

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Economic Analysis and Policy

journal homepage: www.elsevier.com/locate/eap

Modelling Economic Policy Issues

Capitalisation of onshore wind turbines on property prices in Sweden: The need to compensate for negative externalities

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ARTICLE INFO

JEL code:

C21
Q51
R30

Keywords:

Wind turbine
Capitalisation effect
Regional
Staggered dynamic difference-in-difference
Matching
Property values

ABSTRACT

Due to, for example, disturbing sound and deteriorated scenery, wind turbines might constitute a negative externality. By using a revealed preference method, we examine the impact of onshore wind turbines on property values in Sweden, analysing over 600,000 real estate transactions from 2005 to 2018. We find that wind turbines are built in areas with lower prices in general (as they are built outside population centres), that property values start declining when a building process is started (due to anticipations of negative impacts) and that the price decline continues after the wind turbine has been commissioned (due to the perceived negative effects). Property values within 2 km of wind turbines decrease by approximately 10–15 %, diminishing the effect to zero beyond 6–10 km. There are significant differences in capitalisation between regions, with higher capitalisation effects in southern Sweden. These findings suggest the need for policies to internalise external costs and compensate affected property owners, contributing to informed planning for sustainable energy development.

1. Introduction

Politicians and business leaders worldwide are taking steps to reduce CO₂ emissions and produce fossil-free energy in the global effort to combat climate change. 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 industrial projects are being launched to replace fossil energy with electricity/fuel cells. Two large plants are planned for fossil-free production of directly reduced sponge iron and steel in northern Sweden, and their total yearly use of electricity is estimated to be 82 Twh. The branch organisation *Energiföretagen* has estimated an annual demand of 320 Twh electricity in Sweden in 2045, compared to 140 Twh in 2020. Therefore, 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 initiated concerns among property owners near the wind farms over reduced property values and other problems such as noise/air vibrations and changed landscape views.

The international research literature on the 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 nearby properties (*Gibbons*, 2015; *Sunak and Madlener*, 2016, 2017; *Jensen et al.*, 2014, 2018; *Frondel et al.*, 2019; *Dröes and Koster*, 2016, 2021). However, several North American studies have not found any effects (*Hoen et al.*, 2009, 2011, 2015; *Lang et al.*, 2014; *Castelberry and Greene*,

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Received 23 August 2024; Received in revised form 6 June 2025; Accepted 13 July 2025

Available online 14 July 2025

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2018), but some have shown adverse effects (Heintzelmann and Tuttle, 2012) or mixed effects (Vyn, 2018). In an overview of hedonic price literature from 2011 to 21, Parsons and Heintzelman (2022) examined 18 studies. Of those, the 10 European studies all showed negative impacts, while only 3 of the 8 North American studies showed adverse effects. The overview also concluded that after 4 km from wind turbines, effects were "diminishingly small" and that the adverse effects tend to increase with the number and height of the turbines. However, recent American studies have found more unambiguously negative influences. Dong et al. (2023) found negative impacts within 1 km of wind turbines (−2.5 %–4.6 % relative to properties at 3–10 km distance) in Massachusetts and Rhode Island. Their estimations suggest that the adverse effects diminish over time.

While many American studies have been based on specific regions or states, Brunner et al. (2024) analysed the entire universe of housing transactions in the United States from 2005 to 2020. Their results showed that homes within 1 mile from wind turbines, on average, had about an 11 % decline in value compared with homes 3–5 miles away when the building of the turbines was announced. After the construction, property values recovered, and the decrease was statistically insignificant 9 years or more after the announcement (about five years after construction). Another recent American study (Guo et al., 2024) covering all housing transactions (outliers excluded) from 1997 to 2020 in the whole continental USA focuses on the visibility impact of wind turbines on property values.¹ In essence, their results confirm the results of Brunner et al. (2024): House prices decrease on average by up to 8 % after constructing a wind turbine within the viewshed. The effect decays with distance and is not statistically significant after 8 km. Guo et al. (2024) and Brenner et al. (2024) also found that the negative effect decreases over time. The adverse effects peak three years after construction and then decrease as more years pass, but it is also the case that more recently installed wind turbines have a minor negative impact on property values. In the European studies that found an effect, the magnitude of the effect varied considerably. A Danish study by Jensen et al. (2014) found that combinations of visual and noise disturbances decreased house prices by −15.4 % within 250 m from wind turbines and by −5.3 % at 1600 m distance. In another Danish study, Jensen et al. (2018) found that the adverse effects of onshore wind turbines lasted up to 3 km, while offshore turbines (of which the nearest were placed 9 km from land) had no impact. Sunak and Madlener (2017) analysed the effects of the visibility of wind turbines in Germany and found that properties with a view that from "medium to extreme" was dominated by wind turbines had fallen in price by 9–14 % within 3 km from the turbines. Frondel et al. (2019) found in another German study an average effect of up to −7.1 % for houses within 1 km of a wind turbine and that the effect was zero at 8 to 9 km. A study by Dröes and Koster (2016) of the Netherlands found a −1.4 % to −2.3 % reduction in price for houses within 2 km of a turbine, but the effect after that was insignificant. In another Dutch study, Eichholtz et al. (2023) found that properties up to 4 km from wind turbines had lower values between −1.8 % and −2.1 %. A study in England and Wales by Gibbons (2015) found that visible wind turbines within 4 km reduced property prices by −2.4 %.

A consultancy report that analysed the period 2001–2007 found that wind turbines had no impact on property values in Sweden (Svensk Vindenergi, 2011). However, the only academic Swedish investigation on the topic, published 11 years later and covering 2013–2018 (Westlund and Wilhelmsson, 2021), showed effects in line with the other European studies, i.e., adverse effects. They also found that this effect decreased with the distance from the wind turbines and fell to zero after 8 km. They used a hedonic model that controlled for other factors that could influence house prices (size of house and plot, year of construction, distance to an urban centre), but they did not study price changes before the 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 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. Hence, this difference-in-difference method approach compares the development of house prices 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 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 contribution has been analysing the effect of a wind production expansion in Sweden. Few studies have previously been done on this market, with Westlund and Wilhelmsson (2021) as an exception. Unlike their study, our purpose has been to investigate the relationship between house prices and proximity to wind turbines more thoroughly and to examine possible regional differences. The research question aims to estimate the capitalisation effect and calculate the expected impact on property values in the total housing stock in three planned wind power development areas in different parts of Sweden.

We increase knowledge of the subject by analysing data over a more extended period, estimating capitalisation effects using a staggered difference-in-difference approach (e.g. using heterogeneity robust estimators suggested recently by Roth et al., 2023 and Callaway and Sant'Anna, 2021), and testing regional differences in the capitalisation effect. However, even if we may see that we meet the parallel trend assumption, it by design does not meet the requirement of no anticipation, which means we can fully ensure the causal connection. Furthermore, our study confirmed that the hedonic methodology provides results slightly higher than the difference-in-difference models.

This article is divided into six sections. Section 1 provides an introduction and overview of the article. Section 2 presents the theoretical framework and methodological approach: staggered, dynamic difference-in-difference and hedonic price equation. Section three discusses the Swedish case study and institutional context, with three case studies evaluating the total price impact in potential future wind power areas. Section four presents the empirical analysis, staggered dynamic difference-in-difference models, hedonic

¹ It should be noted that the digital elevation model (DEM) used by Guo et al. (2024) for measuring visibility has been criticised as it only takes natural topography into account, and not trees and buildings. Thus, DEMs might overestimate viewsheds and thereby underestimate the negative externalities of wind turbines (Lang et al. 2024; Dong et al. 2024).

price models and an estimate of the effect on total housing stock. [Section 5](#) discusses the study's results and provides policy recommendations, and [Section 6](#) presents the conclusions and policy recommendations. Overall, the study aims to analyse the impact of wind turbines on property values and provides insight into the importance of considering local negative externalities in wind turbine location planning.

2. Theoretical framework and identification strategy

This section will present our identification strategy and how the total effect on property values can be estimated.

2.1. Theoretical framework

The concept of externalities is deeply rooted in microeconomic analysis (Varian, 1992; Mas-Colell et al., 1995). In this context, an externality refers to actions by a landowner that affect others—such as consumers, other landowners, or the broader public—without those effects being reflected in market transactions. For instance, a landowner or a wind power producer might initiate a wind power project that impacts neighbouring landowners. If such effects, whether positive or negative, are not internalised in the project's economic calculations, they can lead to socioeconomic inefficiencies.

The externalities generated by wind power projects are typically categorised into two types. Consumption externalities, such as visual intrusion, noise, light reflections, and barrier effects, directly affect individuals' utility. Producer externalities arise when the installation of wind turbines prevents neighbouring landowners from establishing their wind power facilities. This study focuses exclusively on consumption externalities and their impact on adjacent landowners, excluding the broader public's willingness to pay.

The question of whether wind turbines constitute a negative externality remains debated. Empirical evidence suggests their impact depends on multiple factors, including proximity, turbine height, and local geographical features. Many studies use revealed preference methods to estimate the willingness to pay to avoid turbines, often employing hedonic pricing models (Johansson, 1993; Rosen, 1974). These models assess how externalities are capitalised into housing prices, measuring part of the economic costs of such impacts. Few research studies have relied on stated preference methods for similar evaluations. This study employs the hedonic pricing approach to assess the externalities of wind turbines.

We hypothesise that proximity to wind turbines negatively affects the market value of nearby properties. For instance, given two identical houses in similar environments, if one property has a wind turbine visible at 1000 m, we expect its market value to be lower than the other. We further hypothesise that the negative effect diminishes with increased distance from the turbines, becoming negligible at larger distances (e.g., 2000 m). Additionally, we investigate whether these externalities are more pronounced in densely populated areas.

The timeline for constructing wind turbines is extensive, involving site assessments, planning, public consultations, and permitting before construction begins. Externalities may arise at different stages, including during planning discussions or once the turbines are operational. For example, announcement effects, occurring when construction permits are granted, may already impact property values (Kiel and McClain, 1995). Focusing solely on the operational stage risks underestimating the total negative externality.

The externality costs assessed here represent only a fraction of the total socioeconomic impacts of wind turbines. While high property devaluation could imply significant costs, this does not necessarily undermine the economic viability of wind power projects. Studies have demonstrated that wind turbines can boost local economies, particularly in rural areas, by increasing incomes and supporting ancillary industries (Brunner and Schwegman, 2022). To ensure equitable outcomes, project developers should internalise externality costs, potentially compensating affected landowners.

2.2. Identification strategy

Estimating the relationship between property values and the investment of wind turbines near the properties is challenging. For many reasons, the exogenous assumption (zero conditional means) may not hold. Perhaps the most important reason is the issue of reverse causality, but we can also face problems with omitted variables and selection biases. This section will first present our identification strategy for the capitalisation effects, and then we will show how we have estimated the socioeconomic cost for three different planned wind power projects in Sweden.

A natural starting point is the hedonic price equation. We estimated a classic hedonic price equation (Rosen, 1974), as in (Athukorala et al., 2019; Kim et al., 2020; Westlund and Wilhelmsson, 2021), presented in Eq. (1).

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

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 endogeneity problems should be minimised (Hill et al., 2021). Therefore, in addition to fixed effects, we have included the indoor and outdoor size, age, and distance to the nearest capital and urban area. The basic model consists of the minimum distance between the property and the wind turbine (W) in the price equation as a binary variable where the variable is equal to 1 if the property is located 10 km 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 to up to around 10 km, where it falls to near-zero (Westlund and Wilhelmsson, 2021; Jensen et al., 2018). 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. Moreover, we have also interacted with the distance to a wind turbine with a binary variable indicating whether the wind turbine is above the median height of all wind turbines.

All models have been estimated by adjusting for the fact that properties closer to and farther from wind turbines may differ in characteristics. Simply including property attributes in the hedonic price equation will not necessarily control for it. Therefore, we utilise a propensity score matching approach (Rosenbaum and Rubin, 1983) that calculates the probability that the property is within 5 km of a wind turbine. Independent variables in the propensity score model are property attributes, distance to the nearest urban area and municipality centre, and fixed effect for county, year and county*year. The results are presented in the Appendix (Table A1). We have used the nearest neighbour method with caliper=0.01. The descriptive statistics of the treated and control groups are presented in the Appendix (Table A2). Overall, the treated and control groups show minor differences; hence, the sample is well balanced.

2.3. Staggered dynamic difference-in-difference

The event study methodology is commonly used as an econometric tool to evaluate various treatment effects (Miller, 2023). It allows for assessing different public or private interventions that may not be purely experimental, treating them in a more quasi-experimental manner (Abadie, 2010; Angrist and Pischke, 2009; Wooldridge, 2013). In the traditional Difference-in-Difference (DID) approach, the classic evaluation is a 2×2 setup involving comparing before and after periods and subjects that receive treatment or are included in the control group. The intervention typically occurs at a single point in time. However, in many cases, the quasi-experimental design does not follow this pattern, as interventions may occur at different times, resulting in a multiple-event setup, as with wind power investment over several years.

Instead, we estimate a staggered dynamic difference-in-difference (SDDD) model. This approach involves staggering treatment and control groups over time and accounting for dynamic effects, allowing the intervention to influence the outcome variable before and after implementation. This type of model has been utilised in various applications in recent years (Callaway and Sant'Anna, 2021; Duan and Xu, 2023; Hou et al., 2023, 2023; Hu et al., 2024; Huang et al., 2023; Li, 2022; Lin et al., 2023; Miller, 2023; Peng et al., 2024; Wilhelmsson, 2023; Zhang et al., 2024). The model we will estimate is as follows:

$$Y_{i,t} = \alpha_{k,t} + \beta X_{i,t} + \sum_{j=-7}^7 \gamma_j I(j) + \varepsilon_{i,t} \quad (2)$$

The outcome variable Y is equal to housing prices in our case. Eq. (2) is a two-way fixed effect model (county and year fixed effects) with a fixed effect interaction variable (county*year effects), where the intercept α varies as a function of k and t (Imai and Kim, 2021). The subscripts t represent the year, k for the county, j is the j th event (here, the construction of wind power), and i is the individual observation/transaction. A series of binary variables representing the years before and after the event make up variable I . Seven years before and after the intervention are used here. X is a covariate vector included in the model, as there may be an imbalance in the treated and untreated groups (Abadie, 2005). The covariates in our case are housing and location characteristics.

We have also included probability weights based on the propensity score to balance the potential difference between the treated and untreated groups (Abadie, 2005; Callaway and Sant'Anna, 2021; Rosenbaum and Rubin, 1983; Wilhelmsson, 2023). The standard deviations of the estimators are frequently underestimated by conventional standard errors (Bertrand et al., 2004). Instead, we employ cluster standard errors at a group postal code level (Liang and Zeger, 1986). We use propensity score techniques to control for potential sample selection bias, similar to e.g. (Asharaf and Tol, 2024; Castelnovo et al., 2023; Sethi et al., 2024).

Difference-in-difference is based on the parallel trend assumption; the treated and not-treated observation should follow the same pre-treatment trend in the outcome variable. Our treatments do not occur simultaneously, complicating the possibility of testing the parallel trend assumption (Roth et al., 2023). (Votsis and Perrels, 2016) discusses the parallel trends assumption in the context of the difference-in-differences methodology applied to volatile time series, particularly housing prices. They highlight the challenge of maintaining the assumption of perfectly parallel trends between control and treatment groups. Due to the inherent volatility and non-stationarity of housing prices, expecting a textbook DD effect is difficult. This volatility can cause semi-permanent price jumps, complicating the distinction between natural price changes and treatment effects, which may require relaxing the parallel trends assumption. Roth et al. (2023) also mentions that the choice of functional form can affect the sensitivity of the parallel trend assumption.

We have tested this by graphically estimating the price trend for never-treated observations (control group) with the soon-to-be-treated observation (Roth et al., 2023). It has been done with and without covariates included in the model.

Difference-in-difference is also based on the assumption that there is no anticipation that the observations will be treated (Roth et al., 2023). It is an assumption that is difficult to fulfil in all types of difference-in-difference, but perhaps above all measures that take place in the environment and where there is a long planning phase before the measure is in place. We analyse the effect of when the wind turbine is in place and is in the operating stage. Of course, there has been a more extended period before landowners could expect future wind turbines' capitalisation. An alternative could be to use when the decision was made to build the wind turbine. However, the decision only results from a lengthy planning process that can take many years, from initial consultation with citizens to the actual decision. Throughout this process, it is difficult to assume there is no anticipation. We have estimated the effect based on the operating stage and indicated when the final decision was made on the building permit (when it gained legal force).

Furthermore, we have tested the robustness of our models by doing a placebo test where we have both randomly moved treatment in both time and space (Castelnovo et al., 2023; Aggarwal et al., 2023). The result shows that the placebo model yields non-significant results. We interpret it as supporting the credibility of our main findings.

2.4. Parameter heterogeneity

To test for parameter heterogeneity, we have estimated models that intend to analyse whether the capitalisation effect differs within 0–2 and 0–5 km of wind turbines in the difference-in-difference model. This has been done by including binary variables equal to 1 if the property is within a 2-km range up to 7 years pre-treatment and 3 years post-treatment from the wind turbines (and zero if not treated over the analysed period). The control group is 10–20 km from the nearest wind power; we assume the wind turbine has no capitalisation effect after ten kilometres.

In the hedonic model, we have included the distance to the wind turbine in 2-km intervals from the nearest wind turbine. We have done this up to 10 km from the wind turbine. The hypothesis is that we have a diminishing effect, and there is no expectation that the impact will be significant after 8 km (Brunner et al., 2024)

We also analyse potential parameter heterogeneity by examining whether the capitalisation effect differs between regions. In the hedonic model, 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.

2.5. Estimating the total effects on property values

To estimate the future potential socioeconomic cost of new wind turbines, we have calculated the difference in market value and interpreted them as the willingness to pay to avoid the wind turbines. Of course, it does not constitute the entire socioeconomic cost, only a part. A wind turbine can, of course, also produce effects for non-landowners who are willing to pay. Nor have we had an ambition to analyse the positive impact that a wind turbine gives rise to. These calculations should not be seen as a calculation of whether a wind turbine investment is economically viable.

Estimating the effects on properties has been done in several steps. 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 wind turbines' geocoded locations and calculating the distance to all properties for residential purposes in the housing stock. The social welfare effect (W) is estimated in Eq. (3).

$$W = \sum \left(\sum_{i=1}^m V(x) - \sum_{i=1}^m V(x)\gamma \right) \quad (3)$$

Residential properties (m) within 10 km of the planned wind turbines will then, in the next step, be valued (V) based on the characteristics in X , that is, 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-km intervals from the wind turbine, the valuation (V) will be multiplied by the capitalisation factor (γ) within the selected interval, then summed up, and the difference between the two will be calculated.

3. The case study of Sweden

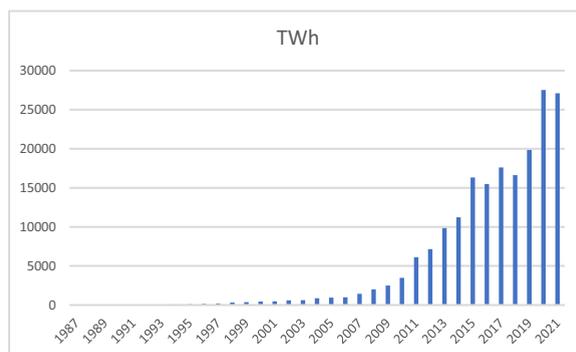
We are analysing the wind power expansion in Sweden over the past 15 years. The plan for the future is that this expansion will continue to reduce and eventually be able to phase out all energy production based on fossil fuels. This means that Sweden will need to invest in new development areas in addition 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 in about 2010 (see Fig. 1). An important factor was a 2006 governmental bill (Prop. 2005/06:143) positing governmental support for municipal master plans that developed prerequisites for the 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.² In 2021, 4754 wind turbines in Sweden produced 27,108 TWh, corresponding to 17 % of total electricity production.

The conversion to CO²-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 offshore wind turbines that would produce 20,000 TWh. However, if the abovementioned plans to produce directly produced 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 its capacity have caused increasing resistance. Studies at Göteborg 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.

² 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.



Note: Source: Swedish Energy Agency.

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

In Sweden, local governments can decide on land use and planning issues, including the location of wind turbines. Local opinions can influence this decision-making process and have delayed or cancelled many planned wind farms. To address this, a recent governmental enquiry has recommended that municipalities base their decisions on their master plans and that permits should be valid for five years (SOU 2021:53). The issue of compensating municipalities and local associations for the potential adverse effects of wind turbines was also discussed. However, compensation for property owners affected by decreases in property values was not addressed.

3.1. Case studies

(1) Östra Göinge

Östra Göinge is a municipality in southern Sweden. It is relatively small, with 15,000 inhabitants in the municipality, which covers 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. The planned expansion of wind power consists of 16 wind turbines [Area: 1256-V-009] and two separate areas west and east of the village of Knislinge. The planned expansion is only about 6 km from Broby and Knislinge, with a population of about 3500, indicating that the investment will affect many property owners.

(2) Finspång

Finspång is a municipality with about 22,000 inhabitants, and the population density is approximately 18 inhabitants per square kilometre, which is lower than average in Sweden. The wind power development area is north of Norrköping, near Simonstorp. The project area [0562-V-004] comprises 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 Cases 1 and 2, with approximately 75,000 inhabitants and an area of 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 near Burträsk and has 33 wind turbines. In the immediate vicinity, there are already former wind power areas. Near the project area, relatively few property owners will be affected.

4. Empirical analysis

The empirical analysis consists of four components: (1) establishing the relationship between property values and wind turbines using the staggered dynamic difference-in-difference, (2) estimating the capitalisation of wind turbines in property values using a hedonic price model; (3) calculating the total socioeconomic cost of three potential development areas; and (4) valuing all properties in the housing stock with and without wind farms to determine the total socioeconomic impact based on property values.

4.1. Data and descriptive statistics

The quantitative analysis utilises data from three sources: Svensk Mäklarstatistik (Swedish Brokerage Statistics) for real estate transactions, Valueguard AB for housing registers, and the Swedish Energy Agency for information on wind turbines. All data are geocoded with longitude and latitude. Real estate transactions cover the period from 2005 to 2018, the housing register is from 2018, and the wind turbines are operational. Descriptive statistics are presented in Table 1. We compare all sales with those within 20 km of a wind turbine at the time of purchase. The location of all wind turbines in Sweden is shown in Fig. F1 in the Appendix. Notably, they are distributed all over Sweden but are concentrated in the southern part of Sweden, the most densely populated area.

>600,000 observations are included in the empirical analysis of the total sample (panel A in Table 1), but most estimations are

based on approximately 390,000 transactions within 20 km of a wind turbine (panel B in Table 1). We have excluded observations that are potential outliers. Transactions with prices less than the one percentile or higher than the 99 percentile are not included in the sample. We have also excluded properties based on living space and plot area. We have also excluded observations with obvious measurement errors, such as the year of construction after the survey period.

It can be observed that the differences between price and independent variables are minor, with a slightly lower average price for properties closer to a wind turbine, while the size, age, and type of properties are comparable. The average distance to urban areas or major cities is similar across the samples. The most significant difference, unsurprisingly, is the proximity to wind turbines; properties within 20 km of a turbine are, on average, closer to them than other transactions.

4.2. Modelling the capitalisation effects

The results of the staggered difference-in-difference (Eq. (2)) and hedonic price models (Eq. (1)) are presented in the following section. We then analyse whether there is any parameter heterogeneity. Finally, we estimate the total societal cost (Eq. (3)) for the case studies.

4.2.1. Staggered difference-in-difference model

Estimating the staggered difference-in-difference model required processing transaction data related to property sales. First, for each property, we calculated the distance to the nearest wind power plant that became operational each year and registered the distance and the year as new variables. Next, we calculated the difference between the transaction year and the year the wind turbine became operational based on whether the property was within the treatment area. For many properties, the transaction occurred several years before the wind turbine became operational, while for others, it happened years afterwards. Thus, we have a variable for each property that measures the distance to the nearest wind turbine for the year. Using this variable, we created binary indicators for each year before and after the wind farm became operational, indicating whether the property was sold that year. Properties outside the treatment area were assigned zero for all these binary variables and thus serve as the comparison objects in the control group.

In the next step, we estimated the parameters in Eq. (2). In addition to the variables indicating when the wind turbines were completed, we included housing and localisation characteristics such as housing size and distance from urban areas. We also included fixed effects for county and years, as well as (county*year) effects. The functional form is not dictated by theory; instead, we empirically tested the form using the Box-Cox transformation (Box and Cox, 1964). The results indicate that neither a linear nor a log-linear model is preferable. The figures below present the results of a model where the treatment area is within 0–2 km with the outcome variable untransformed (left, Fig. 2) or 0–2 km with the outcome variable transformed (right, Fig. 3) from the wind power plant. The control area is 5 to 20 km from the wind turbine. None of the observations in the control group have been treated during the investigation period 2005–2018.

Table 1
Descriptive Statistics (all observations and within 20 km of a wind turbine).

PANEL A (all observations)					
Variable	Obs	Mean	Std. Dev.	Min	Max
Contract price	488,402	2437,047	1741,060	400,000	11,000,000
Living area	488,402	121.809	36.978	36	240
Plot area	488,402	1421.216	1944.553	153	22,046
Number of rooms	488,402	4.960	1.287	3	9
Building year	488,402	1966.029	26.575	1860	2018
Proximity to wind turbine	487,672	17.918	14.957	.064	138.750
Distance to the main town	487,672	10.078	12.229	.009	141.283
Distance to urban area	487,672	3.063	2.903	0.001	108.431
PANEL B (observations within 20 km of a wind turbine)					
Contract price	313,800	2240,985	1406,974	400,000	5000,000
Living area	313,800	121.489	36.726	36	240
Plot area	313,800	1439.769	2016.482	153	22,046
Number of rooms	313,800	4.919	1.272	3	9
Building year	313,800	1963.349	27.278	1860	2018
Proximity to wind turbine	313,800	8.943	5.358	.064	20
Distance to the main town	313,800	9.669	13.317	.009	141.283
Distance to urban area	313,800	2.712	2.549	0.001	64.908

Note: The table shows descriptive statistics on the transaction price of the dependent variable and the independent variables. The price is based on arm's-length transactions between 2005 and 2018. Independent variables are housing attributes: living area (square metres), plot area (square metres), number of rooms, and building year. The characteristics of the neighbourhood 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 >200 inhabitants (distance to the urban area). The distance from the wind turbine (in kilometres) is measured as the minimum Euclidian distance from the house to the wind turbine. Panel A shows all transactions in the sample, and panel B only shows transactions within 20 km of an existing wind turbine. The statistics are average value (mean), standard deviation (Std. Dev.), minimum (min), and maximum (max). The sample is based on transactions where we have excluded potential outliers. In the sample, observations between the 10th and 99th percentiles of the price are included and between the 1st and 99th percentiles for all the other variables. Source: Svensk Mäklarstatistik, Energimyndigheten, Statistics Sweden, and calculations by the authors.

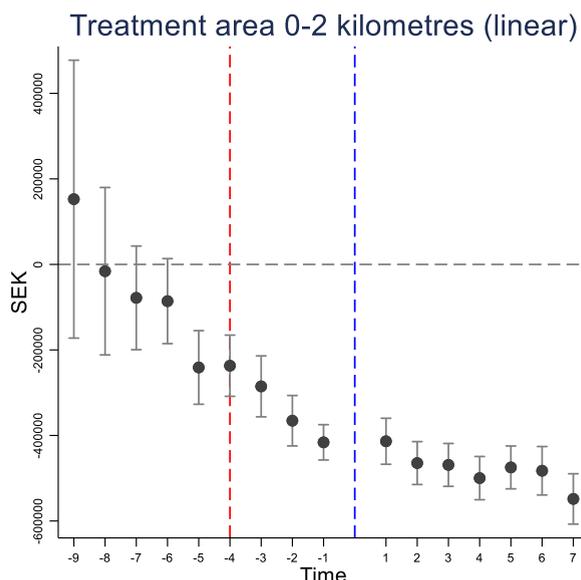


Fig. 2. The impact on the price of windmills within 0–2 km (linear and log-linear model).

We see a downward price effect in three phases. In the phase before building permission, the trend is both upward and downward depending on the specification. There is no clear trend, and the confidence intervals of the point estimates are relatively wide due to the smaller number of observations. The price effect is statistically significantly different from zero. This indicates that wind turbines are generally built in lower-price areas, which is logical as they are built outside population centres. In phase two, the period between the building process and the operating stage, a marked decline is indicated, probably due to anticipated adverse effects, and the price decline continues after the wind turbine has been commissioned. The effect is approximately SEK 200,000, corresponding to a capitalisation of approximately 20 %. However, there is a difference between the left figure (untransformed outcome variable) and the

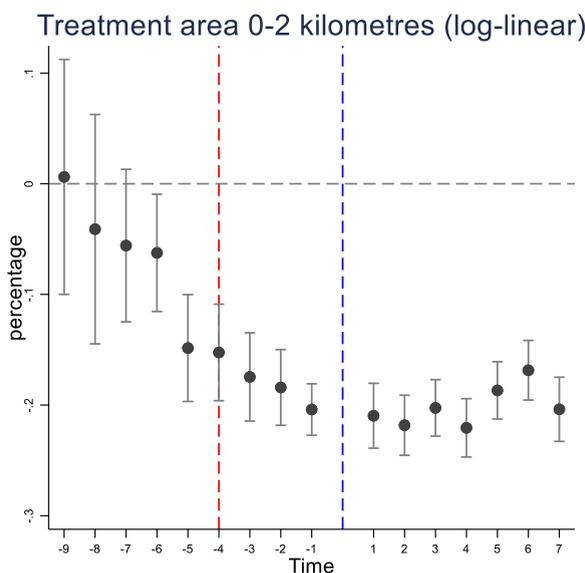
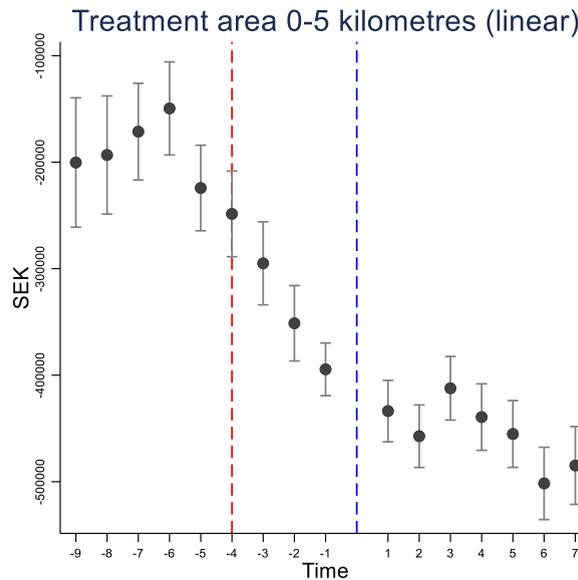


Fig. 3. The impact on the price of windmills within 0–2 km (linear and log-linear model). Notes: The plot shows the price impact of windmills [left plot: treatment area 0–2 km, linear model] and [right plot: treatment area 0–2 km, log-linear model]. The outcome variable in the linear staggered model is transaction price, and the included covariates are living area, lot size, building year, number of rooms, distance to the urban centre and fixed county, year and (county*year) effects. In the log-linear model, all continuous variables are transformed by natural logarithms. All models use propensity score matching. The propensity score strategy is the nearest neighbour with a caliper=0.01. The control area is 5–20 km (never treated observations). We have time from –9 to +7 on the horizontal axis. The blue dashed vertical line indicates the turbine’s operating stage, and the red dashed vertical line indicates the year of decision, impacting the housing price in SEK. The estimates are based on transactions where we have excluded potential outliers. Here, we use the 10th and 99th percentiles, respectively, concerning price. The results are the point estimate and the 95 % confidence interval—figures based on Jann (2014).

right figure (transformed outcome variable). When the outcome variable is expressed as the natural logarithm, there is also a decline in market values, but the confidence interval is significantly larger, and estimates jump precariously. The total effect of treatment is in the range of 10–15 %.

The figures below present the results of a model where the treatment area is within 0–5 km with the outcome variable untransformed (left, Fig. 4) or 0–5 km with the outcome variable transformed (right, Fig. 5) from the wind power plant.



Figs. 4. The impact on the price of windmills within 0–5 km (linear and log-linear model).

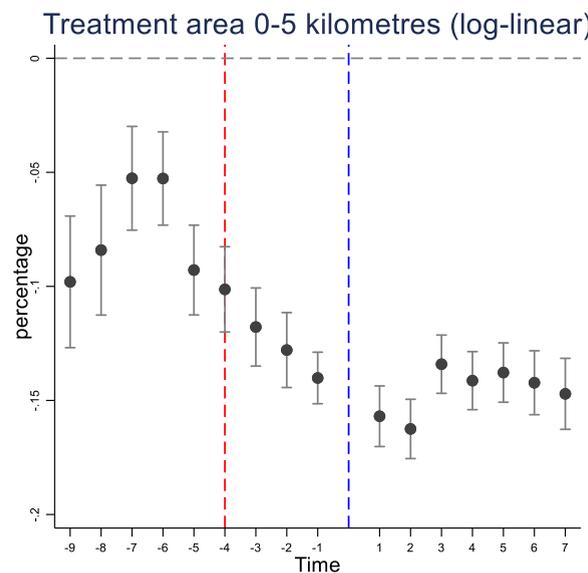


Fig. 5. The impact on the price of windmills within 0–5 km (linear and log-linear model). Notes: The plot shows the price impact of windmills [left plot: treatment area 0–5 km, linear model] and [right plot: treatment area 0–5 km, log-linear model]. The outcome variable in the linear staggered model is transaction price, and the included covariates are living area, lot size, building year, number of rooms, distance to the urban centre and fixed county, year and (county*year) effects. In the log-linear model, all continuous variables are transformed by natural logarithms. All models use propensity score matching. The propensity score strategy is the nearest neighbour with a caliper=0.01. The control area is 5–20 km (never treated observations). We have time from –9 to +7 on the horizontal axis. The blue dashed vertical line indicates the operating stage of the turbine, and the red dashed vertical line indicates the decision year and the impact on the housing price in SEK. The estimates are based on transactions where we have excluded potential outliers. Here, we use the 10th and 99th percentiles, respectively, concerning price. The results are the point estimate and the 95 % confidence interval—figures based on Jann (2014).

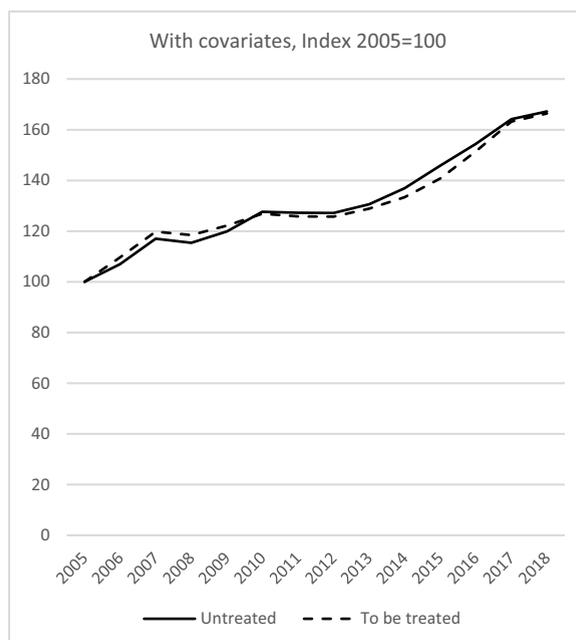


Fig. 6. Pre-treatment difference in trends. Note: Index 2005=100. With covariates, based on coefficients in Table A3 in the Appendix. “To be treated” equals observations that are not treated but will be treated in the future; untreated equal observations were never treated in 2005–2018. Based on Roth et al. (2023).

In 0–5 km, the effect is more clearly measured in SEK (left figure) and percentage (right figure). The confidence intervals are also smaller partly due to more properties in the 0–5-km range than in the 0–2-km range. Before building permits, the price effect is stable, but after the decision, prices fall until the wind turbines are in the operating stage. The price effect does not decrease further after the wind turbines have been commissioned, but for the most part, we can observe that it is an announcement effect and not an operating effect. We can note that the effect has a small positive price effect post-treatment after 2–3 years, where the outcome variable is logarithmic. The rebound in property values might be due to household sorting and housing scarcity, among other things. The same results can be observed in recent articles by Dong et al. (2023), Guo et al. (2024) and Brunner et al. (2024). However, it is clear that there is an announcement effect, but it is also clear that we have a large uncertainty in our estimates. It can be because our test of the parallel trend assumption is not strong enough and thus is not met or because the announcement assumption is not met.

To analyse this further, we have excluded properties with a lower price partly because these are primarily holiday homes. We have excluded properties with a transaction price lower than the 25th percentile (Figs. A3–A6 in Appendix) and those lower than the median price (Figs. A7–A10 in Appendix). The analysis with a limited sample where we excluded less expensive properties shows a significantly more substantial and robust result with less uncertainty. Regardless of whether we logarithms the outcome variable, the results show the same effect. Hence, more unstable prices before the decision, a decline in house prices after the decision on planning permission and a stable effect after the wind turbines are in operation. The Appendix reports in Table Figs. A2 and A3, and Table A3 shows the pre-treatment difference in trends.

Following Roth et al. (2023), we test the parallel trends assumption in staggered difference-in-differences by examining pre-treatment trends. We compare the price index of the never-treated group to that of the group treated later. From 2005 to 2018, both groups show similar trends in the figure. This supports the assumption that, absent treatment, the treated group would have followed the same trend as the control group. After the intervention, the trends diverge, consistent with a treatment effect. Based on Fig. 6, as well as Fig. A2 and Table A3 in the Appendix, the parallel trends assumption appears to hold.

4.2.2. Hedonic price model

The difference-in-difference models indicate that wind turbines affect property values of around 10–15 %. Given our interest in analysing the impacts across different market segments, some of which have limited property transactions, we could not proceed with the staggered difference-in-difference (SDID) model. Instead, we have estimated hedonic price equations.

We present four models relating proximity to wind turbines to property prices by estimating the hedonic price equation. Model 1 in Table 2 estimates the effects of property attributes, distance to urban areas, and distance to the main town in the municipality, in addition to a binary variable representing proximity to wind turbines. Model 2 includes fixed geographical effects, and in Model 3, observations are weighted based on the likelihood of being in the vicinity of a wind turbine. Model 4 tests the hypothesis that capitalisation varies over time by including an interaction term between proximity to wind turbines and a time variable.

Fixed municipal effects are crucial for explaining price variation in Sweden. Model 1 explains just under 25 % of the variation,

Table 2
Hedonic price equation without and with propensity score matching (nearest neighbour).

	Model 1	Model 2	Model 3	Model 4
Living area	0.623*** (140.52)	0.651*** (162.93)	0.655*** (92.53)	0.651*** (93.01)
Plot area	-0.072*** (-54.60)	-0.058*** (-49.37)	-0.091*** (-43.73)	-0.084*** (-40.68)
Number of rooms	0.287*** (54.77)	0.223*** (48.18)	0.226*** (28.09)	0.224*** (28.08)
Building years	6.205*** (81.70)	4.840*** (70.19)	4.549*** (39.01)	4.583*** (39.61)
Distance to the main town	-0.004*** (-4.12)	-0.043*** (-44.50)	-0.012*** (-6.91)	-0.012*** (-7.46)
Distance to urban area	0.0261*** (27.54)	0.035*** (40.51)	0.0441*** (30.01)	0.044*** (30.08)
Proximity to wind turbine	-0.052*** (-26.97)	-0.106*** (-56.36)	-0.093*** (-32.01)	-0.114*** (-33.00)
Wind turbine * period				0.002* (2.44)
Proximity to large wind turbines				-0.192*** (-41.10)
R ²	0.254	0.437	0.395	0.403
Adjusted R ²	0.254	0.436	0.393	0.403
Fixed effects	No	Yes	Yes	Yes
Method	OLS	OLS	PSM	PSM
AIC	474,743.3	387,308.7	191,471.6	189,004.1
Observations	313,800	313,800	148,747	148,747

Note: The table shows the results of four hedonic price equations. The dependent variable is equal to the natural logarithm of the transaction price. The independent variables are the size of the interior, measured in square meters, the number of rooms and the area of the outside plot, the years and distance to the main city in the municipality, and the minimum distance to an urban settlement. All variables are expressed in natural logarithms. The proximity to a wind turbine is a binary variable equal to 1 if the property is within 5 km of the wind turbine measured in Euclidian distance. Model 1 does not include fixed effects, and Models 2–4 include fixed county, time and (county*time) effects. Model 3–4 uses propensity score matching with the nearest neighbour and caliper=0.01. Model 4 includes an interaction variable between the binary variable of the wind turbine and the period, with 2005 equal to 1 and 2018 equal to 13. Model 4 also includes a binary variable indicating proximity to large wind turbines (above median height). *t* statistics in parentheses. The estimates are based on transactions where we have excluded potential outliers. Here, we use the 10th and 99th percentiles, respectively, concerning price.

* $p < 0.05$; ** $p < 0.01$.

*** $p < 0.001$.

while Models 2–4 account for nearly 40 %. The estimates are based on approximately 313,800 observations without matching and 148,747 with matching samples. The effect of housing size is statistically significant, with a 1 % increase in living area leading to an approximate 0.6 % increase in price. This effect remains consistent across all models. Estimates for other attributes vary widely, especially in Model 1. Newer properties are associated with higher prices, whereas greater distance from the main town in the municipality negatively impacts property values. Specifically, we can interpret that a 1 % increase in distance to the main town results in an approximate 0.1 % decrease in property value. However, property values increase in smaller urban areas further away within the municipality.

The primary variable of interest is proximity to wind turbines. The parameter estimates decrease when fixed municipal effects are included in the model (Model 2), but correcting for differences between the properties in the treated and untreated samples (Model 3) has a relatively small effect on the estimates. When the estimated binary parameters indicate a large change in the dependent variable, Halvorsen and Palmquist (1980) suggested that the exact percentage difference should be calculated as $100 * [\exp(b) - 1]$, and Kennedy (1981) argued 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 follow Halvorsen and Palmquist's (1980) suggestion. The capitalisation effect amounts to approximately 9.4 % (compared to 10–15 % in the staggered dynamic difference-in-difference model).

Model 4 includes an interaction term between the year and proximity to wind turbines and an interaction term between proximity to wind turbines and the median size of the turbine. The parameter estimate concerning proximity to wind turbines is still statistically significant at the 5 % level. However, our results do not align with Jensen et al. (2018), as the interaction term of wind turbines with time is not statistically significant. On the other hand, the estimate concerning wind turbines above median height is highly significant. According to the estimates, the capitalisation impact of large wind turbines within 5 km of the property can exceed 30 %.

4.2.3. Parameter heterogeneity

We have analysed parameter heterogeneity by (1) estimating the price impact intramarginally within 0–10 km and (2) estimating regional differences in impact.

One of our research questions was to investigate whether capitalisation differed between regions. There can be many reasons for this, such as the availability of suitable land for wind turbines, the region, and the proximity to urban areas where the wind turbines are located. Therefore, in the subsequent analysis step, we will test the hypothesis that capitalisation differs in years between regions. We

have chosen the NUTS1 classification, meaning Sweden is divided into three regions. The results are presented in Table 3.

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 km. Sunak and Madlener (2017) used 1-km intervals up to 5 km, but we are using 2 to 10 km because of the lack of transactions in a 1-km interval. We are using 2012–2018 to estimate capitalisation effects. The results are presented in Table 3.

The degree of explanation is high in regional models, and the included variables can explain around 30–50 % 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 attributes influencing the value. 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 in south Sweden. The effect of the year of construction is also of great importance, where the desire to pay for newer properties is significantly higher in northern 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; that is, housing prices fall further away from the main town where the property happens to be located. All parameter estimates have expected signs and are of reasonable magnitude. However, it is worth noting that the number of observations is lower in northern Sweden, which may somewhat increase the uncertainty in the estimates.

Estimates on proximity to the wind turbines show significant differences between regions. In the 0–2-km interval, the impact of prices in the country's southern parts is approximately 18 % and decreases to just under 13 % in the northern parts. The parameter estimates within other ranges follow the same pattern, with slightly lower capitalisation in the northern parts of Sweden compared with the southern and central parts of Sweden. Moreover, it is worth noting that the capitalisation is somewhat more local in the north of Sweden, as we cannot find a negative capitalisation further out than 2 km from wind power turbines, while in the southern parts of Sweden, there is a capitalisation up to 8 km.

In addition to interregional effects, we have also analysed the intra-regional impact, where we have explicitly tested the hypothesis

Table 3
Hedonic price equation: 2-km intervals. Regions based on NUTS1. 2012–2018.

	(1) South	(2) East	(3) North
Living area	0.665*** (61.74)	0.624*** (34.65)	0.610*** (19.05)
Plot area	-0.123*** (-38.28)	0.029*** (5.75)	0.079*** (6.64)
Number of rooms	0.246*** (20.03)	0.275*** (13.39)	0.112*** (3.00)
Building years	3.957*** (22.83)	6.604*** (22.98)	6.502*** (10.69)
Distance to the main town	0.008*** (2.98)	-0.118*** (-22.12)	-0.051*** (-6.17)
Distance to urban area	0.047*** (20.01)	0.005 (1.35)	0.026** (2.93)
Wind turbine 0–2 km	-0.183*** (-19.32)	-0.091*** (-6.38)	-0.128*** (-5.22)
Wind turbine 2–4 km	-0.111*** (-12.78)	-0.102*** (-8.85)	-0.037 (-1.90)
Wind turbine 4–6 km	-0.009 (-0.90)	-0.046*** (-3.59)	-0.023 (-1.04)
Wind turbine 6–8 km	0.060*** (5.40)	-0.021 (-1.12)	-0.190*** (-4.29)
Wind turbine 8–10 km	-0.009 (-0.78)	0.032 (1.60)	-0.038 (-0.95)
Wind turbine 10–12 km	-0.042 (-3.05)	-0.055* (-2.45)	-0.097*** (-3.03)
R ²	0.356	0.483	0.460
Adjusted R ²	0.354	0.478	0.442
AIC	94,643.1	13,967.6	4436.2
Observations	70,078	14,386	4213

Note: The table shows the results of three hedonic price equations. The dependent variable is equal to the natural logarithm of the transaction price. Independent variables are indoor size measured in square metres, the number of rooms and the area of the outside plot, the age of the building in years and distance to the main city in the municipality, and the minimum distance to an urban settlement. All variables are expressed in a natural logarithm. The proximity to a wind turbine is a binary variable equal to 1 if the property is within a 2-km interval from the wind turbine measured in Euclidian distance. All models include fixed county, year and (county*year) effects. All models use propensity score matching. The propensity score strategy is the nearest neighbour with a caliper=0.01. Model 1 shows the results for the south region. Model 2 shows the results for the central part of Sweden, and Model 3 shows the northern part of Sweden. *t* statistics in parentheses. *t* statistics in parentheses. The estimates are based on transactions where we have excluded potential outliers. Here, we use the 10th and 99th percentiles, respectively, concerning price. **p* < 0.05.

** *p* < 0.01.

*** *p* < 0.001.

that the capitalisation effect is affected by the distance to urban areas. We have also divided the data into 2-km intervals from urban areas. Thus, we test the hypothesis that the capitalisation effect of a property 2 km from a wind turbine is affected if it is 2 km from an urban area compared to 10 km from an urban area. The results are presented in Table 4.

We note that there is significant intraregional variation in the capitalisation rates. If the property is close to an urban area (column 1–3), the capitalisation rate is generally higher than if the property is further out. However, the degree of capitalisation will be minor if the property is located further from the urban area than 8 km. The effect of wind power on nearby properties will be most significant at 4 to 6 km from an urban area. This result can potentially affect where you plan to locate wind turbines. However, it is essential to remember that even if capitalisation decreases in locations closer to urban areas, the number of affected impacts will increase significantly, which means that the total effect in SEK will increase.

4.2.4. Estimating total socioeconomic costs in three case studies

According to the previous discussion, the estimated total price effect within the impact area of future wind turbines has been calculated (Eq. (3)). 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 through a regression analysis that covers transactions in each geographical area. These valuations have been reduced by the estimated capitalisations found in Table 4. The results of these calculations are presented in Table 5.

The project area in Östra Göinge municipality is close to urban areas, and many property owners will be affected. We have identified 190 properties within 2 km of the nearest wind turbine and as many as 7600 within 10 km 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 2 million in 2018 monetary value. The value estimate after a wind turbine establishment is approximately SEK 9.2 billion, and the decrease in value amounts to approximately SEK 500 million, corresponding to 66,000 per property.

Table 4
Hedonic price equation; 2 km interval. Intraregional effects, 2012–2018, WLS.

	(1) 0–2	(2) 2–4	(3) 4–6	(4) 4–8	(5) 8–10
Living area	0.677*** (46.80)	0.684*** (39.72)	0.561*** (24.59)	0.566*** (17.03)	0.485*** (8.02)
Plot area	−0.0970*** (−20.66)	−0.0924*** (−19.20)	−0.0890*** (−14.84)	−0.0314** (−3.11)	0.00486 (0.24)
Number of rooms	0.223*** (14.65)	0.236*** (11.68)	0.335*** (12.75)	0.189*** (4.61)	0.218* (2.45)
Building year	3.890*** (16.34)	3.259*** (11.99)	4.997*** (13.48)	5.583*** (11.11)	4.514*** (4.70)
Distance to the main town	0.0138*** (4.93)	−0.0355*** (−6.02)	−0.0214 (−1.91)	−0.0366 (−1.44)	0.00697 (0.14)
Distance to urban area	0.0818*** (20.41)	−0.0198 (−1.10)	−0.0942* (−2.04)	−0.276** (−2.85)	−0.674** (−3.02)
Wind turbine 0–2 km	−0.112*** (−10.07)	−0.274*** (−17.87)	−0.318*** (−17.39)	0.118*** (3.73)	0.0747 (1.48)
Wind turbine 2–4 km	−0.0532*** (−5.39)	−0.207*** (−15.59)	−0.274*** (−16.28)	0.0231 (0.76)	0.164*** (3.49)
Wind turbine 4–6 km	0.0547*** (4.99)	−0.111*** (−7.59)	−0.138*** (−6.83)	−0.00193 (−0.06)	0.233*** (4.63)
Wind turbine 6–8 km	0.0816*** (6.18)	0.0189 (1.09)	−0.0895*** (−3.84)	0.0176 (0.44)	0.307*** (4.96)
Wind turbine 8–10 km	0.0537*** (3.60)	−0.0269 (−1.42)	−0.175*** (−7.07)	0.198*** (4.70)	0.151* (2.52)
Wind turbine 10–12 km	−0.0138 (−0.82)	−0.00979 (−0.43)	−0.189*** (−6.91)	0.0418 (0.97)	0.0494 (0.65)
R ²	0.355	0.421	0.418	0.428	0.466
Adjusted R ²	0.352	0.415	0.406	0.397	0.365
AIC	60,397.4	28,518.1	14,535.7	4710.8	1612.9
Observations	46,285	22,817	11,368	4215	1301

Note: The table shows the results of five hedonic price equations. The dependent variable is equal to the natural logarithm of the transaction price. Independent variables are indoor size measured in square metres, the number of rooms and the area of the outside plot, the age of the building in years and distance to the main city in the municipality, and the minimum distance to an urban settlement. All variables are expressed in a natural logarithm. The proximity to a wind turbine is a binary variable equal to 1 if the property is within a 2-km interval from the wind turbine measured in Euclidian distance. All models include fixed municipality effects and fixed-time effects. Model 1 shows the results for 0–2 km from urban area. Model 2 shows the for 2–4 km from urban area, Model 3 shows the results for 4–6 km from the wind turbines, Model 4 shows the results for 6–8 km from urban area, and Model 5 shows the results for 8–10 km from urban area. All models include fixed county, year and (county*year) effects. All models use propensity score matching. The propensity score strategy is the nearest neighbour with a caliper=0.01. *t* statistics in parentheses. The estimates are based on transactions where we have excluded potential outliers. Here, we use the 10th and 99th percentiles, respectively, concerning price. **p* < 0.05.

** *p* < 0.01.

*** *p* < 0.001.

Table 5
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	157	48
2–4 km	675	799	704	95
4–6 km	2645	3138	2885	253
6–8 km	1934	2541	2477	64
8–10 km	2165	3010	2970	40
Total effect	7609	9693	9193	500
Case study: Finspång				
0–2 km	91	154	117	37
2–4 km	141	292	254	38
4–6 km	451	638	622	16
6–8 km	320	517	500	17
8–10 km	285	510	500	10
Total effect	1288	2111	1993	118
Case study: Skellefteå				
0–2 km	15	13	10	3
2–4 km	28	24	23	1
4–6 km	96	73	67	6
6–8 km	135	116	109	7
8–10 km	148	144	144	0
Total effect	422	370	353	17

Note: The table shows the effect of a wind power establishment in three different areas. Column 1 indicates the area and the 2-km intervals from the future wind turbines, and column 2 shows the number of properties that will be affected. We have only included detached dwelling and have not included agricultural properties. In column 3, the valuations of properties are reported in 2018 monetary value. Valuation has been calculated via regression analysis, where we have estimated a hedonic price equation that includes attributes and fixed effects. Column 4 shows the valuation but is reduced by the estimated capitalisation effect (based on the results in Table 4), and column 5 shows the difference in valuation and the summation of the total depreciation effects in the immediate area of the future wind turbines.

Although the cost of establishing wind power is relatively limited per property, the total amount is significant since many property owners will be affected. If the total investment cost for the 18 wind turbines in Östra Göinge amounts to approximately 47 million per wind turbine and a total of SEK 850 million, the impact on property values in the surrounding area will amount to as much as 44 % of the investment cost.

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 91,000 per property, and the total decrease in value amounts to SEK 118 million. One reason for the higher valuation is that there are more properties in the area 0–4 km from the wind turbine than all properties within 10 km. Approximately 20 % of properties are found in this area, compared with 8 % in Östra Göinge. This means that the decrease in value per property is economically more significant (in SEK). The total effect amounts to SEK 118 million, corresponding to as much as 15 % of an estimated investment cost of SEK 750 million.

The project area in Skellefteå has the most negligible impact on property owners among the case studies analysed, with only 422 properties identified within 10 km of the wind turbines and approximately 8 % located within 4 km of the turbines. The total decrease in property value is only SEK 17 million, but per property, it amounts to SEK 40,000. When the decrease in value is compared to the estimated investment cost of SEK 1500 billion, it amounts to only 1 %.

5. Discussion of results

The analysis demonstrates that proximity to onshore wind turbines has a statistically significant negative effect on property values, with the impact diminishing as the distance from the turbines increases. This aligns with theoretical expectations regarding externalities in microeconomic analysis (Varian, 1992; Mas-Colell et al., 1995). Specifically, the findings suggest that visual intrusion, noise, and other consumption externalities associated with wind turbines substantially influence housing market dynamics. The results reveal spatial heterogeneity, where the magnitude of the impact varies across regions and urban-rural gradients, validating prior studies in Sweden and Europe.

These results support the hypothesis that wind turbines represent a negative externality for nearby properties. For instance, the property value reduction of approximately 10–15 % within 2 km aligns with hedonic pricing models, which suggest that disamenities are capitalised into market prices (Rosen, 1974). The diminishing effect with distance, reaching zero at approximately 6–8 km, reinforces that such externalities are highly localised. The observed variation in impact by turbine height and proximity to urban areas is consistent with hypotheses about the amplified visual and noise effects of taller, modern turbines in more densely populated regions.

The finding that negative externalities have intensified over time as modern wind turbines are taller and more prominent, enhancing their visibility and potentially exacerbating community concerns about landscape changes. This supports evolving perceptions in rural and semi-urban areas, where residents often place a high value on unspoiled natural surroundings.

From a policy perspective, the study highlights the importance of internalising the socioeconomic costs of wind turbine installations. While wind energy contributes significantly to climate goals, as evidenced by Sweden's ambitious fossil-free energy targets,

the adverse effects on nearby properties raise equity concerns. Policymakers and developers should consider mechanisms to compensate affected landowners, which could foster greater public acceptance and minimise opposition. For example, direct compensation programs or revenue-sharing schemes could address these external costs and promote equitable development.

Additionally, the spatial heterogeneity in the impact suggests that site selection for wind turbine projects should account for regional and local differences. In rural areas, where adverse effects on property values are more pronounced, planners should prioritise locations farther from residential zones. Conversely, in urban areas, mitigating visual and noise impacts through advanced turbine designs or strategic siting could reduce the magnitude of adverse effects.

The findings contribute to a nuanced understanding of the trade-offs between renewable energy expansion and its localised externalities. They emphasise the need for sustainable planning that integrates economic, environmental, and social considerations. By identifying the conditions under which wind turbines most significantly impact property values, we provide insights for optimising the benefits of renewable energy while minimising its costs to local communities.

Several open research questions remain for further exploration. This study utilised information on granted building permits for wind turbines and their operating stages. Future research could more thoroughly analyse the effects of announcements and incorporate data on granted building permits alongside wind turbine projects that did not receive approval. Additionally, although we conducted robustness tests using a heterogeneity-adjusted staggered dynamic difference-in-difference model, future studies could expand on this approach to examine the effects of heterogeneity over time and among different wind turbines using Swedish data. Finally, like Brunner and Schwegman (2022), using instrument variables such as wind speed for turbine adoption in future research would be interesting.

6. Concluding remarks and policy implications

Our study shows that the current expansion of wind power in Sweden affects apparent losses in property values for homeowners within 0–6 km 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 a significant signal and a perception of justice.

The fact that we, over time, found significant changes in the impact of wind turbines on property values—from no effect to increasing negative impacts, could serve as a starting point for a discussion of 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 rise? Or will we reach a point where wind turbines are ubiquitous and 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 as 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 the variations in results between countries and over time. Testing this hypothesis would require broader perspectives than the previous national ones and access to databases of property transactions over time in several countries.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT and Grammarly in order to proof-read the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRedit authorship contribution statement

Hans Westlund: Writing – review & editing, Writing – original draft. **Mats Wilhelmsson:** Writing – review & editing, Project administration, Formal analysis, Writing – original draft, Methodology, Data curation, Resources, Funding acquisition, Conceptualization.

Acknowledgments

The author(s) would like to express their gratitude to the editor and the anonymous reviewers for their valuable feedback and constructive suggestions, which have significantly improved the quality and clarity of this manuscript. Their expertise and detailed comments were instrumental in refining the analysis and presentation of the results. The authors thank Bo Göransson for thorough proofreading and controlling facts in the first draft of the paper. All remaining possible flaws and errors are the sole responsibility of the authors.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.eap.2025.07.025](https://doi.org/10.1016/j.eap.2025.07.025).

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