Renewable Energy and Negative Externalities: The Effect of Wind Turbines on House Prices

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SUMMARY — In many countries, wind turbines are constructed as part of a strategy to reduce the dependence on fossil fuels. In this paper, we measure the effect of wind turbines on the transaction prices of nearby properties. Using a unique microdataset from the Netherlands from 1985-2011, we exploit temporal variation in the location of wind turbines. The results show that after the first wind turbine is constructed within a 2 km radius of a property, the value of the property decreases by about 1.4 percent on average. We argue that this is mainly a view effect. We also find that anticipation and adjustment effects are important and that the total social costs of wind turbines are substantial.

JEL–code — R31; Q42; Q15; L94
Keywords — renewable energy; wind turbines; externalities; house prices

I. Introduction

The world's primary demand for renewable energy has increased from 1,124 million tons of oil equivalent (Mtoe) in 1990 to 1,684 Mtoe in 2010 and is expected to grow to 3,079 Mtoe in 2035 (IEA, 2012). Indeed, the production of clean electricity — either through renewable energy sources or nuclear power — is high on the political agenda of many countries. Besides hydro energy, wind energy is one of the most important sources of renewable energy accounting for 8 percent of renewable electricity production in 2010. Its share in production is expected to increase to 24 percent by 2035 (IEA, 2012).

Wind energy is produced by wind turbines. The global number of wind turbines is currently about 225,000.[1] At the end of 2012, the total wind power capacity was 283,000 megawatt (39 percent of capacity is located in Europe), an increase of 16 percent in

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[1] www.gwec.net

comparison to a year earlier (GWEC, 2012). Some of the wind turbines are placed in large wind parks (wind farms), some of them offshore, but there is also an increasingly large number of turbines located close to urbanized areas, especially in countries with space constraints. Given that wind turbines make noise, obstruct sight, and cast shadows on nearby properties, we would expect to see a clear negative economic impact as a result of wind turbine construction. There is some anecdotal evidence that homeowners are strongly opposed against the construction of wind turbines nearby their own houses, because of proclaimed negative effects on housing value.[2] However, to date, there is no robust evidence on these external effects.

The aim of this paper is to examine the effect of wind turbines on house prices. We use a highly detailed housing transactions dataset from the Netherlands covering the period 1985 to 2011. Using data on all wind turbines placed in the Netherlands since 1980, we can calculate the distance from every property that is sold to the nearest wind turbine. We employ a difference-in-differences approach to identify the effect of the placement of a wind turbine on the value of nearby properties.

Although literature on this topic is scarce, this is not the first study to examine the effect of wind turbines on property values. Carter (2011) and Sims et al. (2008) investigate the effect of a single wind farm on house prices in the US and UK, respectively. Hoen et al. (2011) examine the effect on house prices of 24 wind farms located in 9 states in the US. All of these studies do not find a statistically significant effect of wind farms on house prices.[3] A notable exception is the study by Gibbons (2013). He finds a decrease in house price of 5 to 6 percent within 2 km of a visible wind park in the UK.[4]

We add to this literature in several ways. First, we adequately address selection and endogeneity concerns. In particular, wind turbines are not randomly allocated across space. A particular concern is that houses are typically not closely located near wind turbines, which can explain the lack of statistical significance in previous studies.[5] This raises the question whether there is no effect of wind turbines or whether the effect simply cannot be identified. We use about 2.2 million transaction prices and all wind turbine in one single country to answer this question. Moreover, wind turbines, especially those with view, tend

[2] See Trouw, 29 October 2013.

[3] Ladenburg and Dubgaard (2007) do find evidence that household in Denmark are willing to pay 122 Euros per year to increase the distance of an offshore wind park from 8 to 50 km (see Snyder and Kaiser, 2009, for the cost-benefit of offshore versus onshore wind energy production).

[4] Our study belongs to a broader line of research on the effect of (environmental) externalities (e.g. distance to toxic sites, churches, airports, air pollution) on house prices (for the effect of air ports, see Ridker and Henning, 1967 or Mieszkowski and Saper, 1978; for toxic waste sites, Kohlhase, 1991, or see Boyle and Kiel, 2001, for a full literature review).

[5] Hoen et al. (2011), for instance, hypothesises that there might be effects relatively close to wind turbines – the observations they use are unfortunately predominately located between 1.6 to 4.8 km from a wind turbine. The average distance to a wind turbine in Carter (2011) is 12 miles. Sims et al. (2008) do have a considerable share of their data that captures the property values within half a mile of a wind turbine, but they only have 120 observations in total.

to be located in locations that are unattractive for unobserved reasons (e.g. rural areas), which might lead to an overestimate of the negative effects of wind turbines. Our differences-in-differences strategy with detailed zip code fixed effects deals with all time-invariant unobserved locational differences. To the extent that there is additional unobserved variation, such as unobserved trends, correlated with the location of wind turbines, we will check the robustness of our results by including location-specific time trends, a rural versus urban indicator, and by focusing on locations close to (within three kilometres) of (future) wind turbines. In sum, the approach taken in this paper allows us to identify the causal effect of wind turbine construction on house prices.

A second important contribution is that we explicitly take into account anticipation and adjustment effects. In particular, the effect of wind turbines on house prices is not necessarily immediate or permanent. For example, one may expect that as soon as a wind turbine is announced house prices begin to adjust. In addition, it is now well appreciated that, because of search and transaction costs, there is inertia in house prices (i.e. Case-Shiller, 1989). This implies that housing markets need time to adjust to shocks like changes in the physical environment. This makes our findings particularly interesting. Many previous studies examine the effect on house prices over a limited period of time (i.e. a maximum 12 years, we use 26 years) and, consequently, these studies limit the scope of the analysis to the average (treatment) effect. The actual effect can be higher or lower depending on when (before or after construction of the turbine) the house is sold.

Finally, most previous studies focus on the external effect of wind turbine parks. This leads to a measurement error problem, especially when examining the effect of distance. Since we have information about each wind turbine in the Netherlands constructed between 1982-2012, we can examine the effect of individual wind turbines on house prices. We focus on the nearest wind turbine, but we also examine multiple treatment effects and the intensity (number of wind turbines) of the treatment effect. Moreover, the data allows us to examine the effect of wind turbine characteristics, such as height of the turbine and diameter of the blades, on house prices. We also create a measure of direct view. To summarize, our study is the most comprehensive study to date about the effect of wind turbines on house prices.

The results in this paper show that after the construction of the first wind turbine house prices within a 2 km radius are, on average, 1.4 percent lower than prices in comparable neighborhoods with no nearby wind turbines.[6] This is a conservative estimate. The effect is highest 500 to 750 meters from a turbine, a negative 2.6 percent. In addition, we find that two years before the placement of a turbine house prices are already 1.7 percent lower than

[6] Beyond 2 km of a wind turbine the effect of wind turbines on house prices is negligible. If observations beyond 2 km are included in the treatment group, the average treatment effect decreases substantially. This may explain why some previous studies did not find any effect of wind turbines on house prices.

prices in comparable neighborhoods. The negative effect increases until about five years after the placement of a turbine, to 3.5 percent, and steadily decreases to an effect of about 2 percent at year eight, after which the effect stabilizes. Further heterogeneity in the treatment effect is discussed in detail in the remainder of this paper.

The results in this paper do not imply that we should not build wind turbines, but that we should be careful where to place those turbines. If wind turbines are placed close to (future) urban areas our findings suggest that there are additional economic costs which should be taken into consideration when constructing wind turbines.

The remainder of this paper is structured as follows. Section II provides a discussion on renewable energy policy and wind turbines. Section III contains the methodology, which is followed by a description of the data in Section IV. In Section V we report the results. Section VI provides a conclusion and discussion.

II. Renewable energy policy and wind turbines

As a result of the Kyoto Protocol, many countries have set targets to reduce their greenhouse gas emissions. Especially for many developed countries these reductions have been legally binding. The Kyoto Protocol has been active for the period 2008-2012 and, after the United Nations Framework Convention on Climate Change (UNFCCC) Conference in 2012, it has been extended (in limited form) until 2020. As of 2015 a new protocol will be developed (for a discussion, see IEA, 2013).

The policy focus on sustainable development is reflected in renewable energy policies around the world. In the United States, there are production tax credits to stimulate the production of renewable energy and regulations regarding renewable portfolio standards for electricity suppliers. China aims to produce 15 percent of energy in 2020 using nuclear or renewable energy sources (IEA, 2012). The European Union issued the Renewable Energy Directive in 2009, which stipulates that the renewable energy part of energy consumption is to increase to 20 percent by 2020. The European Union leaves it up to its member states how to achieve this goal (European Commission, 2013).[7]

Many countries have responded to the policy focus on renewable energy by increasing their wind power capacity. China, for instance, aims to increase its wind power capacity from 62 to 200 gigawatts by 2020 (IEA, 2012). Wind power production has been particularly popular in the European Union. Currently, about 39 percent of the wind power capacity is located in the European Union, 26 percent in China, and 20 percent in the United States (IEA, 2012). Although wind power capacity is increasing, at current rates the European member states will not meet their required targets (European Commission, 2013).

[7] Each member state was required to make its own action plan.

In the Netherlands, the focus area of this study, the goal set by the Renewable Energy Directive is to increase the share of renewable energy to 14 percent (European Commission, 2013).[8] In 2013, a widely supported agreement was reached (Energy Agreement) to increase the wind power capacity on sea from 1,000 megawatt to 4,450 megawatt. Also, the amount of wind power capacity on land needs to increase from 2,160 to 6,000 megawatt (SER, 2013).[9] Because each wind turbine produces about 3 megawatt, this implies that the increase in wind power capacity on land is equivalent to about 1,280 wind turbines (1,150 on sea). Relative to the current stock of about 1,800 onshore wind turbines (100 offshore), this implies a massive increase in the number of turbines.[10] The question is where to exactly place these turbines, especially those turbines that are to be placed on land, since the Netherlands is a relatively small country in terms of land area and a country with one of the highest population density in the world. Besides the current policy focus in Europe on renewable and wind energy, this makes our findings particularly interesting.

III. Methodology

In this paper, we focus on estimating the average treatment effect after the *first* wind turbine is constructed within d km of a property. A difference-in-differences methodology is ideally suited to estimate this effect:

$$\log p_{it} = \alpha w_{it} + \gamma v_i + \theta_t + \epsilon_{it}, \quad (1)$$

where p_{it} is the price of property i in year t, w_{it} is an indicator variable that equals one in the years after the first wind turbine is placed within d kilometres of property i, v_i is the treatment versus control group dummy, θ_t captures year (and month) fixed effects, and ϵ_{it} is an identically and independently distributed error term.[11] The α parameter is the parameter of interest (average treatment effect). Using a distance profile (see the end of this section) we determine the distance d at which the treatment effect occurs. It turns out that this is within a 2 km radius of a wind turbine. The results section, Section V, discusses this issue in more detail.

To control for differences in the (housing quality) composition of the control and treatment group, we subsequently estimate the following hedonic model:

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[8] The share of renewable energy in the Netherlands was 2.4 percent in 2005 and 3.8 percent in 2010. For France the target is 23 percent and it is 18 percent for Germany. The target ranges from 11 percent for Luxembourg to 49 percent for Sweden (European Commission, 2013).

[9] Currently, wind turbines are highly subsidised. The subsidy on wind turbines is equal to the difference in electricity production cost (in euro per kWh, calculated by the government) and the average price of electricity (also calculated by the government).

[10] Not all turbines will be placed on sea because building turbines on sea is relatively costly. It also requires the construction of an offshore power grid (additional investment).

[11] We only know the year of construction, not the exact date of construction. As a result, we use the year after the wind turbine is constructed to avoid coding errors.

(2) $$\log p_{it} = \alpha w_{it} + \gamma v_i + \beta x_{it} + \theta_t + \epsilon_{it},$$

where x_{it} is a standard set of housing attributes including the log size of the house, the number of rooms, house type dummies, indicators for garage, garden, maintenance quality, central heating, whether the house is listed as cultural heritage, and construction year dummies.

When wind turbines are randomly distributed over space and when the effect of wind turbines on house prices is immediate and permanent, α will capture the causal effect of wind turbines on house prices. However, wind turbines are typically not randomly distributed across space: wind turbines are disproportionally located in rural and coastal areas (i.e. lower priced areas). This could potentially lead to a selection bias. The difference in house price between the control and treatment group is captured by the treatment versus control group dummy. However, to filter out additional location-specific effects we also estimate:

(3) $$\log p_{it} = \alpha w_{it} + \beta x_{it} + \eta_j + \theta_t + \epsilon_{it},$$

where η_j is a location fixed effect at the level of the j^{th} 6-digit zip code. Because a zip code consists of about half a street (on average 15 households), we essentially deal with all unobserved time-invariant spatial attributes that may cause the construction of wind turbines and may be correlated with ϵ_{it}.[12] [13]

To account for any other additional unobserved variables, such as local time trends (e.g. changes in local building restrictions), we also estimate equation (3) using a restricted sample:

(4) $$\log p_{it} = \alpha w_{it} + \beta x_{it} + \eta_j + \theta_t + \epsilon_{it}\,, \quad < 3km\ of\ (future)\ turbine$$

In particular, we compare houses within the treatment area with houses outside the treatment area but within a short distance (<5 km) of a current or future wind turbine (local control group). Although this will severely decrease the sample size, it does provide a more convincing story whether the placement of a wind turbine has a causal effect on house prices.[14]

Finally, we estimate the treatment effect before versus after the construction of a wind turbine and at different distances from the turbine. In particular, to determine the exact

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[12] Note that the control versus treatment group dummy (essentially just a location dummy) is excluded in this specification since it is highly collinear with the zip code fixed effects. Including this dummy, however, only leads to a marginal change in the estimated treatment effect.

[13] The benefit of this particular approach is that we do adequately control for neighborhood and (average) housing quality differences, but we do not lose most of the data as a result of differencing (repeat sales), which would result in sample selection bias (see Gatzlaff and Haurin, 1998).

[14] We will also show a model which includes municipality-specific time trends as a robustness check.

radius of the treatment effect, we decompose the treatment effect over different distances from a wind turbine:

(5) $$\log p_{it} = \sum_{z} \alpha_z w_{itz} + \beta x_{it} + \eta_j + \theta_t + \epsilon_{it}\,, \quad < 3km\ of\ (future)\ turbine,$$

where w_{itz} equals one in the year after the first wind turbine is placed within d kilometres of property i and d is within the distance range z. For each 250 meter within a 2.5 km distance from a wind turbine we create a different category z. The cut-off value d is determined by examining the statistical significance of α_z.[15]

Finally, we would expect the effect to differ before and after the turbine is constructed. New wind turbines are usually announced some years before construction will start. It is likely that house prices already incorporate this information, which implies that α may be an underestimate of the causal effect if we do not take into account anticipation effects. On the other hand, when information only becomes available after the wind turbine has been constructed, it might also be the case that housing markets need time to adjust to the new equilibrium. To account for anticipation and adjustment effects, we therefore estimate the following specification, which essentially is a dynamic response function:

(6) $$\log p_{it} = \sum_{\underline{t}<t} \alpha_{\underline{t}} w_{i\underline{t}} + \sum_{\bar{t}>t} \alpha_{\bar{t}} w_{i\bar{t}} + \beta x_{it} + \eta_j + \theta_t + \epsilon_{it}\,, \quad < 3km\ of (future)\ turbine,$$

where $\underline{t}$ is a year preceding the year of construction and $\bar{t}$ denote the year including and following the year of construction, $w_{i\underline{t}}$ equals one when the property is treated in year $\underline{t}$ and is zero otherwise, and similarly, $w_{i\bar{t}}$ captures the treatment effect after construction. Hence, $\alpha_{\underline{t}}$ is a set of coefficients that capture anticipation effects of wind turbines that will be constructed in the future, whereas $\alpha_{\bar{t}}$ capture adjustment effects after the wind turbine has been constructed. We also show estimates of a more restricted polynomial function.

IV. Data

The analysis in this paper is based on two main datasets. The first dataset contains the exact location of all wind turbines in the Netherlands from 1982-2012 and is obtained from www.windstats.nl. For each wind turbine we know the exact location, the axis height, the diameter of the rotor blades, the installed capacity, the manufacturer, and importantly, the construction year.[16]

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[15] This approach is based on the assumption that outside a 2.5 km radius (the reference category) the effect is zero.

[16] We do not have information about the exact date the construction of the turbine is completed. We only know the construction year. We also do not have information about the announcement date of the construction plan.

TABLE 1 — DESCRIPTIVE STATISTICS: WIND TURBINES

	Full sample			
	mean	std	min	max
Axis height (*m*)	59.496	20.231	21.000	135.000
Diameter of rotor blades (*m*)	55.997	21.963	11.000	127.000
Capacity *(MW)*	1.260	0.953	0.015	7.500
Onshore	0.949	0.219		
Construction year	2002	5.507	1982	2012
Number of observations	1,898			

Notes: This table contains descriptive statistics on all wind turbines constructed between 1982-2012. The axis height (diameter) is only available for 1,793 (1,893) observations.

Table 1 contains the descriptive statistics for the wind turbine dataset. There are 1,898 wind turbines in the Netherlands. The average axis height is 59 meters, with a minimum of 21 meters and a maximum of 135 meters. The average diameter of the rotor blades is 56 meters. The average capacity is 1.3 megawatts.[17] About 95 percent of wind turbines are placed on land (96 are offshore). The main manufacturer of wind turbines in the Netherlands is the Danish company Vestas. They produced 1,128 (59.4 percent) of the wind turbines in the Netherlands.[18] Large owners of wind turbines are Dutch power companies NUON, Eneco, and Essent.

Figure 1 shows the spatial distribution of wind turbines across the Netherlands. Wind turbines are predominately clustered in Flevoland (27.6 percent), a mostly rural area in the centre of the Netherlands which has been reclaimed from the sea. The early wind turbines were mainly constructed in the northern part of the Netherlands. In part, this reflects that northern part is not so urbanized as, for instance, the western part of the Netherlands. In addition, the wind force – also depicted in Figure 1 – is relatively high in the northern part of the Netherlands.[19] Other concentrations of wind turbines can be found in the coastal province of Zeeland. More recently, two offshore wind parks have become operational (in 2006 and 2008). These offshore wind parks are located more than 10 km out of the coast. In this paper, we will focus on the external effects of wind turbines placed on land.

The second dataset we use in this paper covers about 70 percent of all housing transactions in the Netherlands from 1985-2011 and is obtained from the Dutch Association of Realtors (NVM). For more than two million observations we know the transaction price of each property, as well as a host of housing attributes, such as the size in square meters, the

[17] Construction costs are proportional to the installed capacity of the turbine (as a rule of thumb, about 1325 Euros per kW installed capacity, see ECN, 2008). A typical wind turbine has a life span of 20 years or even longer (if it is properly maintained).
[18] This includes the turbines placed by NEG Micon. In 2004, NEG Micon and Vestas merged, which resulted in the creation of one of the largest wind turbine manufacturing companies in the world.
[19] Figure 1 shows the wind at 100 meters above ground level (calculated by KEMA Netherlands B.V. and Geodan IT, 2005).

construction year, number of rooms and variables that indicate the presence of a garage, garden and central heating. Because the exact location of each property is known, we can calculate the straight-line distance of each property to the nearest wind turbine.

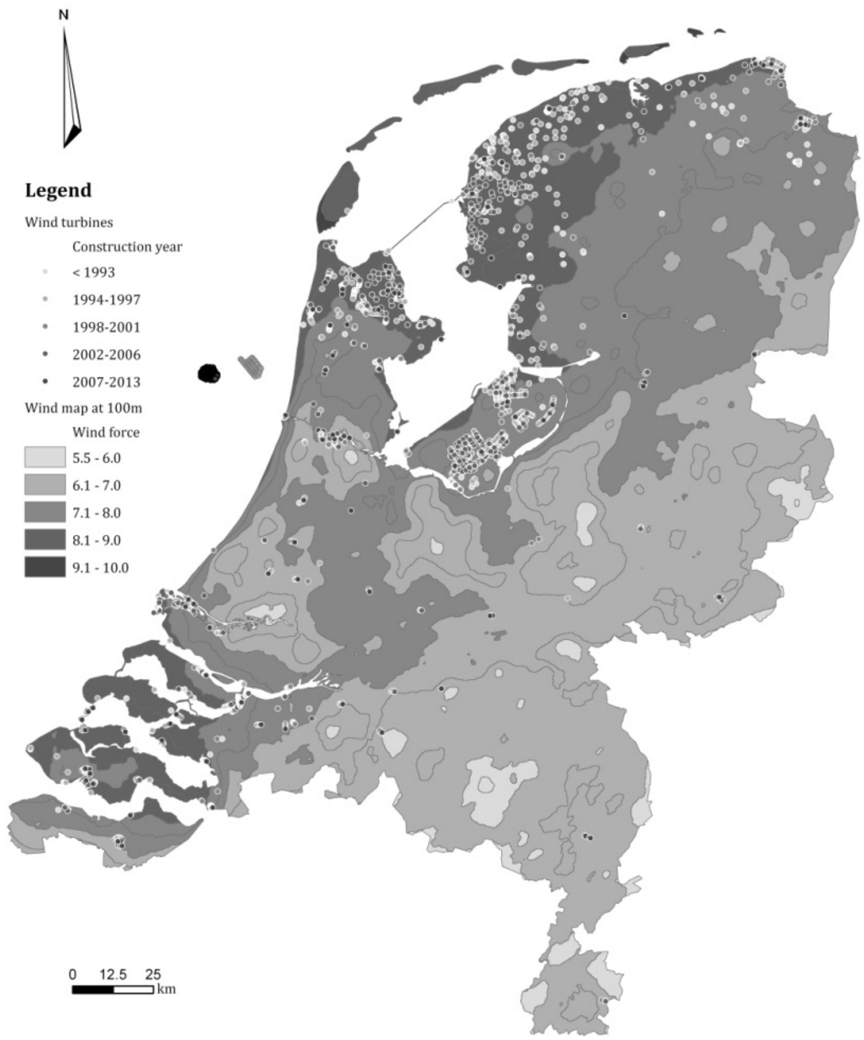

FIGURE 1 — SPATIAL DISTRIBUTION OF WIND TURBINES

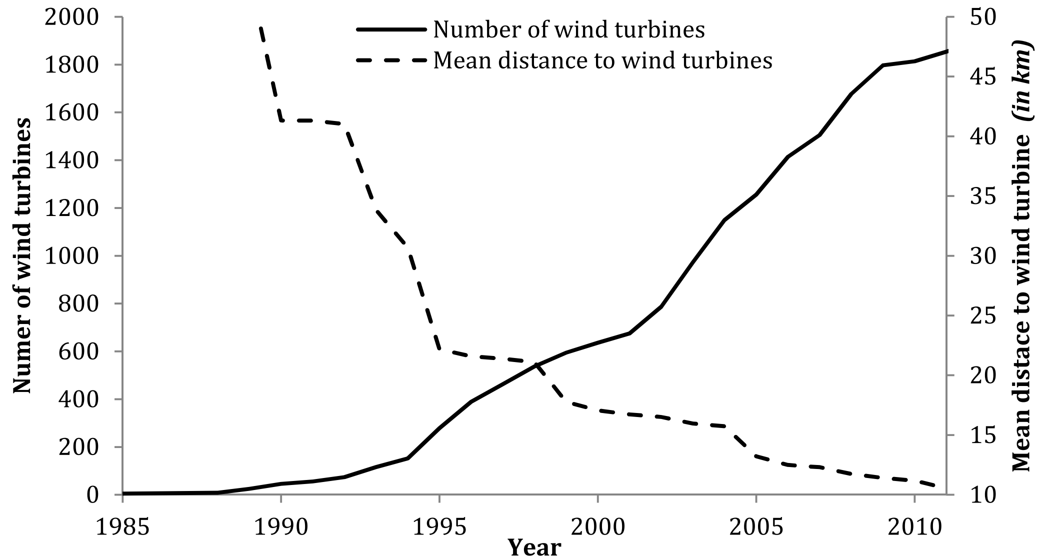

FIGURE 2 — NUMBER OF WIND TURBINES IN THE NETHERLANDS

Figure 2 shows that the number of wind turbines has been steadily increasing since the construction of the first wind turbine in 1982. Before 1990 only a limited number (25) of wind turbines were constructed. Not surprisingly, the average distance of a property to the nearest wind turbine has been decreasing over the years, although the average distance only decreased with 2.68 km on average since 2005, while the number of wind turbines has increased with 34 percent during the same period.

Table 2 presents descriptive statistics for the housing transactions dataset.[20] The average distance to the nearest wind turbine is about 20.5 km. We consider observations within 2 km of a (future) wind turbine as part of the treatment group. Table 2 shows that 6.7 percent of observations (about 150,000 observations) are in the treatment group and 4.1 percent of the housing transactions (about 90,000 observations, 80,000 houses) are located within a 2 km radius of a wind turbine after it has been constructed.

Table 3 reports the descriptive statistics for those observations within versus outside a 2 km radius of a (future) wind turbine (treatment versus control group). As expected, wind turbines are placed in areas with a relatively low house price (i.e. rural areas, selection effect). In the regression analysis, because we include a treatment group indicator, we control for these differences. More in general, any differences in (average) house prices across locations are captured by the 6-digit zip code fixed effects. There are 161,065 unique 6-digit zip codes in our dataset with, on average, 14 observations per zip code. There are 15,456 zip codes for which we only have one observation per zip code (0.7 percent of the

[20] We exclude transactions with prices that are above € 1.0 million or below € 25,000 or a square meter price below € 500 or above € 5,000. Furthermore, we exclude transactions that refer to properties smaller than $25m^2$ or larger than $250m^2$. These selections refer to less than one percent of the observations.

total number of observations). Moreover, given the other differences in housing characteristics between the treatment and control group, it is important to also control for housing characteristics in the empirical analysis. There are, for example, relatively a lot of detached houses and a low share of apartments close to wind turbines. To avoid that the treatment effect we estimate is biased, we explicitly control for the differences in composition of the control versus treatment group.

TABLE 2 — DESCRIPTIVE STATISTICS: HOUSING TRANSACTIONS

	Full sample			
	mean	std	min	max
Price (Euros)	193,960	114,713	25,000	1,000,000
Price per m^2 (Euros)	1,654	750	500	5,000
Distance to nearest wind turbine *(km)*	20.523	27.706	0.081	315.606
Treatment group (1 if turbine in 2012< 2000m)	0.067	0.251		
Treated (1 after placement turbine <2000m)	0.041	0.198		
Density wind turbine <2000m	0.006	0.040	0	1.989
Size in m^2	118.089	37.765	26.000	250.000
Rooms	4.333	1.317	0	25.000
Apartment	0.271	0.444		
Terraced	0.319	0.466		
Semi-detached	0.281	0.449		
Detached	0.130	0.336		
Garage	0.338	0.473		
Garden	0.652	0.476		
Maintenance quality – good	0.863	0.344		
Central heating	0.900	0.300		
Listed (as cultural heritage)	0.006	0.078		
Construction year <1945	0.248	0.432		
Construction year 1945-1959	0.074	0.261		
Construction year 1960-1970	0.161	0.368		
Construction year 1971-1980	0.186	0.389		
Construction year 1981-1990	0.152	0.359		
Construction year 1991-2000	0.130	0.337		
Construction year ≥ 2000	0.049	0.216		
Year of observation	2002	5.896	1985	2011
Number of observations	2,219,088			

Finally, to better understand whether we measure the effect of noise, shadow, or view, it is important to examine the distribution of the observations within a 2 km radius of a wind turbine. Figure 3 shows this distribution. There are few observations that are within 500 meter of a wind turbine (about 1.6 percent of transactions in the treated category). In part, this reflects zoning restrictions. It also implies that the main effect we will be measuring is not the effect of noise. As a rule of thumb, wind turbine noise is typically deemed to be a problem within 4 to 5 times the axis height (Dooper et al., 2010).[21] Since the typical (current generation) of wind turbines have an axis height of about 100 meters (note that the average

[21] It turns out that at about 400 to 500m distance a turbine makes about 40 to 50 dB noise, which is about the amount of noise a refrigerator makes.

is much lower), the effect of noise on house prices should be predominately occur within a 500 meter radius.[22]

TABLE 3 — DESCRIPTIVE STATISTICS: TREATMENT VERSUS CONTROL GROUP

	Observations within 2000m of a turbine				Observations outside 2000m of a turbine			
	mean	std	min	max	mean	std	min	max
Price (Euros)	180,183	102,471	25,865	1,000,000	194,959	115,486	25,000	1,000,000
Price per m^2	1,552	659	500	5,000	1,661	756	500	5,000
Size in m^2	116.075	35.597	27.000	250.000	118.235	37.913	26.000	250.000
Rooms	4.361	1.240	0.000	24.000	4.331	1.323	0.000	25.000
Apartment	0.197	0.398			0.276	0.447		
Terraced	0.367	0.482			0.315	0.465		
Semi-detached	0.284	0.451			0.280	0.449		
Detached	0.152	0.359			0.128	0.334		
Garage	0.322	0.467			0.339	0.473		
Garden	0.708	0.455			0.647	0.478		
Maintenance quality – good	0.856	0.352			0.863	0.343		
Central heating	0.885	0.320			0.901	0.299		
Listed (as cultural heritage)	0.005	0.072			0.006	0.078		
Construction year <1945	0.276	0.447			0.246	0.430		
Construction year 1945-1959	0.068	0.251			0.074	0.262		
Construction year 1960-1970	0.143	0.350			0.163	0.369		
Construction year 1971-1980	0.167	0.373			0.187	0.390		
Construction year 1981-1990	0.153	0.360			0.152	0.359		
Construction year 1991-2000	0.139	0.346			0.130	0.336		
Construction year ≥ 2000	0.055	0.228			0.049	0.215		
Year of observation	2002	5.839	1985	2011	2002	5.900	1985	2011
Number of observations	149,939				2,069,149			

A further issue is the effect of shadow and flickering on house prices of nearby properties. As a rule of thumb, this effect is only regarded as a problem within 12 times the rotor diameter (Dooper et al., 2010).[23] The typical rotor diameter of current wind turbines is 90 meters (again, the average is much lower), which suggests that this effect is mainly relevant within about 1000 meters of a turbine. If a turbine creates more than about 6 hours of shadow, it is required to have a 'stand-still' feature installed to reduce the amount of flickering (Dooper et al., 2010). As a result, we argue that the shadow effect is not the main driver behind the decrease in property values after the construction of a wind turbine.

We argue that we predominantly measure the effect of view. Because the Netherlands is a flat country, a wind turbine can be seen from many locations close to the turbine, although the direct view from one's house might be obstructed by other buildings. Outside a 1 km range of a turbine the effect on house prices is most likely a view effect. We will show some

[22] We do not argue that noise is not a problem for those households living close to a wind turbine, but just that we do not have enough data to identify its effect on house prices.

[23] A typical turbine creates flickering at a rate of 1.5 Hz. Flickering between 2.5 and 14 Hz is considered to be a health risk (Dooper et al., 2010).

results where we interact the treatment effect indicator with an indicator for direct view. As mentioned, we will also measure the treatment effect at different distances from a wind turbine.

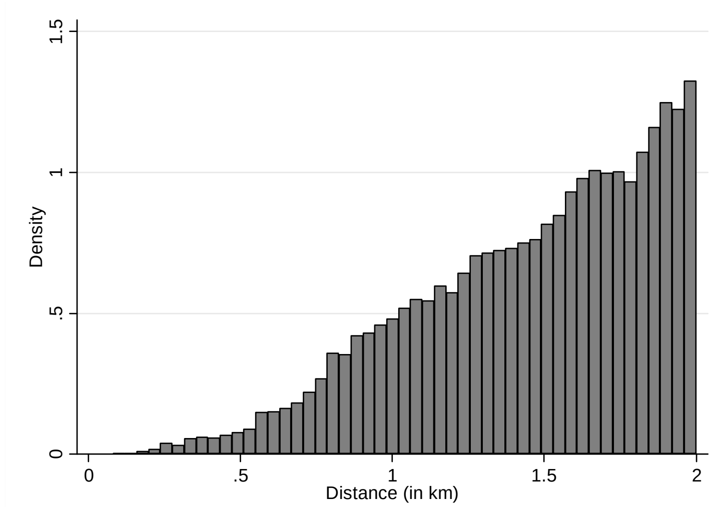

FIGURE 3 — DISTANCE TO WIND TURBINES, KERNEL DENSITY, <2KM

V. Results

A. Average treatment effect

Table 4 contains the regression estimates based on equations (1) to (6). Column 1 shows the regression estimates of equation (1), the classical difference-in-differences model. The results in column 1 suggests that the placement of a wind turbine decreases house prices within a 2 km radius by about 6.8 percent on average in comparison to the control group. Column 2 adds housing characteristics as additional control variables. The treatment effect decreases to 6.3 percent. The results also show that wind turbines are placed in locations where house prices are on average 2.8 percent lower. This selection effect (together with the treatment effect) can explain why many homeowner might think that a wind turbine decreases house prices. This decrease, however, is not causal. The results in column 2 further show that most of the hedonic characteristics are statistically significant and of the expected sign. Interestingly, according to the estimates, terraced and semi-detached houses are on average cheaper than apartments, the reference category. This is already an indication that the results of the simple hedonic model might be biased. In particular, in this model there are most likely omitted time (in)variant determinants of house prices that are correlated with the location of wind turbines. Column 3 adds 6-digit zip code fixed effects. House prices, according to this model, decrease by 1.2 percent after a wind turbine is constructed. Still, there might be unobserved changes, like changes in zoning regulations,

TABLE 4 — REGRESSION ESTIMATES: AVERAGE TREATMENT EFFECT

	(1) Classical dif-in-dif	(2) With house characteristics	(3) With 6-digit zip code FE	(4) Control group < 3km	(5) Effect over distance	(6) Dynamic response
Treatment effect	-0.0682***	-0.0626***	-0.0123**	-0.0144**	See	See
	(0.0252)	(0.0190)	(0.005)	(0.006)	Fig.	Fig.
Treatment – Control group	-0.0365	-0.0284**			4	5
	(0.0225)	(0.0142)				
Log(size)		0.8566***	0.5961***	0.5762***	0.5762***	0.5764***
		(0.0104)	(0.0042)	(0.0088)	(0.0088)	(0.0088)
Rooms		0.0076***	0.0161***	0.0195***	0.0195***	0.0195***
		(0.0014)	(0.0003)	(0.0009)	(0.0009)	(0.0009)
Terraced		-0.1142***	0.0396***	0.0511***	0.0512***	0.0510***
		(0.0114)	(0.0036)	(0.0084)	(0.0084)	(0.0084)
Semi-detached		-0.0743***	0.1004***	0.1044***	0.1045***	0.1042***
		(0.0121)	(0.0036)	(0.0080)	(0.0080)	(0.0080)
Detached		0.0950***	0.3258***	0.3223***	0.3223***	0.3221***
		(0.0142)	(0.0043)	(0.0103)	(0.0103)	(0.0103)
Garage		0.0956***	0.0987***	0.1046***	0.1046***	0.1046***
		(0.0032)	(0.0010)	(0.0022)	(0.0022)	(0.0022)
Garden		-0.0016	0.0069***	0.0061	0.0061	0.0061
		(0.0024)	(0.0020)	(0.0049)	(0.0049)	(0.0049)
Maintenance quality		0.1070***	0.1000***	0.1036***	0.1035***	0.1035***
		(0.0027)	(0.0009)	(0.0022)	(0.0022)	(0.0022)
Central heating		0.0959***	0.0746***	0.0829***	0.0829***	0.0826***
		(0.0033)	(0.0013)	(0.0025)	(0.0025)	(0.0025)
Listed		0.2398***	0.0604***	0.0773***	0.0774***	0.0768***
		(0.0288)	(0.0055)	(0.0112)	(0.0112)	(0.0112)
Construction year 1945-1959		-0.0810***	-0.0218***	-0.0078	-0.0077	-0.0079*
		(0.0118)	(0.0022)	(0.0047)	(0.0047)	(0.0047)
Construction year 1960-1970		-0.1504***	-0.0328***	-0.0083	-0.0082	-0.0083
		(0.0126)	(0.0024)	(0.0056)	(0.0056)	(0.0056)
Construction year 1971-1980		-0.1565***	-0.0010	0.0242***	0.0242***	0.0242***
		(0.0118)	(0.0024)	(0.0056)	(0.0056)	(0.0056)
Construction year 1981-1990		-0.0829***	0.0371***	0.0647***	0.0648***	0.0647***
		(0.0118)	(0.0027)	(0.0060)	(0.0060)	(0.0060)
Construction year 1991-2000		0.0028	0.1058***	0.1341***	0.1342***	0.1340***
		(0.0122)	(0.0037)	(0.0068)	(0.0068)	(0.0068)
Construction year ≥ 2000		0.0398***	0.1513***	0.1881***	0.1881***	0.1879***
		(0.0126)	(0.0042)	(0.0095)	(0.0095)	(0.0095)
Hedonic characteristics	NO	YES	YES	YES	YES	YES
6-digit zip code FE	NO	NO	YES	YES	YES	YES
Year (and month) FE	YES	YES	YES	YES	YES	YES
Local control group	NO	NO	NO	YES	YES	YES
Nr. Obs.	2,219.088	2,219,088	2,219,088	357,745	357,745	357,745
Adj. R-sq.	0.3632	0.7381	0.9243	0.9231	0.9232	0.9232

*, **, ***, 10%, 5%, 1% significance, respectively. Clustered (4-digit zip code) standard errors in parentheses. The treatment dummy is 1 if <2km of a wind turbine and 1 year after construction.

that affect the estimates. Consequently, we examine house prices of the treatment group versus a local control group (<3km of a current, previous, or future wind turbine). The results are reported in column 4. House prices decrease by 1.4 percent, our preferred estimate, after a wind turbine is constructed within a 2 km radius. This is most likely a conservative estimate, many of the estimates reported in the sensitivity analysis are higher. Moreover, column 1-4 show estimates of the *average* treatment effect, while the next sections show that there is considerable heterogeneity in this effect.

B. The impact radius

To determine the size of the treatment area we decomposed the treatment effect (i.e. see equation (5)) over distance within a 2.5 km radius of a wind turbine. In essence, we just include a set of dummy variables for each distance category (for each additional 250m). Figure 4 plots the percentage effect on house prices (the other coefficient estimates are reported in Table 2, column 5) relative to the observations outside the 2.5 km circle but within a 3 km distance from a turbine (the reference category).[24]

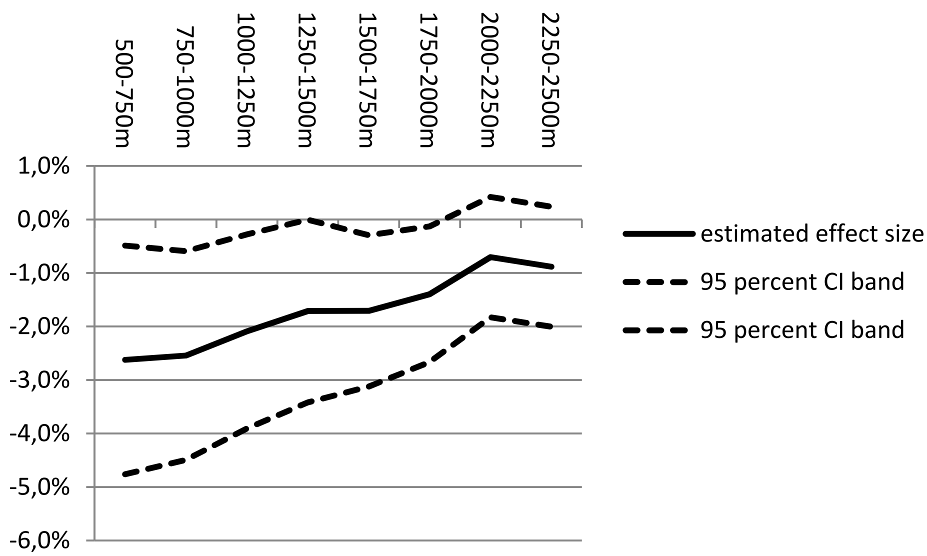

FIGURE 4 — DISTANCE PROFILE TREATMENT EFFECT

Figure 4 shows that the treatment effect is -2.6 percent at a 500-750m distance from a turbine and it gradually decreases to about -1.4 percent at 1750-2000m after which the effect drops substantially (below -1 percent) and becomes statistically insignificant.[25] Again, this does not imply that there is no effect after a 2 km distance from a turbine, but that the

[24] Note that we do not depict the category <500m as it has a positive and statistically insignificant coefficient.
[25] If we use the full sample and a 3km distance profile we find quantitatively similar results.

effect is most likely so small that, on average, we cannot reject the null hypothesis that there is no effect. Based on the these considerations, we decided to use a 2km radius as the relevant treatment area throughout this study.[26]

C. Dynamic response function

In Table 4, column 6, we decomposed the treatment effect in years before and after treatment, in line with equation (6). In essence, we just add a set of dummy variables with reference category 5 years or more before construction of a turbine (the last category is 10 years or more after construction). The resulting response function (x 100 percent) is also depicted in Figure 5. There are five phases in the estimated dynamic effect.

First, 3 to 4 years before the placement of a turbines there is no statistically significantly different effect on house prices for the control and treatment group. This is exactly what we would expect to find. Housing market trends in these different groups are the same in this phase.

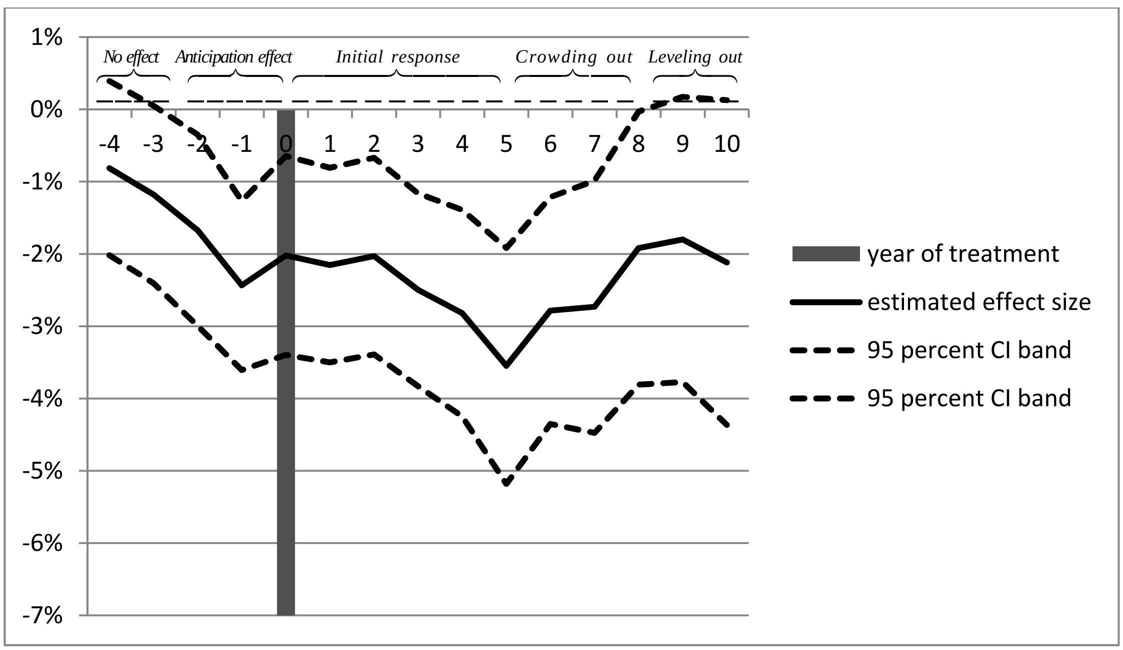

FIGURE 5 — DYNAMIC RESPONSE FUNCTION: EFFECT ON HOUSE PRICES AFTER THE CONSTRUCTION OF A WIND TURBINE WITHIN 2KM , IN PERCENTAGES

Second, there is a phase in which the turbine has not been placed yet, but we do find a statistically significant effect on house prices. This phase starts about 2 years before the

[26] Also note that the confidence bands become smaller as distance to the turbine increases, which is the result of an increase in the number of observations further away from the turbine (see Figure 3).

placement of a wind turbine. At year 2 before placement the effect is about -1.7 percent and statistically significant at the 5 percent significance level. The effect becomes -2.4 percent 1 year in advance and bounces back a little to -2.0 percent the year the wind turbine is constructed. We interpret the effect before construction of the turbine as an anticipation effect.[27]

Third, there is an initial response phase in which the effect gradually increases over time. In the year of treatment (the year after construction) the negative effect on house prices is -2.1 percent and it increases to -3.5 percent after 5 years. This result implies that information regarding the placement of a wind turbine is not directly capitalized into house prices. This possibly reflects the inefficiency in housing markets (market frictions, inertia).

Fourth, the effect on house prices decreases after year 5. It decreases to about -1.9 percent in year 8. This can potentially be explained by a sorting effect. Household that move to an area with wind turbines close by are households that do not care so much about the visual disamenity of the nearby wind turbines. We denote this phase as the crowding out phase.

Finally, the effect levels out after about 8 years. This is labelled in Figure 5 as 'Leveling out'. The effect between years 8 to 10 (and beyond) ranges between 1.8 to 2.1 percent. The effect for year 8 is statistically significant at the 5 percent significance level. The effect for the years 9 and 10 only at the 10 percent significance level. This may reflect that the number of observations decreases as the number of years after the placement of a turbines increases. In sum, however, the results seem to provide evidence that there is a permanent effect on house prices of about 2 percent 8 years or more after the construction of a wind turbine.

D. Sensitivity analysis and other results

There is considerable heterogeneity in the treatment effect. Table 5 reports several alternative specifications. First, and foremost, the treatment effect may depend on the number of wind turbines that are constructed. For example, wind parks are likely to have much stronger price effects than single wind turbines. As a result, we interacted the treatment effect dummy with the number of wind turbines within a 2km radius at the time the first wind turbine was constructed. We divided the number of wind turbines into the following categories: 1 turbine, 2 turbines, 3 turbines, 4 turbines, 5 or more turbines. Of the 80,000 'treated' houses 63 percent gets treated by the construction of a single wind turbine, 12 percent by two turbines, 8 percent by three turbines, 11 percent by four turbines, and the remaining 6 percent by 5 or more turbines. Table 5 column 1 reports the regression results including the interaction effect with the number of wind turbines. It turns out that

[27] To fully identify this effect further research would be needed using information on when the turbine was publically announced.

the interaction terms are not statistically significantly different from zero. The results in column 1 suggest that if there is more than one turbine placed close to a property there is not an additional negative effect on house value.[28]

TABLE 5 — REGRESSION ESTIMATES: SENSITIVITY ANALYSIS AND OTHER RESULTS

	(1) Nr. of wind turbines	(2) Control for density turbines	(3) Effect of turbine height	(4) Effect of diameter blades
Treatment effect	-0.0185***	-0.0212***	-0.0150***	-0.0113*
	(0.0064)	(0.0071)	(0.0057)	(0.0059)
Treatment * 2turbines	0.0097			
	(0.0068)			
Treatment * 3turbines	0.0039			
	(0.0095)			
Treatment * 4turbines	0.0312			
	(0.0172)			
Treatment * >5turbines	0.0181			
	(0.0105)			
Treatment * >90m height			-0.0188*	
			(0.0099)	
Treatment * >85m diameter				-0.0371***
				(0.0104)
Hedonic characteristics	YES	YES	YES	YES
6-digit zip code FE	YES	YES	YES	YES
Year (and month) FE	YES	YES	YES	YES
<3km control group	YES	YES	YES	YES
Nr. Obs.	357,745	357,745	319,796	357,058
Adj. R-sq.	0.9232	0.9231	0.9245	0.9233
	(5) Decade * Zip code FE	(6) Direct view	(7) Urban/rural	(8) Potential wind area control group
Treatment effect	-0.0080**	-0.0145**	-0.0126**	-0.0294
	(0.0040)	(0.0057)	(0.0059)	(0.0200)
Treatment * Direct view		0.0334*		
		(0.0187)		
Treatment * Urban			-0.0043	
			(0.0098)	
Hedonic characteristics	YES	YES	YES	YES
6-digit zip code FE	YES	YES	YES	YES
Year (and month) FE	YES	YES	YES	YES
<3km control group	YES	YES	YES	YES
Nr. Obs.	357,745	357,745	357,745	2,570
Adj. R-sq.	0.9296	0.9231	0.9231	0.9114

*, **, ***, 10%, 5%, 1% significance, respectively. Clustered (4-digit zip code) standard errors in parentheses. The treatment dummy is 1 if <2km of a wind turbine and 1 year after construction).

[28] A further concern is that there are turbines placed successively closer to those houses that already have been coded as treated within a 2 km radius (multiple treatment effect). It turns out that this is a relatively minor issue (less than 0.3 percent of total observations). Excluding these observations does not change our results.

Table 5, column 2, contains an alternative measure to control for the number of wind turbines. In particular, we included the (time-varying) density of wind turbines per square kilometre (within a 2 km radius of a property), such that we can single out the effect of the placement of the first wind turbine in a particular area. It turns out that the effect including wind turbine density as control increases the negative treatment effect on house prices. In particular, house prices decrease by about 2.1 percent after the construction of the first wind turbine within a 2 km radius of a property.

We would expect to find that wind turbines that are higher are visually less appealing and, as such, the negative treatment effect on house prices is larger for those turbines. To test this hypothesis, we included an interaction term between the treated dummy and a dummy that is one if the axis height of the turbine is larger than 90 meters (we lose some observations because the axis height is missing in some cases). Table 5, column 3, shows the regression estimates. We find some evidence that if the nearest wind turbine is above 90 meters there is a 1.9 percent additional decrease in house prices on top of the estimated 1.5 percent effect.

Similarly to turbine height, we also included an interaction effect with the diameter of the blades. Table 5, column 4 shows the regression estimates. Those turbines with blades larger than 85 meters have an extra negative effect of 3.7 percent. The base effect decreases a bit to 1.1 percent.

One further problem with the estimated average treatment effect is that it may be biased due to unobserved time-varying factors, such as changes in local zoning regulation, which may be correlated with the construction of wind turbines and also affect house prices. As such, we also included the interaction between the zip code fixed effects and decade dummies (1985-1990, 1991-2000, 2001-2011). The results are presented in column 5. The treatment effect decreases to -0.8 percent which is not surprising given that the effect of wind turbines on house prices is captured by the differences in local trends.

The 'view' effect of wind turbines is inherently difficult to measure. A wind turbine might only be visible from some places inside the house or might only be visible in the garden belonging to the house or a wind turbine might be visible when walking around in the neighborhood even though the wind turbine cannot be seen from inside the house. We created lines of sight from each house to the nearest wind turbine (limiting the maximum distance to 2 kilometres). We used the total stock of wind turbines in 2012 because the first and nearest wind turbine within a 2 km radius virtually does not change over time. Based on the contour of all buildings in the Netherlands (in 2010), we created an indicator whether a wind turbine is in direct view of a house. Although there is most likely measurement error in this indicator, it is the best we could do with this large amount of data. Only 0.7 percent of the transactions belonging to the 'treated' group are from houses with direct view to a wind turbine. Table 5, column 6, contains the regression results where we included the interaction between direct view and the treatment effect. Unfortunately, we do not find a negative view effect (i.e the effect is of the wrong sign and barely statistically significant). This does not necessarily imply that there is no effect of view, but simply that even with this quality of data we cannot identify this effect.

Most of the turbines may be located in rural areas. To examine whether the effect is mainly a rural or urban effect we estimated the interaction effect between the treatment effect and an indicator for urban versus rural areas. Houses that are located in places with more than 5000 persons per square kilometre are urban areas (45 percent of observations). Table 5, column 7, shows the regression estimates. It turns out that the effect of wind turbines on house prices is not particularly linked to whether the house is located in an urban or rural area.

Finally, we imposed an additional restriction on the control group. In particular, in 2014 the areas where future wind turbines are allowed to be placed were announced by the Dutch government. These areas are located in Groningen, Flevoland, and Zeeland, which are the areas where there are already a lot of wind turbines. Conditional on the choice to locate wind turbines in a particular area is there still a negative effect on house prices? If so, the effect we find is not the results of the fact that wind turbines are not randomly allocated across space. Table 5, column 8, shows the estimate of the treatment effect with this additional restriction imposed. House prices are 2.9 percent lower relative to the control group. This effect is statistically significant at the 15 percent significance level, which is, given the low number of observations (2,570), not surprising, but still shows that the effect we find is quite robust.

TABLE 6 — ESTIMATED TOTAL LOSS IN HOUSE VALUE

	Total loss, nominal	Total loss, house price appr. adj.	Total loss, all owner-occupied houses	Total loss, all houses
Total loss (Euros, in millions)	226	282	403	733
Total loss / house (Euros)	2,800	3,500	3,500	3,500
Total loss / wind turbine (Euros)	126,000	157,000	224,000	407,000
Total loss / wind turbine / year (Euros)	6,300	7,800	11,200	20,300

Notes: The total nominal loss is based on house prices at the time the house is sold and the estimated loss based on equation (4). We use the price index estimated in equation (4) to adjust for house price appreciation (all values have 2011 as base year). The sample used in this paper only captures about 70 percent of all owner-occupied housing transactions. About 55 percent of all houses are owner-occupied.

E. Counterfactual analysis

Table 6 contains a back of the envelope calculation about the total loss in house value as a result of the wind turbines that have been built in the Netherlands. The total loss in house value is 226 million if we multiply the average treatment effect of -1.4 percent by the nominal transaction price at the time a 'treated' house is sold. If we correct for house price appreciation (2011 becomes the base year), the total loss is 282 million euros. Since the transactions data we use only covers about 70 percent of all transactions, the total loss for all owner-occupied houses is about 403 million euros. Finally, if we take into account that 55 percent of the population are homeowners, the total amount of accumulated loss in house value is 733 million. This is about 3,500 Euros per (treated) house, 407,000 Euros per wind turbine, and 20,300 Euros per wind turbine/year. Although it is apparent that there are quite some assumptions behind these estimate, it does suggest the order of magnitude: The total loss in house value in the Netherlands as a result of wind turbine construction is substantial and runs into the hundreds of millions of euros.

VI. Conclusion

This paper has investigated the effect of wind turbines on house prices. The results show a pronounced negative effect of the construction of a wind turbine on house prices of about 1.4 percent on average within a 2km radius. The negative effect ranges from 1.4 to 2.6 percent, depending on the distance to the turbine. We also show that anticipation effects are important: house prices start to decrease about 2 years before the completion of a nearby wind turbine. The negative effect eventually levels out at about 2 percent.

Our results indicate that the effect of wind turbines on house prices is an extremely local effect. This implies that the effect on house prices can be avoided by constructing wind turbines further away from urbanized areas. Our results do not suggest that wind turbines should not be constructed on land, but that policy makers and wind turbine owners should take account the external economic costs of wind turbines as is reflected in nearby property values.

A particular concern is whether there are viable alternatives. Building wind turbines at sea, for instance, is still very costly. That being said, it might be that the external costs of onshore wind turbines outweighs the additional costs of building wind turbines at sea. Another option would be to coordinate the placement of wind turbines not at a national level, but a supranational one. Currently, each European country has to arrange the increase in renewable energy itself. Why not buy green energy, created by wind turbines located at places (countries) where both the opportunity cost and the effect of externalities is lowest (outsourcing)? Another initiative that is currently being used in the Netherlands is that homeowners can become a shareholder of a wind turbine. This can potentially increase the societal support for the placement of wind turbines. It can partly compensate homeowners for the loss in house value and potentially decrease the 'not in my backyard' mentality.

Finally, it is important to recognize that many wind turbines are placed in rural areas. This, however, does not mean that such turbines have no external economic effects. Since wind turbines are an asset for a land owner it potentially increases the value of the land on which the turbine is placed. In addition, the value of nearby land is expected to decrease since the option value of the land decreases (i.e. no houses can be constructed on nearby land). Future research should thus focus on the effect of wind turbines not only on house prices, but also on the value of (rural) land.

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