minor if the property is located further from the urban area than 8 kilometres. The wind power effect on nearby properties will be most significant in intervals 4 to 6 kilometres from an urban area. This result can have potentially major effects on where you plan to locate wind turbines. However, it is essential to keep in mind that even if capitalisation decreases at locations closer to urban areas, the number of affected impacts will increase significantly, which means that the total effect in SEK will increase. This will be exemplified in one of the case studies below.

Estimating total socioeconomic costs in three case studies

The estimated total price effect within the impact area from future wind turbines has been calculated according to previous discussion. The location of future wind turbines is geographically coded, and the distance to these turbines has been calculated for all properties in the housing stock. The property value has been estimated via a regression analysis covering transactions in each geographical area. These valuations have been reduced by the estimated capitalisations found in Tables 5. The results of these calculations are presented in Table 7.

Table 7. Estimates of total housing value before and after investment, million SEK.

	Number of properties	Valuation before (MSEK)	Valuation after (MSEK)	Difference (MSEK)
Case study: Östra Göinge				
0–2 km	190	205	181	24
2–4 km	675	799	735	64
4–6 km	2,645	3,138	3,002	136
6–8 km	1,934	2,541	2,496	45
8–10 km	2,165	3,010	2,970	39
Total effect	7,609	9,692	9,384	308
Case study: Finspång				
0–2 km	91	154	140	14
2–4 km	141	292	279	13
4–6 km	451	638	629	10
6–8 km	320	518	501	17
8–10 km	285	510	501	9
Total effect	1,288	2,112	2,049	63

Case study: Skellefteå

0–2 km	15	13	10	2
2–4 km	28	24	22	2
4–6 km	96	73	66	7
6–8 km	135	117	107	9
8–10 km	148	145	145	0
Total effect	422	371	349	21

Note: The table shows the effect of a wind power establishment in four different areas. Column 1 indicates the area and the 2 kilometre intervals from the future wind turbines. Column 2 shows the number of properties that will be affected. We have only included detached, semi-detached, and rowhouses here, and we have not included agricultural properties. In column 3, valuations of the residential properties are reported in 2018 monetary value. The valuation has been achieved via regression analysis where we have estimated a hedonic price equation including value-affecting attributes and fixed municipal effects. Column 4 shows the valuation but is reduced by the estimated capitalisation effect, and column 5 shows the difference in valuation and the summation of the total depreciation effects in the immediate area of any future wind turbines.

The project area in Östra Göinge municipality is close to urban areas and many property owners who will be affected. We have identified 190 properties within 2 kilometres from the nearest wind turbine and as many as 7,600 within 10 kilometres of the nearest wind turbine. The total valuation of these properties amounts to approximately SEK 9.7 billion, which gives us an average price of around SEK 1.3 million in 2018 monetary value. The value estimate after a wind power establishment is approximately SEK 9.4 billion, and the decrease in value amounts to approximately SEK 308 million, which corresponds to 40,500 per property.

The project area in Finspång affects fewer property owners, but the impact will be more significant per property. On average, there is a decrease in value of approximately SEK 49,000 per property, and the total decrease in value amounts to SEK 63 million. One reason for the higher average valuation is that there are more properties in the area 0–4 kilometres from the wind turbine than all properties within 10 kilometres. Approximately 18% of properties are found in this area, compared with 11% in Östra Göinge. This means that the decrease in value per property is economically more significant.

The project area in Skellefteå affects the least number of property owners in the case studies examined—only 422 properties have been identified within 10 kilometres of the wind turbines, and about 10% of these are found within 4 kilometres of the wind turbines. The decrease in value amounts to only SEK 39 million, but per property, it will be SEK 50,000, which is higher than Östra Göinge due to the higher estimated capitalisation.

5. Discussion of results

Based on data from nearly 600,000 Swedish property transactions from 2005 to 2018, our analysis has shown that proximity to wind turbines has a negative effect on property values and that this effect decreases with distance from the wind turbines and falls to 0 after 10 kilometres. The latter result holds true for Sweden as a whole, but when we analyse NUTS1 regions, it is only in southernmost Sweden that the effect stretches 10 kilometres; in the other two regions, the effect is 0 after 8 kilometres. We have also shown that the negative impact of wind turbines on property values has increased over time and with the total number of wind turbines being built.

This study broadly confirms the results of Westlund and Wilhelmsson (2021), even if this study offers a somewhat lower capitalisation effect. There might be several reasons for this difference. We have used a long interval of 10 kilometres, which means that the estimate is naturally lower. If we compare our results in the 2 kilometre intervals, our results deviate only in the nearest interval (0–2 kilometres). This may be because we have, in part, been more accurate in excluding any measurement errors and outliers, have more observations, using a different form of function (log-linear instead of semi-log linear) and that we use a slightly more extended investigation period (2011–2018 instead of 2013–2018). However, this study mainly distinguishes itself from Westlund and Wilhelmsson (2021) because we have analysed causality and regional capitalisation differences more in-depth.

The interesting point is that this study also supports the consultancy study (Svensk Vindenergi 2011) that did not find any impact of wind turbines on property values in Sweden for the period 2001–2007. During the significant expansion phase from about 2010 onwards, wind turbines have increasingly negatively influenced property values. Another factor that probably has contributed to the increased adverse effects is the increased height of wind turbines. In the last twenty years, the height of wind turbines has almost doubled.

The main result of this study—that wind turbines exert a negative effect on property values—corresponds with the results of the abovementioned earlier European studies. However, compared with these studies, our results mainly indicate a stronger effect and an effect with a longer spatial extension. Except for Sunak & Madlener (2017), all the referred European studies show lower impacts of wind turbines on house values. Also, most of the studies only find this impacts up to 2–3 kilometres from the wind turbines; the only exception is the study by Frondel et al. (2019), which covers the period 2007–2015 and finds effects up to 8–9 kilometres, which is similar to this study. Besides differences in scope and methods, one explanation might be that most studies were based on data from the first decade of the 2000s; in one case analysis started as early as 1985. If our finding that the impact of wind turbines has increased over time also holds true for other countries, this might explain the difference.

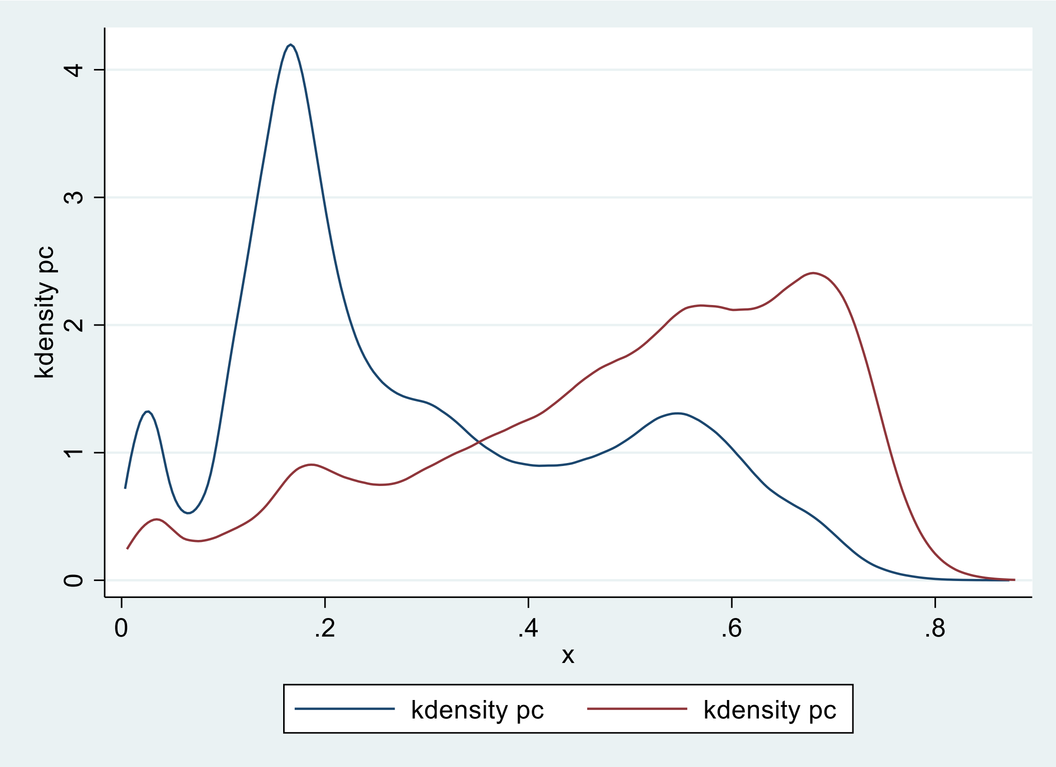
6. Concluding remarks and policy implications

Our study shows that the current expansion of wind power in Sweden causes comprehensive losses in property values for homeowners within 10 kilometres of a wind turbine. From a legal perspective, this is not satisfactory. The Swedish government should urgently investigate this problem and propose an economic compensation system for those affected. Such a system might never be perfect, but it would still offer an important signal and the perception of justice.

The fact that we found significant changes in wind turbines' impact on property values—from no impact to increasing negative impacts—might serve as a starting point for a discussion on the long-term connections between wind turbines and property values. If wind power continues to be extended according to current plans or even more extensively due to increased demand for fossil-free electricity, will the adverse effects on property values continue to increase? Or will we reach a point where wind turbines are ubiquitous and thereby less important for property values? In the latter case, it can be hypothesised that the relationship between wind power and property values can be expressed in the form of an inverted U-curve. Furthermore, if such a relationship exists, various countries might be in different positions on the curve, depending on how much wind power has been expanded. This would then explain variations in results between countries and over time. Testing this hypothesis would demand broader perspectives than the previous national ones and access to databases over property transactions over time in several countries.

Appendix

F1. Propensity scores in the treated group (red) and the untreated group (blue)



A1. Hedonic price equation: controlling for outliers

	(1) a1	(2) a2
lnliving_area	0.575***	0.575***
	(248.54)	(249.11)
lnplot_area	0.0615***	0.0616***
	(73.98)	(74.16)
lnnumber_of_rooms	0.138***	0.137***
	(55.60)	(55.54)
lnb_year	6.018***	6.018***
	(175.72)	(176.02)
lndist_ort	–0.184***	–0.184***
	(–294.14)	(–294.65)
lndist_urban	0.0360***	0.0360***
	(70.36)	(70.58)
bin_wind_post	–0.0425***	15.33***
	(–28.03)	(30.19)
bin_wind_post_year		–0.00764***
		(–30.28)
R^2	0.811	0.811
Adjusted R^2	0.810	0.811
AIC	.	.
Observations	490667	490667

t statistics in parentheses
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

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