

Article

# Explanations for Wind Turbine Installations: Local and Global Environmental Concerns in the Central Corridor of the United States?

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**Abstract:** Even where physical conditions appear perfectly suited for wind power production, there is significant variation in the number of turbines installed. This pattern suggests that physical conditions are a pre-requisite for, but not a determinant of, that production. This study reports the results of an analysis of the county-level correlates of wind power installations in the north–south corridor of the central United States, which contains much of the country’s greatest land-based wind resources. This study focuses on the relative effects of social capital, global climate change concern, and local biodiversity, while controlling for other potential explanations that previous research has identified as leading to support for or to opposition to turbine installation. We find (1) that greater local biodiversity is associated with fewer turbine installations; (2) that the percent of the public who believe humans are causing climate change is not associated with the number of installed turbines; and (3) that a higher degree of county-level social capital is associated with fewer installations. These findings suggest the predominance of local considerations over global ones when it comes to the actual siting of turbines.

**Keywords:** wind power; turbine installation; social capital; globalist; localist worldview



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## 1. Introduction

Widespread concern with global climate change has led to the development of a variety of non-carbon-based alternative energy modes and technologies (AETs). Those AETs include solar, wave, hydroelectric, geothermal, and both onshore and off-shore wind turbines, as well as others (such as biofuel and nuclear energy) whose AET status remains debated. The geographic siting of those technologies ranges widely across the United States, often depending on the degree to which particular physically amenable conditions are present in specific locations. Thus, it is evident that wave energy is more likely to be produced in coastal areas, solar energy in sunny areas, hydro-energy where more rivers are located, geothermal power where active subsurface heat is found, and wind energy where high velocity air movement occurs. Nonetheless, even where physical conditions may seem perfectly suited for such AET production, one often finds significant variation in their actual installation and use [1,2].

In this context, this paper reports the results of an analysis of the county-level correlates of land-based wind power installations in the north–south corridor of the central United States. This research focuses on the relative effects of social capital, global climate change concern, and local biodiversity, while controlling for other potential explanations that previous research has identified as leading to support for or to opposition to AETs.

While climate change concerns and resource depletion patterns fuel much of the social and political pressure for alternative energy technologies, there often are other benefits identified as well. For example, alternative energy technology development may include economic incentives for local communities and individuals, such as payments for land lease

and support for planning and development or for long-term management and maintenance. Unexpectedly, though, while global environmental change often drives support for AET development, opposition to AETs is frequently rooted in pro-environmental concerns as well [3]. That is, opponents of AET projects often focus on possible local negative environmental impacts of AET installation and use, such as harm to endangered species, rather than on more global positive ramifications [4]. Moreover, both support for or opposition to large-scale AET projects may be driven by collective (e.g., social capital) and individual dynamics (e.g., economic rewards).

As context, in 2020, wind-powered turbines generated 26 percent of the renewable energy consumed in the United States. By share of electricity produced, this makes wind power the largest of the AETs deployed in the United States, surpassing in 2019 the amount generated from hydroelectric sources [5]. Despite the consistent growth in wind energy production since the early 2000s, considerable potential remains untapped. A disproportionate amount of that untapped land-based potential is located in six US states that together comprise the country's central north-south corridor: Texas, Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota [6]. This region is thus of particular importance in the United States' energy transition.

Thus, the central questions addressed in this paper include: (1) Are the correlates of levels of county-aggregated wind power installations in the central US corridor consistent with those found in other prior individual and aggregate studies of the same relationships, in particular with respect to the roles of political, social, economic, and geographic conditions? (2) Are there significant relationships between the relative presence of globalist or localist environmental perspectives and the differences in the county-level rates of the installation of wind turbines in counties? Additionally, do those relationships exist even for counties that otherwise share a number of other attributes that are correlated with such an installation? (3) Are county levels of social capital associated with greater or lesser levels of wind turbine installation?

## 2. Review of Literature and Hypotheses

The research and findings presented in this paper are structured around two sets of hypotheses, major and minor. The major hypotheses reflect the core motivating concerns of this study in the context of its central and significant contributions, namely: the contrasting role of globalist and localist environmental concerns; the role played by social capital; the motivating force of economics; and the political and institutional constraints within which wind power installations must operate. The minor hypotheses focus primarily on fundamental conclusions reached in prior research as to correlates of wind power turbine installation and which we employ as fundamental statistical controls for the effects found in testing the major hypotheses.

### 2.1. Major Hypotheses

Our first major hypotheses concern the relative importance that ideas of "place" have on perceptions of the various environmental effects of wind power production. Although over the past three decades a large research effort has been directed towards examining the acceptance of wind turbines and other AETs [3,7], our assessment adds value to this on-going conversation. Unlike prior research, we examine the simultaneous effects of globalist and localist environmental variables. We define globalist motivations as driven by the pursuit of public benefit, broadly considered, which in the current context directly reflects the aggregate beliefs that humans are causing climate change. This is a pervasive and highly public rationale expressed for investment in alternative energy technologies [8]. On the other hand, localist motivations often emphasize proximate costs and benefits and prioritize local sovereignty over decision-making [9]. In the current context, localist motivations focus on the perceived negative effect that wind power installations might have on site-specific ecological attributes in the community in which the AET would be installed [2]. Assessing the independent and simultaneous effects of globalist and localist

variables will provide evidence for understanding the areal correlates (local or global) of potential sources of support for windfarm installations. That evidence will reflect on likely appropriate strategies for the successful installation of the turbines. Thus, we hypothesize that:

**Hypothesis 1 (H1a).** *Counties with greater aggregate globalist public beliefs will have relatively more wind power turbines.*

**Hypothesis 1 (H1b).** *Counties with a greater presence of site-specific ecological attributes that have the potential to be negatively affected by wind power turbines will have relatively fewer installed.*

A second major hypothesis concerns the effect of social capital on AET installation. Like many other large scale AETs, wind installations are often perceived as generating relatively immediate cost and risks, to be borne by the host community, while producing mostly private rents and long-term globally public benefits [10]. In light of this, past studies indicate that a community's social capital, or trust-based networks, is often influential in shaping the relative acceptance of wind projects and can be activated via public engagement in the planning and implementation processes [11,12]. These studies note that a transparent, fair, and participatory process provides community members with information needed for decision-making and offers them a fuller role in negotiations [11,13–15]. Project negotiations, in turn, leverage local social capital in the form of participation, trust, and investment [16].

Yet, in the case of AET installations, the presence of strong social capital or community networks could lead towards differing outcomes. On the one hand, high levels of social capital may be associated with a larger number of installed wind turbines in a county. Some research indicates that social capital and frequent communication decrease freeriding and increase individuals' contributions to the production of public goods [17]. Wind turbines produce clean renewable energy, a global public good, and thus the residents of counties with higher social capital may be expected to be more welcoming to their installation. On the other hand, organized opposition to wind farms may be strengthened by efforts and communication channels, enabled by strong pre-existing social networks. Thus, county-level social capital may be associated with a smaller number of installed wind turbines. Because we have no a priori reason to expect that the impact of social capital will be net positive or net negative, we present two contrasting hypotheses:

**Hypothesis 2 (H2a).** *Counties with greater social capital will have relatively more wind turbine installations.*

**Hypothesis 2 (H2b).** *Counties with greater social capital will have fewer wind turbine installations.*

Although, in the extant literature, social factors at times seem to yield conflicting explanatory effects, perceptions of the individual and collective economic benefits that wind farms generate are consistently strong covariates with local support for their installation [18–20]. Although wind power projects have been found to create the most economic benefit in the locations that manufacture turbine and construction inputs, economic benefits also accrue in host communities. These include: jobs during installation and operation, property tax revenue, lease payments to landowners, reduced energy bills, and community funds [14,21,22]. Lease payments, which can range between USD 3000 and USD 7000 per turbine per year, provide a consistent stream of income and are particularly important for farmers and ranchers struggling with unpredictable weather and commodity prices [23]. Such economic benefits are expected to have the greatest influence in areas with greater economic distress, a stronger farming economy, and a greater amount of agricultural land providing the space and resources for turbine installations. Thus, we hypothesize that:

**Hypothesis 3 (H3).** *A larger number of wind power turbines are installed in counties where economic need is greatest.*

The institutional and procedural environment also has an effect on turbine installation patterns. Much of the research on the politics of turbine acceptance in the US hinges on the transparency and degree of engagement in the planning process. The level of procedural fairness perceived by the public influences participation, trust, and consensus in the acceptance of a wind farm [11,12]. Political efficacy, i.e., the perception that participation makes a difference, has been used to explain the strength of public participation [24]. In an important article published over 20 years ago, Wolsink (2000) argued that more scholarly attention should focus on institutional constraints, suggesting that top-down policy style, ineffective planning, and the difference in political efficacy and activity between the public, stakeholders, and interest groups are the missing links to understanding gaps in wind implementation. More recently, Wolsink (2018) reiterated the continued under-examination of the role institutions play in shaping wind power acceptance [25]. Indeed, the locus of siting control may be an important factor determining the extent of county-level wind energy development. Across the United States, there is variation in whether the state government or local governments have authority over installation siting decisions. A third set of states use a “hybrid” authority model, which requires approvals from both state and local regulators [26]. Understanding that there may be a negative influence on wind farm installation due to top-down approval structures, we hypothesize that:

**Hypothesis 4 (H4).** *Counties with local siting control have a smaller number of wind turbine installations.*

Although we hypothesize that the need for state-level approvals of individual installations may act as a barrier, other state-level policies may act as accelerants. Most notably, Renewable Portfolio Standards (RPSs) require that a specified minimum percent of the electricity sold by utilities be generated from renewable sources. State RPSs vary on numerous dimensions including the percentages they specify, what clean energy sources are acceptable, target dates, and whether they are mandatory or voluntary. More stringent RPSs are found to increase renewable energy capacity at the state level [27]. However, it is unclear whether mandatory RPS targets, which are enforceable with penalties, lead to significantly more installed capacity than do voluntary targets, which rely on political signaling [28]. We thus hypothesize that:

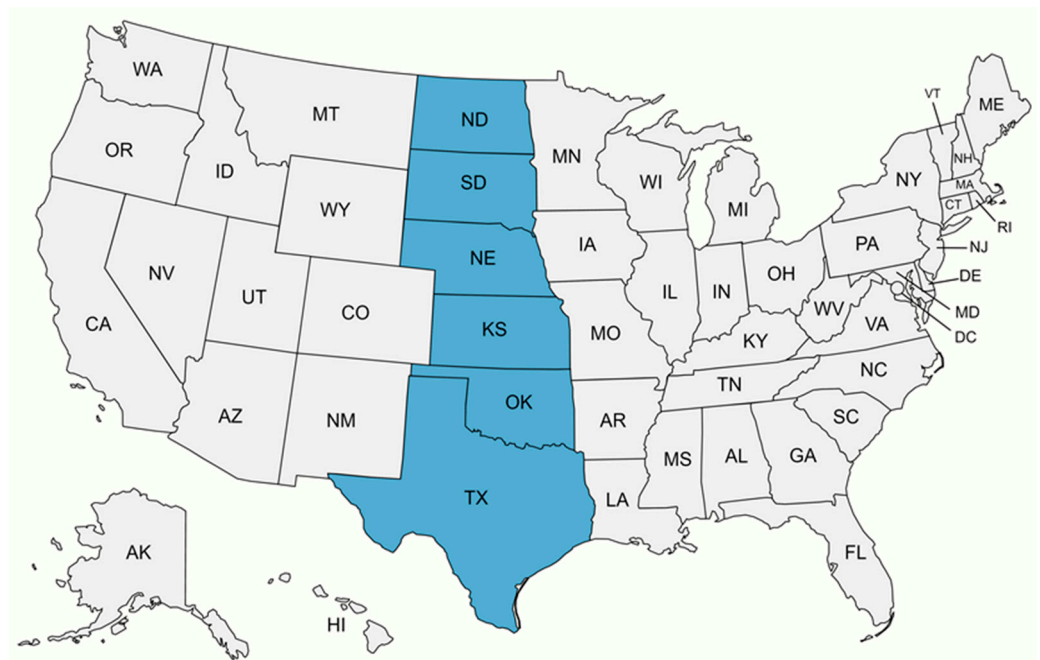
**Hypothesis 5 (H5).** *Counties in states with renewable energy portfolio standards have a greater number of wind turbine installations.*

## 2.2. Minor Hypotheses

In addition to these primary hypotheses regarding the impacts of social capital, climate change attitudes, localist environmental concerns, economic considerations, and institutional structures, other potential correlates of wind power installation would include such previously researched factors as: available wind velocity (the greater the velocity, the greater the hypothesized number of turbines); population density (the greater the density, the lower the relative hypothesized number of installed turbines); internet connectivity (the greater the internet connectivity, the greater the hypothesized number of installed turbines reflecting greater pre-existing connections to transmission lines—albeit a different kind of line); and aggregated citizen educational level (the greater the citizen educational level, the greater the hypothesized number of wind turbines). We include these variables in our models as controls for the independent effects of our primary variables, as well as for confirmation (or not) of the consistency of the results from this study with prior research.

### 3. Sample and Data

We examine these hypotheses in the central geographic corridor of the United States, the area with the greatest wind potential on the continent [6]. Specifically, we consider the 648 counties contained in the US states of Texas, Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota (see Figure 1). As of early 2020, 244 of the counties in these states had at least one operating turbine. The maximum number of turbines in any single county was 1374 (Nolan County, TX, USA). Of the sample counties, 404 do not have any turbines installed, even if they possess great wind potential. Moreover, a majority of wind turbines are located on unincorporated county land (i.e., land outside city boundaries), making counties an appropriate unit of analysis for this study.



**Figure 1.** United States map indicating states in central corridor.

The number of turbines in each county in 2020, per the US Geological Survey Wind Turbine Database, serves as the dependent variable in our model. The independent variables examined here come from a range of archival sources, as described in Table 1, and represent a variety of social, physical, and policy variables. Per our hypotheses, the focal explanatory variables are the degree of social capital in each county, residents' dominant beliefs about climate change and the percent of each county's land area that has significant biodiversity. The estimated percent of county residents who believe humans are mostly responsible for causing global warming and the percent who voted for the Democratic presidential nominee in the 2016 election correlate at 0.86. As a result of this high correlation, we do not include voting returns in the model. Table 2 presents the bivariate correlations between all of the variables contained in the model. It shows a low to modest association between the variables in the model, with none of them exceeding a correlation of 0.55.



Table 2. Cont.

	1	2	3	4	5	6	7	8	9	10	11	12	13
4. Farming Economy	0.02	0.51	0.12	1.00									
5. Education	−0.03	0.05	0.36	−0.12	1.00								
6. Internet connectivity	−0.04	0.13	0.22	0.03	0.06	1.00							
7. Climate change belief	−0.01	−0.40	−0.14	−0.12	0.10	0.06	1.00						
8. Avg wind power	0.13	0.54	0.30	0.45	0.06	0.25	−0.09	1.00					
9. Land area	0.12	−0.05	−0.03	0.04	−0.02	0.00	0.24	0.13	1.00				
10. Population density	−0.07	−0.23	0.09	−0.20	0.41	−0.01	0.29	−0.26	−0.07	1.00			
11. Biodiversity	0.16	−0.43	−0.36	−0.31	−0.11	−0.17	0.12	−0.54	0.10	0.12	1.00		
12. State RPS policy	0.06	−0.19	−0.20	−0.18	−0.04	−0.09	0.13	−0.18	0.02	0.07	0.70	1.00	
13. Siting control	−0.12	0.20	0.18	0.20	0.04	0.08	0.00	0.23	0.04	−0.07	−0.56	−0.36	1.00

#### 4. Methods and Results

A count of the number of turbines in each county serves as the dependent variable. However, because 62% of the counties have no wind turbines, there is an excessive number of zeros, causing the dependent variable to be over-dispersed (mean = 45.09, variance = 11,818.3). Moreover, there are likely to be different dynamics at play in the counties that do not have any turbines. For example, some counties may not have wind turbines because they do not have sufficient wind power to support their operation, while others may have enough wind power, but have not experienced investment conducive to their installation, such as establishing access to transmission lines. In this case, the first category of counties can be considered “certain zeros”, whereas the lack of turbines in the second category is a result of a different set of reasons. A zero-inflated negative binomial (ZINB) model accounts for this complication by combining a logit distribution and a negative binomial distribution [38]. It jointly estimates an inflate model, which here uses logistic regression to predict the probability of seeing a county with no opportunity for turbine installation, along with a response model, which uses a negative binomial model to predict the number of turbines in each county where opportunity exists. The formal notation of a ZINB is:

$$\Pr(y_i = 0 | x_i, z_i) = \Psi_i + (1 - \Psi_i)f(x_i\beta) \quad (1)$$

where this predicts the probability of always seeing a zero, and

$$\Pr(y_i > 0 | x_i, z_i) = (1 - \Psi_i)f(x_i\beta) \quad (2)$$

predicts the number of nonzero observations, given that  $\Psi_i = G(z_i\gamma)$  [39].

Table 3 shows the results of the ZINB model. Looking first at the inflate model, the spatial average of the wind power class in each county is used to predict that county’s membership in the “certain zero” group. As expected, counties with a higher average wind power class are significantly less likely ( $\alpha = 0.01$ ) to be in the certain zero group. Specifically, for each one point higher that a county’s wind power average is on the seven-point wind power scale (i.e., a 14% increase), the likelihood that it would be in this certain zero group decreases by  $\exp(0.450)$ , or a factor of 1.57.

In the count model, average wind power is significantly and positively associated with the number of turbines in a county. Thus, among counties that may have turbines, those with greater wind power are predicted to have more. However, of the six social and economic variables in the model, only social capital is significantly associated with wind turbine installation. All else equal, counties with higher levels of social capital have fewer turbines. A higher population density and a larger proportion of county land area characterized as having important biodiversity are also significantly associated with a smaller number of turbines. Finally, all else equal, there are more turbines in counties in states with Renewable Portfolio Standards.

Reflecting on our central hypotheses, two of the study's three focal variables have a statistically significant negative impact on county-level turbine count: social capital and biodiversity. The third central independent variable, the percent of each county's residents that agree that human activities are mostly responsible for climate change, is not significantly associated with the number of installed wind turbines. Although not presented in this model, interaction terms between social capital and biodiversity and social capital and climate change beliefs are insignificant and their inclusion reduces the overall fit of the model.

**Table 3.** Factors influencing the number of wind turbines present in each county.

Count Model		
Social capital	−0.187 **	(0.08)
Economic distress	−0.004	(0.04)
Farming economy	0.121	(0.19)
Educational attainment	0.008	(0.02)
Internet connectivity	−0.427	(0.26)
Climate change beliefs	−0.011	(0.02)
Avg wind power	0.296 **	(0.12)
Land area	0.000	(0.00)
Population density	−0.212 ***	(0.05)
Significant biodiversity	−0.013 **	(0.01)
State RPS policy	0.546 **	(0.24)
Siting control	−0.219	(0.26)
Constant	4.281 ***	(1.24)
Inflate model		
Avg wind power	−0.450 ***	(0.08)
Constant	1.698 ***	(0.11)
$n = 648$ , Non-zero $n = 244$		
$LR \chi^2 = 61.58$ (0.000)		

Zero-inflated binomial. Standard errors in parentheses. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

## 5. Discussion and Conclusions

Five of the independent variables in the model above exhibit significant effects on wind turbine installation numbers. Several of the effects are expected and make considerable sense. There are more wind turbines where there is greater average wind velocity, meaning where the resource is greater, the potential for wind energy is also greater, and thus there is more to gain both economically and efficiently from the installation of turbines. Moreover, the greater the population density, the lower the number of wind turbines, likely reflecting the lesser availability of the acreage needed to install the turbines in a number that would make them more economically viable. Additionally, one might expect that greater population density may be associated with an increased possibility of a critical mass of individuals opposed to their installation.

Perhaps most interesting is the contrasting relationships of the presence of a significant negative effect of biodiversity on the one hand, and the absence of a significant effect of the relative presence of citizen beliefs that humans are the cause of climate change on the other hand. As former Speaker of the U.S. House of Representatives, Tip O'Neill, famously stated, "all politics is local" [40], and so might it be in the siting of wind farms, since the biodiversity effect measure focuses on local environmental conditions. For many in the host community, the immediacy of the possible negative impact of windmill installation sites on those local conditions surely could override the more diffuse consequences of human impact on climate change, even in the face of the reciprocal potential negative effects of climate change on humans.

Social capital also has a surprisingly negative effect on windmill siting, suggesting that networks are used to oppose wind turbine siting. Those oppositional networks are likely to be of at least two forms. First, the networks may be formed from local community

members who are simply opposed to the wind turbines, perhaps for aesthetic reasons, or for the particularistic selective economic benefits to be distributed to land owners whose property will be sited for the installations. Second, the social capital effects may be linked to community opposition to the perceived effects of the wind farm installations on sensitive local biodiversity. Those putative local negative effects would provide selective incentives for community members either to organize in opposition or to mobilize existing networks in opposition. Recall, though, that the effects of social capital and biodiversity interaction are non-significant in explaining the variations in the number of installed wind turbines. Looking closely at place at the state level indicates the importance of policies like RPSs, but looking at place at the county level indicates the importance of networks to the windmill siting equation as well. Place matters.

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