Have They Gone with the Wind? Indirect Effects of Wind Turbines on Bird Abundance

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Abstract: This paper examines indirect effects of wind turbines on grassland bird species in the two selected regions of the United States: the Pacific region and the Northeast region. We estimate Poisson fixed effect estimators by using an unbalanced panel data for a seven-year time period between 2008 and 2014. Our results show that one additional unit of wind turbine in the Pacific region is associated with a decrease in annual grassland bird count within the 400 meters radius around a route, on average, by a range between 5% to 10%, holding climate and other wind turbine attributes constant. In the Northeast region, however, an additional unit of wind turbine is associated with, on average, barely 0.4% decrease in annual grassland bird count within the 400-meter radius, while its magnitude reduces even further within the 800-meter radius, holding all other parameters constant. Moreover, adverse climate is negatively associated with the number of grassland birds observed annually around a route across the study regions.

Keywords: Bird Abundance, Cropland, Grassland, Wind Energy, and Wind Turbines

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Introduction

Wind energy is widely viewed as one of the most promising alternatives to fossil fuels and the past three decades have witnessed dramatic increase in installed wind capacity globally, from about 8 Gigawatts (GW) in 1997 to 370 GW in 2014. The United States, as the second largest producer of wind energy in the world, had installed capacity at 66 GW as of 2014 and the capacity is expected to continue growing (Global Wind Energy Council 2016). The U.S. Department of Energy (USDOE) has set a goal to generate 20% of the nation's electricity from wind energy by the year 2030 (USDOE 2008). The dramatic development of wind energy have caused concerns about its impacts on birds and bats because direct mortality of these animals (mainly caused by collisions) occurs at wind energy facilities.

The majority of current studies have been focusing on fatalities of birds caused by collisions with wind turbines (termed as direct effects of wind turbines on birds). However, indirect effects of wind turbines, such as habitat loss and bird avoidance, may have larger impacts than do the direct effects (Mockrin and Gravenmier, 2012; Jones et al., 2015). There are only a few peer-reviewed studies about the indirect effects of wind turbines on birds with a focus on U.S. regions (Jones et al., 2015). Moreover, these studies either focus on a specific wind facility or some specific bird species in a short period of time. Studies that cover a broad region and long period are missing. Such studies are important because they would mitigate measurement and estimation errors that are more likely to occur during observations in a shorter period and small scale of studies, and therefore would provide more reliable evaluation of the indirect effects.

The present paper is an attempt to fill this gap. The primary purpose of this research is, therefore, to assess both short run and long run indirect effects of wind turbines on birds across the United States. We have used a new approach and comprehensive data set that incorporates wide range of information on climate change and land coverage across the United States. Our analysis harnesses tremendous information from two extensive datasets of wind turbines and bird abundance using an econometric approach. A visual presentation of the two datasets are presented in Figure 1. The first dataset is "Onshore Industrial Wind Turbine Locations for the United States through July 2013" compiled by U.S. Geological Survey (USGS). It includes not only precise latitude and longitude data for each of the 48,976 onshore wind turbines established over period 1981-2013 but also some other critical information such as a turbine's establishment year, tower type, tower height, blade length, and power generation capacity. The second dataset is North American Breeding Bird Survey (BBS) compiled by USGS' Patuxent Wildlife Research Center. This dataset includes annual bird count data for over 400 breeding bird species along more than 3,000 observation routes since 1966. Each observation route is about 24.5 miles long and has 50 observation stops. Since changes in land cover (e.g., conversion between cropland and grassland) have been found to influence bird abundance, we control for land cover changes by using land cover data obtained from National Land Cover Database and from the National Agricultural Statistics Service's Cropland Data Layer program of the U.S. Department of Agriculture. Climate variables are also controlled for.

Our fine-scale data allow us to identify the presence of wind turbines in near proximity to each bird observation stop. Our main dependent variable is the sum of 30 grassland bird species (listed by Peterjohn and Sauer (1993)) observed at each bird observation route. We choose grassland bird species because the Great Plains in the U.S. have the largest amount of wind turbines (see Figure 1) and are expected to experience further increase in wind farms (Fargione et al., 2012). We construct a panel dataset that covers stop level bird count in 48 contiguous states in the United States over 2008-2014. The large amount of observations enable us to conduct detailed econometric analysis on various characteristics of wind turbines and degree of proximity to the observation stops. Economic values of birds obtained from the related literature (see Martín-López (2008) for a comprehensive review regarding wildlife's economic value) are used to calculate the economic values of birds reduced by wind turbines. Time invariant factors such as field topography and soil characteristics that may affect bird abundance are controlled for by using fixed effects estimation.

Literature Review

Concerns about effects of wind facilities on birds surfaced in the United States in the late 1980s (Arnett et al., 2007; Cohn, 2008; Manwell et al., 2010). In addition to making mechanical and aerodynamic noises, wind turbines impose collision danger to birds. Many studies have analyzed bird fatalities due to collision with turbines, changes in abundance and distribution of breeding birds, movements and flight patterns of bird (e.g., Kunz et al., 2007; Pearce-Higgins et al. 2008; Cruz-Delgado et al. 2010; Douglas et al., 2011; Garcia et al., 2015 and many more). Considerable amount of controversy has been generated regarding the direct and indirect impacts of wind turbines on birds (Morrison and Sinclair, 2004; Manville 2005; Kunz et al., 2007a, 2007b; Pearce-Higgins et al. 2008; Diffendorfer et al., 2015). Here direct impact refers to bird fatalities caused by collision with turbines. Indirect impacts refer to disruption effects of wind turbines on birds' nesting and foraging behavior, flight patterns, habitat, as well as breeding and migration patterns (Desholm et al., 2006; Drewitt and Langston 2006; Kunz et al., 2007; Larsen and Guillemette 2007; Cruz-Delgado et al., 2010).

Numerous studies have reported that birds are sensitive to wind farm, due to collision mortality, reduced habitat utilization, or habitat loss near the turbines (e.g., Langston and Pullan 2003; Drewitt and Langston 2006; Stwart et al. 2007; Pearce-Higgins et al. 2008; Garcia et al. 2015). On the contrary, another group of studies has claimed that birds can detect the presence of wind turbines and avoid them (e.g., Nelson and Curry, 1995; Osborn et al., 1998; Lucas et al., 2003; Leung and Yang, 2012). They claim that birds either change their flying route in areas with wind facilities or change flying patterns in reference to status of rotating turbines.

Studies reveal that a wide variety of factors such as size of a wind turbine, bird species and their population density, and landscape play crucial role in determining magnitude of the effect of a wind turbine on birds (Percival, 2000; Lucas et al., 2003; Barrios and Rodrı´guez, 2004; Hoover and Morrison 2005; de Lucas et al., 2008; Farfan et al., 2009). For instance, Farfan et al. (2009) investigated bird density and flight behavior of birds in the proximity of a wind farm in the southern Spain between March 2005 and February 2007. Their results indicate that presence and operation of wind turbines affect differently to different bird species. They find that wind turbines have negative effect on few raptors species including eagles, hawk, and vultures, negligible effect on passerine species. They, however, pointed out that scientists have poor understanding about medium- and long-term impacts of a wind turbine on birds' abundance in its neighborhood.

Studies indicate that bird species such as golden plovers move their habitats at least 200 meters away from a wind turbine (Finney et al., 2005, Hotker et al., 2006, Pearce-Higgins et al., 2008) and avoid flying in areas around a wind turbine (Nelson and Curry 1995; Osborn et all., 1998; De Lucas et al., 2004). However, this impact varies across species and locations (Carrete et al., 2009; Pearce-Higgins et al., 2009).

A growing body of literature investigates how bird population changes over time in the proximity of an individual wind facility in the United States and a few other countries. However, no study has made an attempt to either compare results across wind farms or entire United States (Sovacool 2013; Diffendorfer et al., 2015). Moreover, a number of studies have made attempt to quantify decline of birds in relation to distance from a wind turbine either locally or at a global scale using statistical tools such as logistic regression, analysis of covariance design, generalized linear models, and generalized linear mixed models (Forman and Deblinger, 2000; UNEP, 2001; Howe et al., 2002; Nellemann et al., 2003; De Lucas et al., 2004; Fahrig and Rytwinski, 2009; Pearce-Higgins et al. 2009; Benitez-Lopez et al., 2010; Winder et al., 2014). For example, Howe et al. (2002) used analysis of variance (ANOVA) to examine whether number of species or number of individual birds differed in the proximity of a wind turbine. In another study, Pearce-Higgins et al. (2009) used generalized linear models and generalized linear mixed models to examine effects of a wind farm on bird distribution. Data for these studies came from an individual wind farm for a number of bird species.

The existing studies either mainly focus on a specific wind facility or some specific bird species in a short period of time. Studies that cover a broad region and long period are missing. Such studies are important because they will mitigate measurement and estimation errors that are more likely to occur during observations in a shorter period and small scale of studies, and therefore will provide more reliable evaluation of the indirect effects. The present study is an attempt to fill in this gap.

Methodology

We are interested in analyzing indirect effects of wind turbines on grassland birds in the two regions of the United States. Our dependent variable is the sum of 30 grassland bird species observed at each bird observation route, which is basically a count depended variable. Moreover, our data incorporates wide range of information on climate and land use across the United States. Unlike existing literature (see e.g., Desholm, 2003; Pérez Lapeña et al., 2010; Peron et al., 2013; Bastos et al., 2015; Garcia et al., 2015), we apply the Poisson fixed effects estimator (hereafter, PFE). The PFE estimation approach was developed by Palmgren (1981) and Hausman, Hall, and Griliches (1984). The PFE estimator can be used for the count dependent variable that takes nonnegative integer values such as number of grassland birds observed in a year on a route (Cameron and Trivedi, 2013). The PFE estimator assumes that the conditional mean be of correctly specified exponential form, and the conditional distribution belongs to the linear exponential family. The advantage of the PFE estimator is that estimates of the slope parameters in a short panel are consistent.

The conditional mean of the PFE estimator, which is restricted to be positive, can be expressed as:

(1) $$E[\, y_{it} | x_{it}, \alpha_i] = \alpha_i \exp(x_{it}'\beta)\,, \qquad i = 1, \dots, n; and\ t = 1, \dots, T$$

where the intercept is merged into α_i. The regressors x_{it} do not include the intercept in this model. The merginal effect is espressed as

(2) $$ME_{itj} = \frac{\partial E[y_{it} | x_{it}, \alpha_i]}{\partial x_{itj}} = \alpha_i \exp(x_{it}'\beta)\, \beta_j = \beta_j E[y_{it} | x_{it}, \alpha_i],$$

which depends on unknown α_i. The slope coefficient β_j can be interpreted as proportionate change in $E[y_{it} | x_{it}, \alpha_i]$ associated with one-unit change in x_{itj}. For example, if $\beta_j = 0.2$ then a one unit change in x_j is associated with 20% increase in y_{it}, holding all other regressors and unobserved individual effect α_i constant.

Data

We have collected data from four different sources. The first source is “Onshore Industrial Wind Turbine Locations for the United States through July 2013” compiled by U.S. Geological Survey (USGS). It includes not only precise latitude and longitude data for each of the 48,976 onshore wind turbines established over period 1981-2013 but also some other critical information such as a turbine’s establishment year, tower type, tower height, blade length, and power generation capacity.

The second dataset is North American Breeding Bird Survey (BBS) compiled by USGS’ Patuxent Wildlife Research Center. This dataset includes annual bird count data for over 400 breeding bird species along more than 3,000 observation routes since 1966. Within certain pre-defined radiuses (400m, 800m, 1,600m, 3,200m, 8,000m, and 16,000m in this study), we identify total number of wind turbines along a route for each year between 2008 and 2014. Figure 2 presents a sample of bird observation route and wind farm in our dataset. From the figure, we can see that 12 out of 100 wind turbines of Minonk Wind Farm are within the 400-meter buffer zone of the observation route Monica (route number: 34026). For turbines located within a buffer zone, we calculate the average values of the turbine, such as blade length, tower height, and total height. Moreover, we calculate total turbine area associated with a route by multiplying rotor swept area of a turbine with number of turbines within a certain radius around a route.

The third data source is Parameter-Elevation Regressions on Independent Slopes Model (PRISM) that generates detailed weather information across the contiguous United States at 4km-by-4km grid level. Monthly average of daily mean temperature and monthly total precipitation are used in our analysis. We incorporate climate data in our study because changes in temperature and precipitation directly affect birds’ reproduction, timing of breeding, and migration (Crick, 2004). Tingley et al. (2009) claim that some bird species are highly sensitive to temperature shifts while others are very sensitive to changes in precipitation. We focus only on temperature and precipitation data between January and June for the seven-year study period because the bird observation were mainly conducted in June of every year.

The fourth dataset is the Cropland Data Layer (CDL) obtained from the U.S. Department of Agriculture (USDA). The CDL data contains detailed land-use information for the United States at 30m-by-30m scale over 2008-2014. We overlay the CDL data with the bird observation buffer zones to obtain the land-use information within each buffer zone of each bird observation route. We then specify the land-use types and obtain acreage of crop land and grassland for each observation route with a certain buffer zone.

Based upon the four datasets, we construct an unbalanced panel dataset for a seven-year period between 2008 and 2014 for (a) number of birds observed on each route, (b) monthly average of daily mean temperature for each route, (c) monthly total precipitation for each route, (d) acreage of different crops cultivated near each route, and (e) wind turbines near each route across the United States. Table 1 contains the summary statistics for all four data sets: stop level bird count data, climate data, wind turbine data, and stop level land-use data.

Regression Results

We conduct the Poisson fixed effects estimations of equation (1) for the Pacific region and the Northeastern region of the United States. Tables 2 and 3 present estimation results for 400-meters and 800-meters buffer zone around each route in the Pacific region and the northeastern region respectively. In each of those two tables, columns 1-3 contain the Poisson fixed effects estimations of regression (1) for 400 meters radius around a route in the respective regions; and columns 4-6 contain PFE estimations of equation (1) for 800 meters radius around a route in the respective regions. Robust standard errors are reported in these two tables.

The results indicate that installation of one additional unit of wind turbine is associated with decrease in annual grassland bird abundance in a route across the study regions. For example, row 1 in Table 2 indicates that one additional unit of wind turbine in the Pacific region is associated with a decrease in observed grassland bird species with in the 400 meters radius around a route, on average, by a range between 5% to 10%, holding climate and other wind turbine attributes constant. However, rows 3 and 4 indicate that tower height and blade length of a wind turbine in the pacific region are, on average, positively associated with the number of grassland birds observed within 400 meters radius around a route. One possible reason of this positive association might be that, as a turbine tower becomes higher, the blade will be further from ground, and hence the turbine might has lower impact on grassland bird species which fly at a relatively low altitude. However, further investigation is required for better understanding of this phenomena. Table 3 shows similar trends in the Northeastern region, however, magnitudes of the estimated values of the respective coefficients are relative lower in the Northeastern region as compared to Pacific region. Moreover, row 1 in table 3 indicates that variable distance from a turbine is positively associated with abundance of grassland birds. More precisely, row 1 in Table 3 indicates that an additional unit of wind turbine in the Northeastern region is associated with, on average, 0.4% decrease in the grassland bird species within the 400-meter radius, while its magnitude reduces to 0.1% within the 800-meter radius. This is intuitive because the impact of the establishment of one wind turbine will be diluted when a larger area is considered.

Table 3 also indicates that adverse climate is negatively associated with the number of grassland birds observed around a route in the Northeastern region. For example, relatively high temperature (or relative higher precipitation) during summer is adversely associated with the abundance of grassland birds in the Northeastern region. Table 2 shows similar trends for the temperature, while sustained drought might have negated probable association of trivial volume of rainfall with abundance of grassland birds across routes in the pacific region, particularly in California.

Comparing these results with existing literature, we see that effect of wind turbines varies across bird species and across various buffer zone around a rout, which is consistent with our findings. For example, Winder et al. (2014) find that prairie-chickens are less sensitive to presence of wind turbine on a route. On the contrary, Benitez-Lopez et al. (2010) find that, unlike other bird species, raptors species prefers to be around the proximity of wind firms. However, like row 1 in the Table 3, Benitez-Lopez et al. (2010) find that variable distance around a route affects bird abundance on a route.

Conclusions

This paper examines an important problem faced by wind farms in the Pacific region and the Northeast region of the United States: to what extent wind farms affect abundance of grassland bird species on a route? By compiling data from various sources, we conduct the Poisson fixed effects estimations on an unbalanced panel data set for a seven-year period between 2008 and 2014. Our preliminary results are consistent with the literature. We have found that one additional wind turbine in the Pacific region is associated with a decrease in observed grassland bird species with in the 400 meters radius around a route, on average, by a range between 5% to 10%, holding climate and other wind turbine attributes constant. In the Northeastern region, however, an additional unit of wind turbine is associated with, on average, barely 0.4% decrease in the grassland bird species within the 400-meter radius, while its magnitude reduces even further if distance is expanded to 800-meters, holding all other parameters constant. Results also indicate that adverse climate is negatively associated with the number of grassland birds observed along a route.

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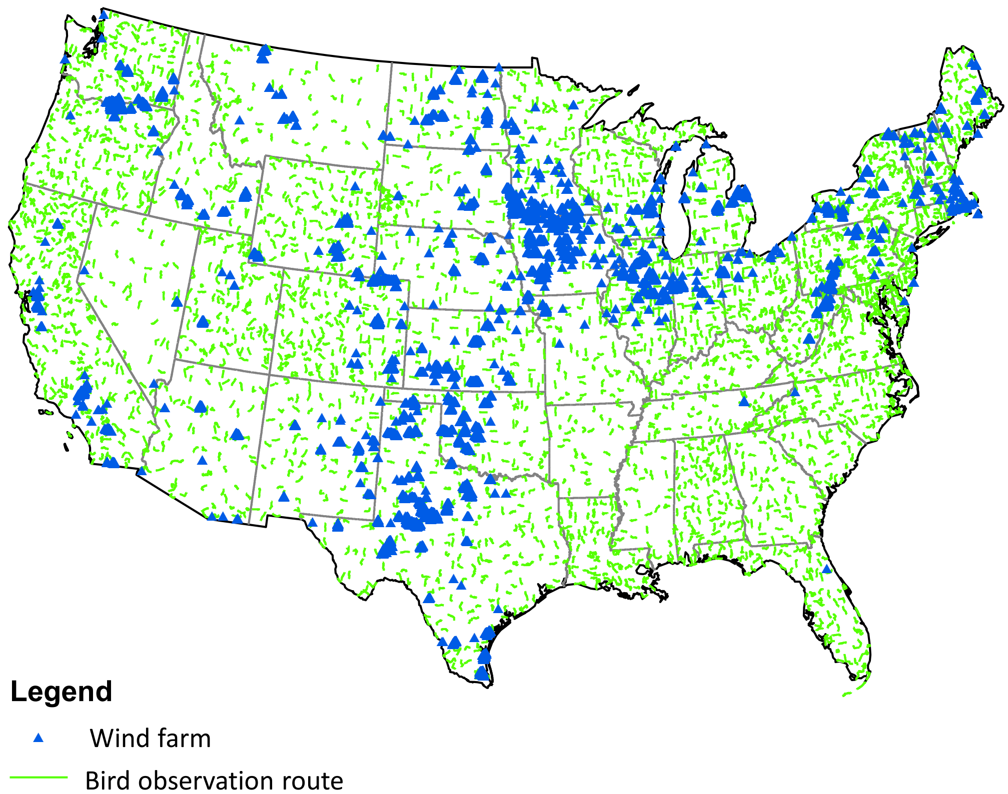

Figure 1. Locations of Wind Farms and BBS Bird Observation Routes in the United States

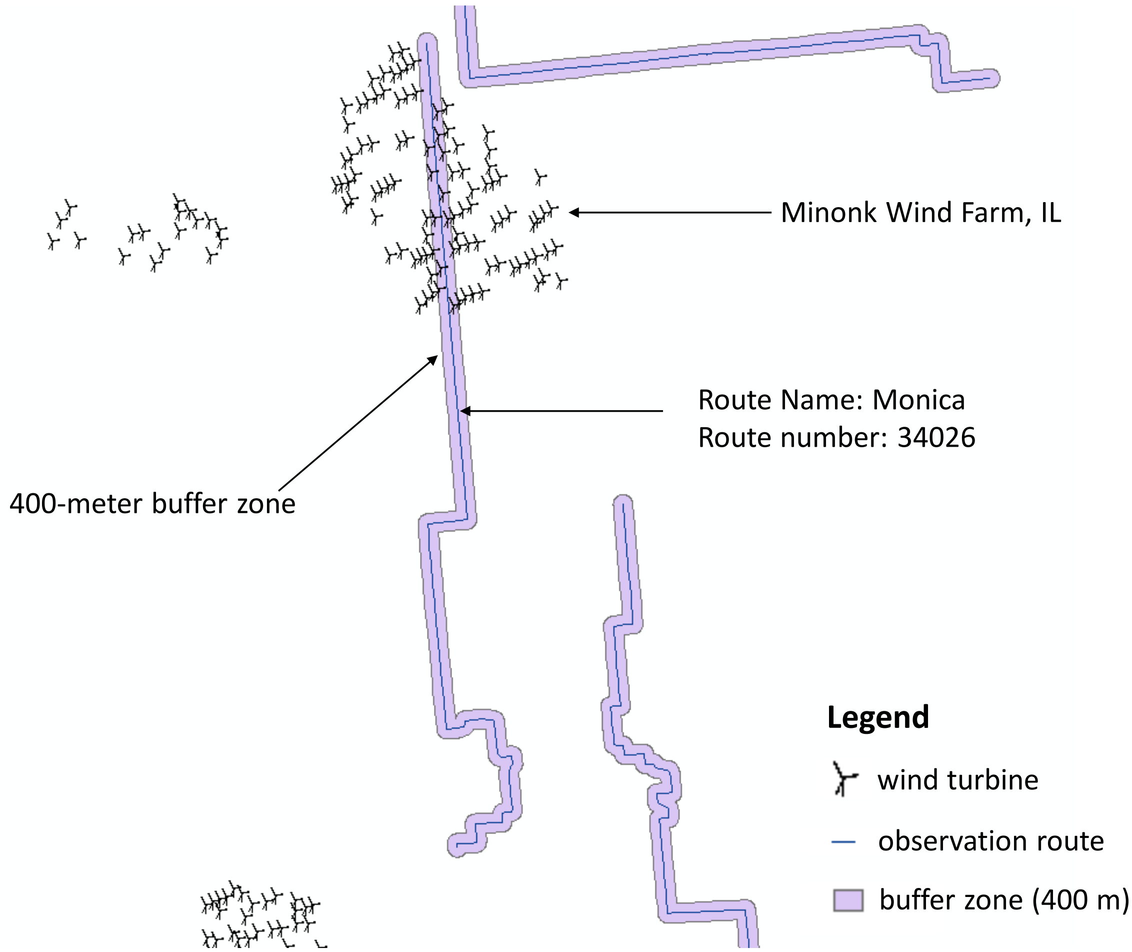

Figure 2. A Sample of Bird Observation Route and Wind Farm

Table 1: Summary Statistics of Data

Variable	Obs.	Mean	Std. Dev.	Min	Max
Bird Count on a Route					
Total Bird Observed	18,206	701	474	11	13,628
Total Grass-Land Bird Observed	38,117	81	130	1	2,042
Climate Data: Temperature (Measured in Celsius)					
Average of Daily Mean Temperature in January	27,825	-0.2	7.154	-21	23
Average of Daily Mean Temperature in February	27,825	1.31	7.196	-19	24
Average of Daily Mean Temperature in March	27,825	6	6.524	-13	24
Average of Daily Mean Temperature in April	27,825	11	5.695	-4	27
Average of Daily Mean Temperature in May	27,825	16	5.177	-0.26	32
Average of Daily Mean Temperature in June	27,825	20	5.045	-8	36
Climate Data: Precipitation (Measured in Millimeter)					
Total Precipitation in January	27,825	63	65.504	0	737
Total Precipitation in February	27,825	64	58.642	0	650
Total Precipitation in March	27,825	78	74.797	0	997
Total Precipitation in April	27,825	81	64.557	0	675
Total Precipitation in May	27,825	88	63.039	0	506
Total Precipitation in June	27,825	89	69.654	0	762
Land-Use Data					
Crop Acreage (in acre)	26,355	827	1,296.92	0	5,750
Grass-Land Acreage (in acre)	26,355	4,337	1,586.53	8	6,200
Percentage of Crop Acreage	26,355	0.133	0.209	0	0.927
Percent of Grass-Land Acreage	26,355	0.701	0.255	0.0013	1
Wind Turbine Data: Within 400 Meters Radius					
Number of Wind Turbines	52,059	0.036	0.706	0	31
Average Height of a Wind Turbine (in meters)	52,049	0.568	8.208	0	150
Average Height of the Tower (in meters)	52,049	0.375	5.406	0	100
Average Length of a Blade (in meters)	52,052	0.191	2.787	0	50

Table 1: Summary Statistics of Data (continued)

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Average Rotor Diameter (in meters)	52,052	0.385	5.625	0	102
Average Rotor Swept Area (square meters)	52,052	25.043	381	0	8,336
Wind Turbine Data: Within 800 Meters Radius					
Number of Wind Turbines	52,059	0.078	1.362	0	59
Average Height of a Wind Turbine (Meters)	52,025	0.742	9.331	0	150
Average Height of the Tower (Meters)	52,025	0.489	6.133	0	100
Average Length of a Blade (Meters)	52,028	0.251	3.182	0	50
Average Rotor Diameter (Meters)	52,028	0.505	6.427	0	103
Average Rotor Swept Area (Square Meters)	52,028	32.727	436.055	0	8,380

Table 2. The Poisson Fixed Effect Estimation Results (Pacific Region)

	400-Meters Radius Around a Route			800-Meters Radius Around a Route		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Wind Turbines	-0.098**	-0.058*	-	-0.019	-0.006	-
	(0.046)	(0.031)		(0.017)	(0.009)	
Area of a Wind Turbine (Sq. Meters)	-	-	0.00002**	-	-	-0.000003
			(0.000008)			(0.000002)
Tower Height (Meters)	0.222**	-	0.251**	0.148	-	0.146
	(0.089)		(0.103)	(0.099)		(0.104)
Blade Length (Meters)	-	0.183**	-	-	0.082	-
		(0.073)		-	(0.056)	
Grass-land Acreage (%)	-0.181***	-0.181	-0.181	-0.183	-0.182	-0.181
	(0.371)	(0.371)	(0.371)	(0.373)	(0.373)	(0.373)
Temperature in March (Average)	-0.034	-0.034***	-0.034***	-0.034***	-0.034***	-0.034***
	(0.012)	(0.012)	(0.012)	(0.011)	(0.011)	(0.011)
Temperature in April (Average)	-0.019***	-0.019	-0.019	-0.019	-0.019	-0.019
	(0.021)	(0.022)	(0.022)	(0.021)	(0.021)	(0.021)
Temperature in May (Average)	-0.027	-0.026***	-0.026***	-0.027***	-0.027***	-0.027***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Rainfall in March (Average)	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Rainfall in April (Average)	-0.0007	-0.0007	-0.0007	-0.0007	-0.0007	-0.0007
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Rainfall in May (Average)	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)

Note: Robust standard errors are shown in parentheses. * Significant at 10%; ** Significant at 5%; *** Significant at 1%.

Table 3. The Poisson Fixed Effect Estimation Results (North East Region)

	400-Meters Radius Around a Route			800-Meters Radius Around a Route		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Wind Turbines	-0.0039**	-0.004**	-	-0.002**	-0.001**	-
	0.0015	0.001		0.0007	0.0007	
Area of a Wind Turbine (Sq. Meter)	-	-	-0.0000006**	-	-	-0.0000002**
			0.0000002			0.0000001
Tower Height (Meter)	0.0007*		0.0007**	0.0007*	-	0.0007**
	0.0003		0.0004	0.0003		0.0003
Blade Length (Meter)	-	0.001*	-	-	0.001*	-
		0.0006			0.0006	
Grass-land Acreage (%)	0.202	0.202	0.203	0.203	0.203	0.202
	0.831	0.831	0.831	0.831	0.831	0.831
Temperature in March (Average)	0.027**	0.027***	0.027***	0.027***	0.027***	0.027***
	0.009	0.009	0.009	0.009	0.009	0.009
Temperature in April (Average)	0.006	0.006	0.006	0.006	0.006	0.006
	0.016	0.016	0.016	0.016	0.016	0.016
Temperature in May (Average)	-0.073***	-0.073***	-0.073***	-0.073***	-0.073***	-0.073***
	0.021	0.021	0.021	0.021	0.021	0.021
Rainfall in March (Average)	-0.0009***	-0.0009***	-0.0009***	-0.0009***	-0.0009***	-0.0009***
	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Rainfall in April (Average)	0.0012***	0.001***	0.001***	0.001***	0.001***	0.001***
	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
Rainfall in May (Average)	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005
	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004

Note: Robust standard errors are shown in parentheses. * Significant at 10%; ** Significant at 5%; *** Significant at 1%.