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The impact of on-shore and off-shore wind turbine farms on property prices

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ABSTRACT

We present the results of a large-scale analysis on how on-shore and off-shore wind turbines affect the property prices of nearby single family residential and vacation homes in Denmark. We find that on-shore wind turbines negatively affect the price of surrounding properties to a distance of three kilometers. The negative impact increases with the number of wind turbines at a declining marginal rate but declines with distance. In the case of off-shore wind turbine farms, we do not find a significant effect of having an off-shore wind farm in view from a property itself or from the nearest beach, likely because the closest off-shore turbine is 9 km from the closest traded home. We illustrate the policy relevance of our findings by providing maps showing how the marginal impact of a wind turbine varies across the landscape according to the spatial distribution of home density and homes values in the proximity of a wind turbine site. The results suggest that *ceteris paribus*, wind turbine farms should be built quite far away from residential areas with turbines gathered in larger wind farms rather than installed as single turbines.

1. Introduction

The increasing presence of wind turbines in the landscape both on- and off-shore has grown more contentious as investments in renewable energy have surged, creating local conflicts regarding where to place key energy infrastructure (Wolsink, 2000; Goetzke and Rave, 2016). The negative externalities associated with wind turbine farms include reductions in aesthetic amenity values, light flickers from blades and noise pollution (Devine-Wright, 2005) and in some places, even threats to migrating and foraging birds (Drewitt and Langston, 2006).

Environmental economists and other social scientists have studied people's preferences regarding wind turbine farms as a source of energy and their preferences for living in close proximity to wind farms. The latter is the focus of this study. Stated preference studies have documented that people view wind energy itself as a positive thing (Borchers et al., 2007) but also express a disutility from externalities such as visual impact and noise (Ladenburg, 2009; Meyerhoff et al., 2010; Ladenburg and Möller, 2011; Brennan and Van Rensburg, 2016; García et al., 2016). Stated preference studies can be designed flexibly enough to capture the possible externalities experienced by people living or working in close proximity to wind farms and those experienced by people just travelling through or visiting the area. However, the values are derived on stated preferences, which can be subject to different biases (Carson, 2012; Hausman, 2012).

These issues have also been investigated with the revealed preference technique of hedonic pricing, but so far, this investigation has occurred only in a modest number of studies and with mixed evidence (Sims and Dent, 2007; Sims et al., 2008; Hoen et al., 2011, 2015; Heintzelman and Tuttle, 2012; Vyn and McCullough, 2014; Jensen et al., 2014; Lang et al., 2014; Hoen and Atkinson-Palombo, 2016; Sunak and Madlener, 2016). The literature takes different approaches to handle challenges of omitted variables and in particular endogeneity, which may hamper proper identification. Concerning endogeneity, a particular concern has been if wind turbine farms are more likely to be placed in areas with lower property prices. These conclusions could be incorrect about both causality and magnitudes of effects if they are not controlled for. Greenstone and Gayer (2009) and Kuminoff et al. (2010) show that, e.g., spatial fixed effects or similar specification may solve both omitted variable and endogeneity issues under certain conditions, and studies such as Heintzelman and Tuttle (2012) and Jensen et al. (2014) pursue this strategy in identification. A different and potentially more potent approach taken in recent studies such as Hoen et al. (2015, 2016) and Sunak and Madlener (2016) is the difference-in-differences approach. This approach can be a strong identification tool when

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suitable data are available. In this study, we apply both of these identification strategies because we believe both are suitable.

We add to and extend this still scarce literature in the following ways. First, we undertake analyses of the negative cumulative effect of on-shore and off-shore wind turbine farms, with the latter analysis being a first in the literature to our knowledge. Second, we add to the literature by presenting analyses of dwellings bought as a property for permanent residential use (residential homes) and dwellings bought as a property for part-time use (vacation homes). Our analysis covers parts of the Danish landscape in which the majority of new wind turbines have been installed.

For on-shore wind turbines, we present further evidence of effects of a wider set of spatially distinct housing markets in rural Denmark based on a cross-sectional analysis, taking an identification strategy similar to Heintzelman and Tuttle (2012) and Jensen et al. (2014). We also pursued the difference-in-differences identification strategy for on-shore turbines but faced limited data availability for treatment variables, as we discuss further below. As a further addition to the literature, we investigate if the effect of proximity to on-shore wind turbines is sensitive to the number of wind turbines in the surrounding area. We find that it is and that there is also a strongly decreasing effect of an additional wind turbine in the surrounding area. This is an important finding for policy because it suggests that clustering of turbines is preferred.

The Danish off-shore wind production is less developed, more recent and on-going than on-shore wind production. Here, we a purse a difference-in-differences identification strategy to analyze the effect in a case area in the Southern part of the Baltic Sea. The effect of off-shore wind farms on property prices has never been studied before, but the growing number of wind farms visible from the shore calls for such analyses to be undertaken. The identification of an effect from off-shore wind turbines can be difficult due to the spatial structure of data. We find no effects of being able to see the off-shore wind farm from houses or beaches, but we note that the closest wind farm is placed 9 km from the coast and thus even farther away from the majority of houses. Thus, the results cannot be extrapolated to, e.g., wind farms closer to land.

We illustrate the potential value of our analyses for policy and planning by using geodata to map out approximate marginal gains (costs) in terms of property value increases when a turbine was removed from (added to) existing turbine sites. We show how two main drivers affect these results, namely, the number of wind turbines already placed in an area and the value and density of properties in the proximity.

2. Case areas and data

2.1. On-shore wind turbines

The first research question of this paper focuses on the relationship between on-shore wind turbines and the property prices of residential and vacation homes. We obtained data on on-shore wind turbines' longitudinal and latitudinal coordinates and other technical specifications (ENS, 2016), the prices of detached residential housing, and vacation homes (OIS, 2016). Properties traded following bankruptcies, sales within the family and similar circumstances were excluded from the dataset. The dataset includes structural data on each property, including the number of bedrooms, the living area and lot size, roofing type, etc. Using geographical information about land use and information on the surroundings of each property, we calculated a number of other variables representing the spatial attributes of each property in the dataset. These included variables describing the number of wind turbines within various distances and the distance to each wind turbine from the individual property. To illustrate, Tables 1, 2 include selected descriptive statistics for the traded properties (residential and vacation homes, respectively) and the wind turbines in their surroundings for the region of Central and Western Zealand in Fig. 1. Approximately half of the two samples from Zealand have at least one turbine within 3 km, ranging from 1 to 15, as shown in Tables 1, 2. The corresponding descriptive statistics on properties and wind turbines for the remaining regional markets are provided in the appendix to this paper.

Wind turbines are not evenly distributed across the Danish landscape, and at the same time, property markets may also show spatial variation in the pricing of a number of property characteristics, potentially among them the effect of nearby wind turbines on property prices. To account for this possibility, we undertook several spatial analyses in order to define and select a suitable set of spatially distinct areas for our purposes. We selected areas that had sufficiently coherent and active property markets in the sense that we had enough property trades within the considered time period and that property prices were described well by a single hedonic function with little or no systematic spatial variation in residuals. Furthermore, the areas should have a suitable number of wind turbines of varying types affecting a sufficiently large set of properties to allow for a reliable estimation. This approach resulted in the selection of areas shown in Fig. 1, and we estimated separate models for single residential and vacation homes in these areas. The five areas cover a total of 17,788 km^2, which is more than 40% of Denmark's total area.

2.2. Off-shore wind turbines

The second main research question of this paper focuses on whether the view of an off-shore wind farm affects the price of residential housing. We use the same data sources in the analysis on off-shore turbines as we did in the analysis of onshore turbines. In order to statistically identify an effect, we need a sufficient number of properties that can see a wind farm either from the home or nearby beach. We selected two farms, Nysted and Rødsand II, which were constructed at two different times but placed rather close to each other several kilometers apart on the southern coast of the Danish island of Lolland. The wind turbines at Nysted and Rødsand II are placed between 9.5 and 3.5 km off the coast. Nysted was completed and in use by 2003 and contains 72 wind turbines with a hub height of 72 m. Rødsand II was completed and in use by 2010 and contains 90 wind turbines with a hub height of approximately 80 m, cf. Fig. 2. A selected set of descriptive statistics is shown in Table 3.

2.3. The wind turbine variables

The negative impact of wind turbines on sales prices of neighboring properties are often attributed to noise and visual pollution (Jensen et al., 2014). In this paper, we specifically focus on the cumulative impact of the number wind turbines in an area. The relationship between property sales prices and wind turbines were captured in two variables. The first is a simple count of the turbines within a 3-kilometer radius of each property. The second variable is denoted *weighted density* and accounts for both the number and the proximity of wind turbines around each property. It is calculated as follows: for each home i, we recorded the number of turbines within 3 km, call it n_i, and the Euclidian distance in km between each turbine j and each property i denoted $distance_j$. Then, we calculated a weighted density d_i for each property in the sample and took the natural log of this measure:

$$\ln(d_i) = \ln\left(\sum_{j=1}^{n_i} \max(0; 3 - distance_j)\right)$$

The max function is used to ensure that a turbine 4 km away will add 0 to d_i and hence not be counted, whereas a turbine 2.4 km away will add 0.6 km to the index. We tested a number of distances and functional specifications before arriving at this choice. For all trades in the sample, we calculated the Euclidian distance between each property in the dataset and each turbine within 10 km of it. We then tested