The socio-economic cost of wind turbines: A Swedish case study

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Abstract:

The expansion of wind turbines plays a significant role in developing the ability of a country like Sweden to achieve climate-neutral energy production without relying on nuclear power plants. Wind-turbine energy production is expected to grow in coming decades. Conflicts may arise between, on the one hand, the government and the energy authority, and, on the other hand, between municipalities and property owners, especially if this expansion affects other economic activities, such as tourism and reindeer husbandry, or affects property values. This report aims to analyse the negative capitalisation of wind turbines on property values in Sweden over the last ten years. Our conclusions clearly show a relatively significant capitalisation, and that this capitalisation is relatively local, within ten kilometres of the wind power plant. Large wind turbines, or larger clusters of wind turbines in wind farms, impose a greater socio-economic cost in lower property values.

Keywords: sustainability, wind turbines, capitalisation, housing values, hedonic analysis

JEL-codes: Q01, Q53, R31, R53

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1. Introduction

In the wake of the 1973 oil crisis, several experimental wind turbines were set up in the 1970s. However, not until the early 2000s did electricity production from wind turbines increase markedly, especially between 2008 and 2019. In 2019, wind energy produced 20 TWh, which corresponded to 12% of the Swedish production. Sweden's goals to make electricity production 100-percent renewable by 2040, to discontinue nuclear power, and transform production and transportation to be fossil-free, require a large increase of wind power electricity. According to the Swedish Energy Agency (Energimyndigheten 2020), at least 100 TWh new electricity must be produced by 2045, which means that current wind power production must increase fivefold. The plan is to allocate new wind farms relatively equal according to the size of geographical regions. Of the 100 TWh, 80 TWh will be produced on land, and 20 TWh offshore. With an estimated average turbine effect of 6 MW, about 1% of Sweden's land area will then be used for wind farms [1].

Energy planning in Sweden takes place at both the national, regional, and local level. According to the Environmental Code, particularly suitable areas for a certain activity in Sweden must be pointed out as a ‘national interest’. The designation does not mean that a national interest has been determined, but it signals to courts and public authorities that determine whether such areas are, in fact, a national interest, and give increased weight to the interest. The Swedish Energy Agency is responsible for designating areas of national interest for wind farms. Exceptions are made for national interest areas in national parks, natural coast and mountains, Natura 2000 areas, and nature and cultural reserves.

Except for mineral extraction permits, local municipalities have unilateral authority over development and land use. Municipalities can veto even projects designated for areas of national interest for wind farms. Thus, strong local opposition might influence political decision-makers, preventing the establishment of wind farms.

This paper is the first academic analysis of the possible impact of wind turbines on property values in Sweden. Factors such as the proximity to wind turbines, their amount, and size/height, are the focus of the analysis.

A large number of articles deal with the socio-economic cost of wind power plant expansion. Most of these articles use the so-called indirect method by analysing whether wind turbines are capitalised in property values. We have also used this method. Our study's contribution is an analysis of approximately 4,000 wind turbines spread throughout Sweden, in the period 2013–2018. In addition, our results are based on about 100,000 single-family house sales. Another reason why Sweden provides an interesting case study is that Swedish municipalities can veto the continued expansion of wind power. This has made local municipal politicians sensitive to local opinion. As academic studies of this topic have not yet been conducted in Sweden, the results from the analysis will have major policy implications for discussions on compensation and expansion. Methodologically, we have tried to control for endogeneity by estimating the effect within a relatively limited area in the vicinity of wind turbines, and using the propensity score method to estimate a weighted hedonic price model, which, to our knowledge, has not been done before.

The remaining part of the article is arranged as follows: in the next section, a brief review of the literature in the research area is reproduced; the third section presents the theoretical platform and the methodological approach that we have used are presented; the fourth section presents our case study of Sweden; and the fifth section presents the empirical analysis. This is followed by our conclusions and a discussion of policy implications.

2. Literature review

Global warming, mainly caused by significantly increased CO^2 emissions since the 1950s, has led many governments to develop policies for sustainable, fossil-free energy production. Swedish Prime Minister Stefan Löfven has declared that Sweden will be one of the world's first fossil-free nations, and the Swedish Parliament has decided that the nation's electricity production will be 100-percent renewable by 2040. Because Sweden has simultaneously, slowly discontinued its nuclear power, and because any remaining hydroelectricity potential is limited by nature preservation, wind power is at present considered the only way to produce the energy needed for this transformation.

In 2020, about two-thirds of the Swedish population felt positively about increasing wind power electricity production to provide half of the country's electricity consumption by 2040 [2]. However, at the local level, where wind farms are being planned, there are several examples of strong opposition, both from residents and cottage owners. One of the most visible examples of this opposition is renowned footballer Zlatan Ibrahimović, who protested in April 2021 against a wind farm near one of his cottages in Jämtland County. The widespread Not-In-My-Back-Yard (NIMBY) phenomenon seems to also concern wind turbines.

The arguments of the protesters are well known in the literature: wind parks create unpleasant sounds, and "air vibrations" up to 5 kilometres from their location (depending on wind direction and topography), and are often located on mountains and ridges, making them visible from afar, especially with their blinking lights after dark. Thus, it could be hypothesised that these negative externalities (or ‘disamenities’) should be reflected and internalised by the values of properties surrounding the wind farms.

The only study of wind turbines' influence on property values made hitherto in Sweden is a non-peer-reviewed report [3[that did not find any significant support for the hypothesis. However, many studies in other countries find that wind turbines and wind farms have a negative influence on property values, although several studies find no capitalisation.

Studies in Denmark [4, 5], Germany [6, 7, 8], England and Wales [9], the Netherlands [10] and of New York State, USA [11], all found wind turbines/parks to have a negative effect on property values. In a study of two Greek islands, [12] found a negative impact up to two kilometres from wind turbines on one of the islands, but no effects on the other, probably due to the fact that the second group of turbines were on a very sparsely populated part of that island.

Several British [13, 14] and a number of North American studies have found no correlation between wind turbines/farms and changes in property value. [15] found no significant effects on prices of houses or farmland. [16, 17, 18] found no effects of wind farms on house prices in studies across the US. Studies of individual states with different characteristics, such Rhode Island [19] and Oklahoma [29], came to similar conclusions. In Denmark, [5] found that offshore wind farms (at least nine kilometres from land) did not affect property values.

Many of the abovementioned studies noticed the lack of consensus in the literature, but few have tried to develop the analysis further. The only example we have found is [21], a study of Ontario, Canada, which divided the local municipalities after they had expressed opposition to wind energy development. [21] found that in municipalities where the municipalities had protested, the wind parks exerted a negative impact on property values, while in municipalities where no protests were raised, no impact of wind parks on property values was found. [21] concluded that an explanation of the relatively large number of studies that found no impact on property values could be that they included areas of both these types. The results also indicate that local protests against wind farms in themselves might contribute to decreasing property values.

It can be assumed that studies that found negative impacts on property values would also find that the density of turbines in an area reinforces the negative impacts. However, only a few studies have included turbine density as a control variable, and the assumption is supported by [5, 21], but not by other studies [10, 11].

3. Theoretical and methodology framework

Like many previous studies [4, 5, 7, 11, 13, 14, 15, 17, 181 19] our analysis is based on the theoretical framework of hedonic models presented by [22]. There he showed that under certain conditions, the relationship between property prices and the value-affecting attributes could be interpreted as marginal willingness to pay. These value-affecting attributes primarily consist of characteristics that the property possesses, such as size and quality, but different types of amenities are also expected to be capitalised in property values. These can consist of different types of negative and positive externalities and the presence of public goods. One such is, for example, the negative externality of proximity to wind turbines. The hedonic price equation that we will estimate is as follows:

$$HP_{i,t} = \alpha_j + \beta_1 X_{i,t} + \beta_2 WT_{i,t} + \beta_3 T_t + \varepsilon_{i,t} \qquad \textit{(equation 1)}$$

where *HP* is equal to house prices (all models are estimated with price as natural logarithm based on a Box-Cox transformation), and the matrix *X* represents all value-affecting attributes such as size, age, and location. The variable WT represents proximity to a wind turbine. In the empirical analysis, we either used proximity to a wind turbine as a binary variable, or the shortest distance to a wind turbine. The vector *T* is a binary variable measuring the month the property was sold (fixed time effects). The subscripts i and t indicate transaction and time. All Greek letters indicate parameters that are estimated. The parameter α has a subscript of j for a municipality, indicating that fixed regional effects are included in the model.

The parameter estimate for wind turbines is the implicit or hedonic price and is interpreted as the marginal willingness to pay. In a cost-benefit analysis, this socio-economic cost must be set against the socio-economic benefits that a fossil-free energy source creates. The purpose here, however, is to estimate the capitalisation effect of wind turbines on property values.

One of the most serious problems in this type of analysis is the issue of endogeneity. Here, there is a risk that wind turbines have been located in areas that are less attractive and thus have lower property values. The parameter estimates of being located near a wind farm will then obviously show a negative correlation. An argument against this reasoning could be that wind turbines have not primarily been located in areas with lower property values, but areas with primarily good wind conditions. However, there is also a risk that they are located where they have the least impact on housing.

A few different methods reduce the risk of detecting a spurious relationship. Perhaps the most common is to use different instrument variables [23], and another is the so-called difference-in-difference methodology [5, 23]. Here, we have not used any of these, but instead the propensity score method [24], to identify properties similar in size and location but not in proximity to wind turbines. Thereby, the intention is to reduce the endogeneity problem, even if we cannot completely ignore it. We have also estimated models within a relatively narrow distance from the wind turbines to minimise the risk that properties near the wind turbines are different from properties further away. It will also reduce the risk of spatial dependence. We have also included fixed municipal effects, distance to urban areas, longitude, and latitude in the hedonic price equation, to reduce the risk of spatial dependence [25].

In the first step, we have estimated a logistic regression model, where the dependent variable consists of a binary variable that indicates whether the property is close to the wind turbine. For each property, we have then estimated a probability that they are located near a wind turbine. These probabilities have then been used as weights (the inverse of the probability) in the second step when we have estimated the hedonic price equation. Thus, properties with a high probability of being close to a wind turbine will be weighed heavier in the regression analysis than those that are further away, regardless of whether they are close to the wind turbine or not. The propensity score method has been used in this way in, for example, [24].

$$HP_{i,t} = \alpha_j + \beta_1 \frac{X}{PS_{i,t}} + \beta_2 \frac{WT}{PS}_{i,t} + \beta_3 T \frac{1}{PS_t} + \varepsilon_{i,t} \qquad \textit{(equation 2)}$$

where *PS* is the estimated propensity score. The higher the probability that the property is similar to the properties close to wind turbines, the greater weight the observation will have in the estimate.

Parameter heterogeneity

Proximity to wind turbines has been calculated by the shortest Euclidian distance between a wind turbine and the property. However, very rarely are wind turbines located in isolation. Instead, they are located in wind farms with two or more wind turbines relatively close together. To obtain a better estimate of the capitalisation effect, we have identified wind power plants close to each other through cluster analysis.

5. Empirical Analysis

Data

We use two data sources. First, we utilise sales data regarding single-family houses provided by the company Mäklarstatistik AB; second, we use data regarding the location of wind turbines in operation, from the Swedish Energy Agency.

The data is based on sales transactions provided by several member companies of one of Sweden's largest property agents. The coverage rate of sales is good overall, with around 80–90 percent, but slightly better in urban than rural areas. Wind turbines are primarily rural, so there is a risk that the number of analysed sales is slightly lower than the total number of sales. There is a risk of selection bias, but it should be limited to the cheapest properties not included in the analysed data. The available information includes when the property was sold, the transaction price, living space, and plot area, detached or semi-detached house, and latitude and longitude coordinates.

The information from the Swedish Energy Agency consists of each wind turbine in operation in Sweden, its location (latitude and longitude), its height, and its energy capacity. The calculation of the shortest distance between property and wind turbine has been done similarly to that of [11]. Hence, we calculate the shortest Euclidean distance to a wind turbine for each property.

In addition to this information, we have also used information about 1,600 urban areas in Sweden, and calculated the shortest distance between a property and an urban area. An urban area, in this study, is defined as a collection of buildings where the distance between the properties is less than 200 meters, and with a population greater than 200 (in the cohesive community). Furthermore, the daytime population must be greater by at least 10 percent than the resident population. Descriptive statistics for the two data sets are given in Table 1.

Table 1. Descriptive statistics.

	Full sample		Restricted sample	
	Mean	Standard deviation	Mean	Standard deviation
Price	3,079,324	2,135,857	2,717,670	1,657,671
Living area	129.5	36.0	129.0	35.8
Age	52.2	28.5	52.7	29.2
Rooms	5.2	1.3	5.1	1.3
Row house	0.08	0.3	0.07	0.2
Semi-detached	0.06	0.2	0.05	0.2
Distance to urbanization	2.9	2.4	2.6	2.2
Distance wind turbine	14.9	11.4	8.8	5.4
No. of obsevations	97,229		69,941	

The number of single-family house sales has been divided into a full sample (97,229 transactions) and a reduced sample (68,941 transactions), where the reduced sample includes only sales within 20 kilometres of the wind power plant. The descriptive statistics show that the dependent variable transaction price amounts to just over SEK 3 million in the full sample, compared with approximately SEK 2.7 million in the reduced sample. The lower purchase price indicates that properties closer to wind turbines are affected by the proximity. However, the causal relationship here can be questioned. A bit surprising is that properties within 20 kilometres of wind turbines are also nearer urbanised areas, which is expected to increase property values. The size of the properties are almost identical, in terms of living space, the number of rooms, and the plot area. The two samples are also equivalent in terms of property age. One difference of note is that terraced houses are more common in urbanised areas, and thus a greater proportion of the full sample than the reduced sample.

The average property distance to the nearest wind turbine is almost 15 kilometres in the full sample, and almost nine kilometres in the reduced sample. In total, just over 4 percent of properties are within two kilometres of a wind turbine. As expected, the share is slightly higher in the reduced sample, but only 6 percent of the total number of transactions are included in the reduced sample. We have used two kilometres, as it has been used previously in the literature, including by [12], which uses the range of 0–2 kilometres, and [18], which uses 1 mile (approximately 1.6 kilometres). Unlike [11] and others, we have relatively many properties close to wind turbines (almost 4,000 properties are located within two kilometres of a wind turbine.

In total, we analyse the impact of 4,337 wind turbines on property values. These wind turbines are spread throughout Sweden, but most numerous in the municipalities of Piteå, Strömsund, Gotland, and Örnsköldsvik. All analysed wind turbines are land-based. Furthermore, they are located at an average of 342 meters above sea level (with a standard deviation of 210 meters), and the average height of the wind turbines is 173 meters, with a standard deviation of 44 meters. Approximately 25 percent of wind turbines have a height above the average height, which means that many wind turbines are significantly smaller than the average. The completed cluster analysis shows that only 100 wind farms are found to have more than ten wind turbines.

Propensity score estimates

In the first step, we have calculated each property's probability to be close to a wind power plant using the so-called propensity score method. In principle, this means that we have estimated a logistic regression where the dependent variable is whether the property is within two kilometres of the wind power plant. As dependent variables, we have used property attributes such as dwelling size in square meters, and the number of rooms, size of plot, property age, and semi-detached or row house. In addition, we included fixed effects for counties, and for when the property was sold. Exact longitude and latitude coordinates are also included in the model. It has been shown that the inclusion of coordinates can remedy the problem of potential spatial dependency [5, 8, 26].

Table 2 shows the results of the logistical regression. In the first model, we have used all properties during the period, and in model two, only the properties within 20 kilometres of the wind turbine are included. Figures 1 and 2 show the distribution of propensity score weights in the full sample and the restricted sample.

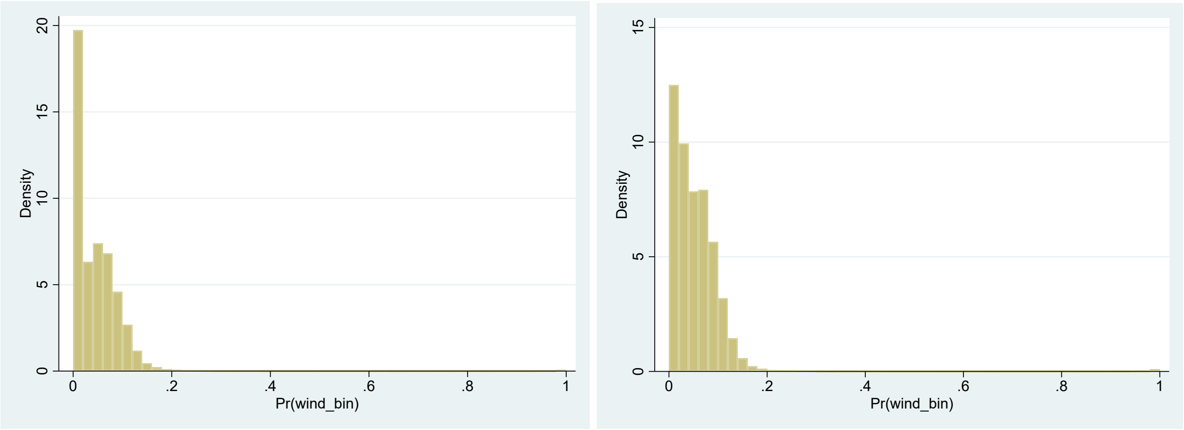
Table 2. Propensity score model (logistic regression)

	(1) Full sample	(2) Restricted sample
Living area	-0.00112	-0.00108
	(-1.83)	(-1.75)
Lot size	0.0000523***	0.0000520***
	(8.17)	(8.06)
Age	0.00485***	0.00489***
	(9.55)	(9.72)
Rooms	-0.0447**	-0.0429*
	(-2.65)	(-2.54)
Rowhouse	-0.382***	-0.375***
	(-4.88)	(-4.78)
Semidetach	-0.342***	-0.367***
	(-4.05)	(-4.34)
Distance to urbanisation	-0.0430***	-0.0420***
	(-5.29)	(-5.19)
Longitude	-0.311***	-0.297***
	(-5.87)	(-5.48)
Latitude	0.0384	0.0346
	(1.26)	(1.15)
Constant	12.35***	13.27***
	(3.93)	(4.14)
N	97161	68909
R^2	0.1067	0.0579
AIC	31522.8	30389.2

The model also includes fixed municipal effects, fixed monthly effects and latitude and longitude.
t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The dependent variable consists of whether the property is up to two kilometres from the wind turbine, i.e. about 4–6 percent of the sample. Larger dwellings (measured by living area and number of rooms) seem to lower the probability that the property is close to wind turbines, while plot size increases the probability. This means that properties closest to wind turbines are smaller indoors, but include larger tracts of land. We can also note that property age has a positive effect on the probability, which indicates that properties closest to wind turbines are older, and probably pre-exist the wind turbines. Townhouses and rowhouses are usually not located within two kilometres of wind turbines. Increased distance to urban areas (also highly correlated with the presence of terraced and row houses) reduces the probability of proximity to a wind turbine, i.e. wind turbines have not been located close to pre-existing urban areas. The differences between the two selections are small. The models also include fixed effects for the county and date of property sale. The degree of explanation is relatively low, which is normal in logistic regression. The logistic regression results in propensity scores that will then be used as regression weights in the hedonic price model. Figure 1 shows the distribution of these weights in the full sample and the reduced sample.

Figure 1. Histogram Propensity Scores



(Full sample) (Restricted sample)

The weights range from 0 to 1. The closer to 0 a sale falls, the less weight the observation will have in the model that estimates the capitalisation effect. Hence, the lower the weight, the worse the observation as a comparative transaction. However, it is important to remember that all observations will be included in the hedonic price model, but some will have a higher or lower weight in the regression (weighted hedonic regression model).

Hedonic price equation

In the second step, we have estimated the hedonic price equation using weighted least square regression (WLS), where the inverse of the propensity score is the weights. Table 3 presents 4 models. Models 1 and 2 include the distance to wind turbines measured in kilometres, i.e. the variable is continuous. Model 1 uses all transactions, and model 2 is based on the restricted sample. In models 3 (full sample) and 4 (restricted sample), the variable proximity to wind turbines is instead measured as a binary variable, equal to 1 if the property is within two kilometres of the wind turbine.

Table 3. Hedonic price equation with PS weights (continuous and binary variables).

	(1) Full sample	(2) Restricted sample	(3) Full sample	(4) Restricted sample
Living area	0.00396***	0.00471***	0.00397***	0.00471***
	(58.01)	(48.65)	(57.45)	(48.80)
Lot size	0.0000111***	0.0000165***	0.00000846**	0.0000169***
	(4.70)	(10.02)	(2.94)	(10.36)
Age	-0.00179***	-0.00307***	-0.00169***	-0.00305***
	(-22.16)	(-28.78)	(-20.89)	(-28.70)
Rooms	0.0368***	0.0268***	0.0374***	0.0266***
	(19.30)	(10.49)	(18.83)	(10.43)
Rowhouse	-0.220***	-0.111***	-0.221***	-0.110***
	(-49.16)	(-15.38)	(-49.45)	(-15.46)
Semidetach	-0.149***	-0.0922***	-0.153***	-0.0918***
	(-30.36)	(-11.75)	(-29.98)	(-11.75)
Distance to urbanisation	-0.00965**	-0.0168***	-0.00483	-0.0166***
	(-2.88)	(-9.32)	(-1.02)	(-9.48)
Distance to wind turbine	0.00775***	0.00333***		
	(7.55)	(4.23)		
Wind turbine (binary)			-0.149***	-0.141***
			(-9.21)	(-14.56)
Constant	14.31***	14.48***	14.45***	14.55***
	(209.50)	(151.36)	(226.14)	(153.54)
N	97161	68909	97161	68909
R^2	0.820	0.690	0.818	0.691
AIC	44841.4	49144.0	46135.2	48931.9

The model also includes fixed municipal effects, fixed monthly effects and latitude and longitude.
t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In general, we have a relatively good degree of explanation in our models. The price variation can be explained better in samples with all sales compared to the reduced sample. This indicates more heterogeneity among the sales found in the reduced sample. In the full sample, the degree of explanation amounts to as much as 82 percent, which can be considered very high; in the reduced sample the degree of explanation amounts to almost 70 percent, i.e. a relatively large difference degree of explanation. Compared with [11] and [12], the degree of explanation is very high, and compared to [18], the degree of explanation in this study is in the upper range.

All estimated parameters show expected signs and a reasonable level compared to other studies. The size of the house, as measured in square meters, number of rooms, and plot size, increases expected prices, while if the property is a terraced house or chain house, expected values decrease. For example, if the number of rooms increases by one room, the price is expected to increase by about 3 percent, and if the property is a row house, the value is reduced by 22 percent in the full sample, and halved in the reduced sample. Longer distances from urbanisation reduce the value of the property, as expected.

Proximity to wind turbines has a clear and statistically significant effect on property values. In economic terms, the effect is relatively significant. Greater distances from wind turbines increase the expected price of the property. In the full sample, the effect is twice as great as in the reduced sample, which is probably due to a certain endogeneity resulting from wind turbines' location in areas with lower housing prices. When we analyse a narrower area around the wind turbines than that found in reduced sample, the effect is lower and more reliable. The economic interpretation of the estimated parameter is that every additional kilometre between the property and the wind power plant increases the housing value by 0.3 percent. Here we have estimated the impact as a linear impact, which it certainly is not. We are expected to have a higher impact nearer the wind turbine than further away.

If we estimate the capitalisation effect using a binary variable (where 1 refers to whether the property is within two kilometres of a wind turbine, otherwise 0), it can be stated that the effect is significantly higher. We can also note that the effect is equivalent regardless of whether we analyse all transactions or only the reduced sample. The effect here is approximate of the order of 14 percent lower value.

If we compare our results, we find that they are in line with many other studies from other countries, such as [12], although our results diverge from the estimates of others, such as [18]. Studies that have found significant effects have drawn criticism for basing their results on small samples and relatively few wind turbines, where only a few properties are located near the wind turbines. This is, among other things, an argument put forward by [18]. However, our sample (regardless of whether we analyse the full sample or the reduced sample) is significantly larger, and significantly more properties are located in the vicinity of a wind turbine.

Table 4 illustrates WLS estimates of the hedonic price equation where the proximity to wind turbines consists of several binary variables, where the first refers to the range 0–2 kilometres, the second 2–4 kilometres, and so on. That is, we are relaxing the assumption about linear capitalisation. It is also a specification used by, for example, [11]. As before, model 1 refers to all transactions, and model 2 refers to the restricted sample. Figure 2 shows the capitalisation effect within the interval 0–14 kilometres based on the estimates in Table 4.

Table 4. Hedonic price equation with PS weights (structure of binary variables)

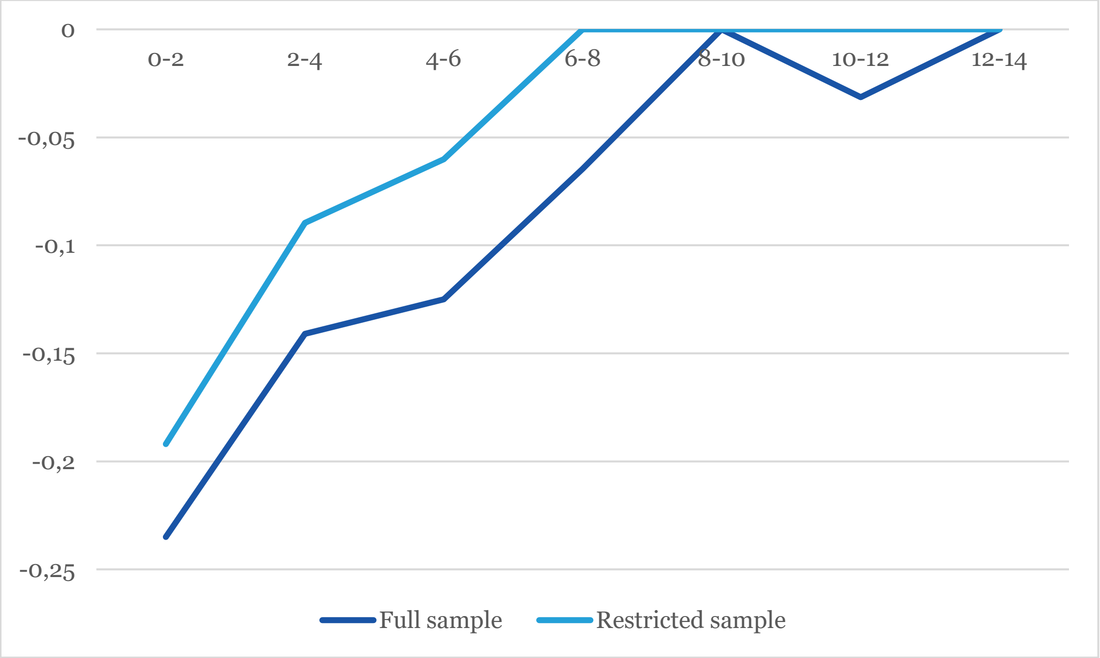
	(1) Full sample	(2) Restricted sample
Living area	0.00396***	0.00470***
	(57.63)	(48.74)
Lot size	0.00000883**	0.0000173***
	(3.17)	(10.55)
Age	-0.00167***	-0.00302***
	(-20.72)	(-28.43)
Rooms	0.0373***	0.0261***
	(18.93)	(10.25)
Rowhouse	-0.222***	-0.112***
	(-48.98)	(-15.50)
Semidetach	-0.153***	-0.0901***
	(-30.00)	(-11.52)
Distance to urbanisation	-0.00553	-0.0169***
	(-1.24)	(-9.21)
Wind turbine 0-2 km	-0.235***	-0.192***
	(-10.41)	(-12.61)
Wind turbine 2-4 km	-0.141***	-0.0896***
	(-6.14)	(-6.01)
Wind turbine 4-6 km	-0.125***	-0.0601***
	(-5.67)	(-4.24)
Wind turbine 6-8 km	-0.0645**	-0.0220
	(-3.28)	(-1.63)
Wind turbine 8-10 km	-0.0127	0.00121
	(-0.83)	(0.10)
Wind turbine 10-12 km	-0.0314*	0.00485
	(-2.29)	(0.40)
Wind turbine 12-14 km	-0.0175	0.0160
	(-1.26)	(1.32)
Wind turbine 14-16 km	-0.0780***	-0.0524***
	(-5.94)	(-4.00)
Wind turbine 16-18 km	-0.0541***	-0.0445***
	(-5.00)	(-3.77)
Constant	14.45***	14.54***
	(225.04)	(152.56)
N	97161	68909
R^2	0.819	0.693
AIC	45612.8	48525.6

The model also includes fixed municipal effects, fixed monthly effects and latitude and longitude.
t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In the models where proximity to wind turbines is included as several binary variables, the degree of explanation is par with previous models. Also, all underlying variables have the same sign and magnitude. This means that regardless of how wind turbines are included in the model parts, other estimates are robust. However, an exception is proximity to urbanisation, which is not statistically significant in the model where all observations are included, but in the model with the restricted sample, the estimate is on par with previous estimates.

The effect of wind turbines is also clear in this model, and it is also clear that the effect is non-linear. For every kilometre from the wind turbine, the marginal effect is lower. Within the range 0–2 kilometres, the effect is greatest. Here, the estimated capitalisation effect is approximately 19–23 percent. This is a significant effect, and greater than the estimates (ref) of many other studies. The estimate is statistically significant, but it should be noted that the estimate is based on relatively few observations. Few properties are in the range of 0–2 kilometres. In the interval 2–4 kilometres, the estimated effect is 10–14 percent, and then drops to 6–12 percent in the interval 4–6 kilometres. In the interval 6–8 kilometres, the effect has fallen to 2–6 percent. Distances greater than 8 kilometres do not appear to have statistically significant estimates, nor does the effect appear to recur at distances greater than 14 kilometres. That effect is difficult to explain. The greater distance to the wind turbine, the closer it is to other ‘disamenities’ that give a negative capitalisation but are not included in the model. However, the results show that further research is needed to understand the wind power plants' capitalisation in property values. The result of the capitalisation in the interval 0–10 kilometres is shown in Figure 2.

Figure 2. Capitalisation effect.



Height and number of wind turbines

In step 4, we have analysed whether the size of the wind turbines has any significance for the capitalisation effect. We have estimated two models to estimate the capitalisation effect when the property is close to large wind turbines or small wind turbines. Moreover, we have also estimated the capitalisation effect when the property is located near larger wind farms. The expected effect is that wind turbines taller than average have a greater capitalisation effect, and that wind farms with more than 10 wind turbines have a greater capitalisation effect. Table 6 illustrates the WLS estimates regarding the effect of height and the number of wind turbines.

Table 5. Parameter heterogeneity in size (altitude and number). Restricted sample.

	(1) Large	(2) Small	(3) More
Living area	0.00500^{***}	0.00462^{***}	0.00533^{***}
	(8.76)	(51.93)	(10.56)
Lot size	0.00000965	0.0000174^{***}	0.0000412^{***}
	(1.93)	(10.36)	(6.11)
Age	-0.00365^{***}	-0.00218^{***}	-0.00473^{***}
	(-5.27)	(-21.13)	(-6.03)
Rooms	0.0205	0.0290^{***}	0.0242
	(1.27)	(11.95)	(1.53)
Rowhouse	0	-0.131^{***}	-0.110
	(.)	(-16.65)	(-0.87)
Semidetach	-0.176	-0.0937^{***}	-0.251^{***}
	(-1.76)	(-13.58)	(-3.62)
Distance to urbanisation	-0.00944	-0.0164^{***}	-0.0351^{***}
	(-1.12)	(-10.44)	(-4.37)
Large wind turbine (binary)	-0.412^{***}		
	(-7.45)		
Small wind turbine (binary)		-0.0985^{***}	
		(-13.51)	
Wind turbine park (binary)			-0.277^{***}
			(-3.51)
Constant	30.42	63.07^{***}	27.46
	(1.18)	(18.64)	(1.23)
N	1054	68178	1845
R^2	0.620	0.723	0.442
AIC	779.8	41912.3	1476.4

The model also includes fixed municipal effects, fixed monthly effects and latitude and longitude.
t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

If we divide the material into properties proximate to higher than average wind turbines, we can first state that relatively few properties are within 20 kilometres of these. The heterogeneity also seems to be greater, as the degree of explanation drops to just over 60 percent. The estimated effect of being in the range 0–2 kilometres, compared to 18–20 kilometres, is statistically significant, and the economic interpretation is that the effect is significant—just over 40 percent lower prices, according to the model.

Compared with the model with only the properties proximate to shorter wind turbines, we have significantly more sales in the interval 0–20 kilometres from the wind turbine. The degree of explanation is also higher in this model. The effect of being a maximum of 2 kilometres from the wind power plant is significantly lower, at just under 10 percent. The interpretation is that the authorities need to be much more careful where they locate the newer, much taller wind turbines than they may have been previously. The effect on property owners will be significantly greater.

In the model where we analyse housing prices for properties close to wind farms, the effect is almost 30 percent. Although the estimate is based on a smaller number of observations, the estimates are statistically significant. The marginal effect of proximity to tall wind turbines, or wind farms, should be studied more carefully to minimise impact on property values when situating future wind turbines, or establish compensation levels for affected property owners.

6. Conclusion and policy implications

The results clearly indicate a negative capitalisation of proximity to wind turbines in property values in Sweden. The relationship between wind turbines and property values is non-linear and decreases exponentially with the distance from the wind turbines. The results also indicate that proximity to tall wind turbines, and proximity to many wind turbines (wind farms) have greater impacts.

Because Sweden plans to increase fivefold its wind power production in the next two decades, these results will doubtless have policy implications. Even if protests against wind power expansion remain at the local level, the expansion is likely to lead to more and better organised protests. It can also be expected that property owners will demand economic compensation for decreased property values. All this indicates the need for a national policy, not only for expanding wind power production (which is underway), and possibly abolishing the municipalities' opportunity to veto against planned wind power establishments (currently being investigated), but also for handling individual demands for compensation and local fears of the eyesore presented by nearby wind parks.

Future research could address the endogeneity problem with a difference-in-difference approach. Wind turbines have been built at different times, so an analysis of before and after construction can be calculated, even if it might be difficult to find fully alternative reference locations. Information about the entire construction process, from building permits, construction, and operation, could also be used to analyse the project's capitalisation effects. Data about rejected building permits are also interesting to further analyse. Another possible topic for further research are the regional or other locational differences in capitalisation.

The significance of this type of study will become increasingly important. The policy implications are clear. Wind turbine energy production has expanded in recent years, and will certainly continue to expand to meet the goal of climate-neutral energy production. To gain acceptance for a continued expansion, values beyond environmental values, including property values, must be considered when wind turbines are built. Further research can form the basis for calculating compensation to property owners.

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