Title: Localized Distributional Injustice: Wind Energy Siting in the Continental United States

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Abstract:

The distribution of the burdens of energy development, relative to the benefits, is a primary concern of sustainable energy development. Thus, energy justice has become a key framework for understanding these concerns. In this paper, we evaluate the current landscape of wind energy development in the continental United States as it relates to energy justice. Through the use of logistic regression and fixed effects we evaluate the social factors currently associated with existing wind energy infrastructure at three spatial scales: the nation, the state, and the county. We find little evidence of distributional injustice related to wind energy at the national or state level. However, when considering census tracts within counties, three variables suggest localized distributional injustice. We find that wind energy is more likely to be sited in areas with lower education, fewer people in the labor force, and lower population density.

Keywords: Environmental justice, Energy justice, Wind farms, Renewable energy, Wind energy, Multilevel model, United States

Distributional justice related to the siting of energy infrastructure and other locally unwanted land uses is a topic of concern for sociology (Jenkins et al. 2016; Mohai and Saha 2015; Sovacool and Dworkin 2015), and while the framework used to analyze and discuss this topic has been termed environmental, or energy, justice, it is more often *in*justice that is the actual concern. Distributional social injustices occur when the costs and benefits of a given action are unevenly distributed throughout the population (Jenkins et al. 2016). In the case of energy injustice, this means that the burden of energy production is felt disproportionately by one segment, or a few segments, of the population in terms of either geography or social groups. Historically, injustices related to the siting of locally unwanted land uses have fallen along societal divisions of both class and race (Brulle and Pellow 2006). In our paper we focus specifically on the distributional injustice that may be present in the current landscape of wind energy development, specifically in relation to existing wind turbines. The purpose of this study was to investigate the current landscape of wind energy infrastructure as it relates to distributional injustice in the contiguous United States at three spatial scales: the nation, the state, and the county.

Wind energy, unlike many other forms of energy development, has experienced a unique ‘social gap’ in public support for development (Bell et al. 2013; Devine-Wright 2005). This gap is marked by widespread public support for increased wind energy development, but considerable and unrelenting localized opposition to many proposed wind farms. Thus, although recent polls suggest that as much as 85% of Americans support increased wind energy development in the United States (Pew 2018), significant opposition to the actual siting of this infrastructure persists (Giordono et al. 2018).

Ultimately, this difficulty in siting is reflective of the efforts of local citizens to resist wind energy development. The consistent, and often successful resistance to wind energy development provides the motivating question of our analysis:

> Are wind turbines currently sited disproportionately in areas with lower relative advantage in society?

Localized resistance to any locally unwanted land use requires significant social and financial capital (Been 1992; Mohai and Saha 2015). Therefore, it is possible that wind energy development, much like toxic waste dumps and other unwanted land uses (Agyeman et al. 2016; United Church of Christ. Commission for Racial Justice 1987), has been disproportionately sited in areas where residents have lower social and financial capital. Thus, placing the cost and burden of wind energy development on groups historically oppressed and disempowered in American society.

We approach our motivating question with a multi-scalar sub-national approach. We view this approach as an answer to Lobao et al.'s (2008) call for more attention at the subnational scale, meaning the scale missing between nation-state focused and locally focused sociology. Scale matters in sociological research and the scale at which we assess issues of inequality, environmental or otherwise, can have a significant impact on our results (Nelson and Brewer 2017; Tickamyer 2000). This issue is known as the modifiable areal unit problem, wherein results are in many ways a product of the chosen scale of analysis (Fotheringham and Wong 1991; Nelson and Brewer 2017). Due to the smoothing effect of aggregation, the choice of boundaries, by definition, has an impact on results. To avoid this pitfall, we answer our motivating question by estimating and comparing models of energy injustice at different levels of geographic aggregation and scale. In particular, we investigate distributional wind energy injustice associated with the social dimensions of age, income, ethnicity/race, education, labor force participation, and rurality at three spatial scales: the nation, the state, and the county.

BACKGROUND

Energy and Environmental Justice

The framework of energy justice emerged from environmental justice, which developed out of the historical siting of environmental hazards, energy infrastructure, and other locally unwanted land uses in areas predominately inhabited by marginalized populations (Brulle and Pellow 2006; Sovacool and Dworkin 2015). Environmental justice is defined by Bullard and Johnson (2000) as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (p.558)." Fair treatment explicitly refers to the belief that no group of people should bear a disproportionate share of the negative environmental consequences that may arise from either regulations, programs or the siting of facilities (Bullard and Johnson 2000). Importantly, the term justice implies injustice, wherein the fair treatment and meaningful involvement of all people does not occur. It is injustice that we focus on in our analysis.

There are three main theoretical explanations for the unjust siting of unwanted infrastructure: economic, social, and racial (Mohai and Saha, 2015). The economic perspective argues that the pattern of uneven infrastructure siting is largely the result of industries finding it cheaper to do business in geographic areas inhabited by those who are historically disadvantaged in American society, such as people of color and the poor.

Thus, in this framework societal discrimination is obviously a factor, but the direct cause of injustice remains economic. The sociopolitical perspective has to do with the “path of least resistance.” This framework argues that those siting unwanted infrastructure will often choose areas where effective protest is unlikely (Been 1992; Mohai and Saha 2015). This perspective acknowledges that industries siting locally unwanted land uses know they face costly opposition, and therefore choose to target areas with lower social and financial capital where local opposition has historically been less effective.

The final explanation for the disparate siting of hazardous and unwanted land uses is racial discrimination. Environmental racism is the most prominent dimension of environmental injustice in the United States, remaining at the forefront of discussion since the start of the movement (United Church of Christ. Commission for Racial Justice 1987). While there remains a debate as to whether intentional racial discrimination is the cause of disparate siting, the consistent findings of unjust distribution make structural environmental racism hard to deny. Even if outright racial animus is not present, siting choices may still be made in communities of color due to the sociopolitical reasons described above (Mohai and Saha 2015). This results in what (Mohai and Saha, 2015) call side effect discrimination, or “discrimination in one area of institutional actions leading to discriminatory outcomes in another, even if there is not intent to discriminate in the other (p. 3).” Ultimately, it is not just one of these perspectives that is the cause of environmental, or energy, injustice, but rather a combination of these dimensions that leads to the persistent environmental injustice faced by marginalized portions of society.

The framework of energy injustice is largely in keeping with that of environmental injustice, except that its focus is explicitly on that of energy development and energy supply (McCauley et al. 2013). There are three main forms of energy injustice: distributional, recognition, and procedural (Jenkins et al. 2016; McCauley et al. 2013). Although this paper only directly considers distributional injustice, we briefly outline all three forms here. Distributional injustice refers to the unequal distribution of the costs and benefits of energy development (Fuller and McCauley 2016), meaning the burdens of energy development are unfairly placed on one, often marginalized, segment of society. A related, but alternative form of injustice is recognition injustice (Walker and Day 2012). This is the failure of society to treat some groups of people with equal respect, thus not giving them recognition as full members of society and resulting in stigmatization, inequality, and injustice.

The final prominent dimension of energy injustice is procedural injustice (Jenkins et al. 2016). Procedural justice represents unequal access to the process of decision-making that occurs concerning energy development for all segments of society. In addition to access to the decision-making process, procedural injustice also involves the incomplete disclosure of information on various forms of energy development, which forms of energy development receive subsidies, and any plans for future development (McCauley et al. 2013).

As stated, in this paper we specifically explore distributive injustice related to the siting of wind energy infrastructure along six dimensions of societal (dis)advantage historically shown to be associated with environmental injustice: income, race and ethnicity, age education, and labor force participation, and rurality. While the presence of distributive injustice may suggest issues of recognition injustice, we are not explicitly assessing that in our analysis. Additionally, as we evaluated the presence of injustice, and not the delivery of justice, this study was not a study of energy justice. Rather, we studied energy *in*justice. While this distinction may seem trivial, or semantic, it is an important distinction to make so that we preserve the term ‘energy justice research’ for those studies which either deliver, or assess the delivery of, energy justice to those who have previously been treated unjustly.

Wind Energy

Wind energy has experienced rapid growth throughout the United States from the early 2000s to today (U.S. Department of Energy 2015), with its contribution to meeting the total electricity demand growing from 1.5% to 4.5% in the period from 2008 to 2013 alone. The growth has continued, and the wind energy industry has been successful at building over 57,000 wind turbines throughout the contiguous continental United States (Figure 1; Hoen et al. 2018). While this growth has continued, resulting in wind turbines being located in 615 counties, the siting of specific wind farms remains highly localized when considering the within-county level. Figure 2 presents an example of this localized siting among four counties in Central Pennsylvania.

[Figure 1 here]

[Figure 2 here]

The land required for wind energy can be significant. Under the current goal of wind energy meeting 20% of U.S. electrical demand, the estimated land area required for on-shore wind energy will reach 50,000 square kilometers, or 19,305 square miles, by 2030 (Wilburn 2011). However, in the case of wind it is important to distinguish between the total wind plant area, meaning the total area occupied by an entire wind farm, and the direct impact area, meaning the actual impact on the ground of individual turbines and support infrastructure (Denholm et al. 2009). Wind energy's presence on the landscape can be diffuse, meaning that the entire square footage of an average 100 turbine wind power plant, or wind farm, occupies around 5,175 hectares, or 20 square miles. However, the direct impact of the wind turbines will only occupy about 150 hectares, or 0.57 square miles (Wilburn 2011). Thus, unlike some other forms of energy development, it is possible for activities such as farming, grazing, or other land uses to occur alongside wind energy development.

Unlike other forms of energy production, the negative impacts associated with wind energy are somewhat more intangible. The most frequently cited concerns of wind turbines include visual impacts from landscape disruption, auditory impacts from the noise generated by rotating turbines, and wildlife impacts due to animals flying into rotors (Saidur et al. 2011). However, the habitat and wildlife related impacts from wind turbines are smaller than impacts from other forms of energy such as coal and oil. A potentially more significant negative impact of wind turbine proximity is that of noise pollution (Pedersen 2011; Saidur et al. 2011). The constant noise associated with wind turbine proximity has been linked to lower sleep quality (Shepherd et al. 2011) and annoyance (Pedersen 2011; Pedersen and Waye 2007). While concerns of chronic stress due to wind turbine noise have been raised as a concern, no peer-reviewed literature has demonstrated this effect (Knopper and Ollson 2011; Michaud et al. 2016).

Wind turbines have commonly been associated with increased annoyance among nearby residents and a large portion of the variation in annoyance due to wind turbine noise has been attributed to visual impacts of wind turbines (Pedersen and Waye 2004).

This visual impact, wherein the implementation of a wind farm disrupts the existing landscape, is a common complaint levied at wind energy development (Bell et al. 2013). But it should be noted that dissatisfaction with wind development is often deeper than simply ‘Not in My Backyard’ visual concerns. Pedersen et al. (2007) found that residents viewed wind energy development as an intrusion and expressed a sense of powerlessness surrounding development. Additionally, the implementation of a large-scale landscape change can impact deep place attachments, which are tied to living in a specific place the way it has historically been known (Bell et al. 2013). This landscape change may cause disruption and what Albrecht et al. (2007) have termed ‘solastalgia’, the feeling of homesickness and distress caused by the radical change of the home environment. Overall, while ‘by the numbers’ wind energy development may have a smaller impact on both communities and the environment than other forms of energy development, its qualitative impacts to both sense of place and individual lives may remain quite significant.

The impacts we have outlined have contributed to what is known as the social gap in wind energy siting (Bell et al. 2013). For example, in the United Kingdom over 80% of residents support increased wind energy development, but only 25%-50% of proposed projects are successfully implemented (Bell et al. 2013). In the United States, the context of this study, as much as 85% of residents support increased wind energy development, but local opposition to specific projects persists (Pasqualetti 2011; Pew 2018). In an analysis of 53 wind energy proposals in the western United States, Giordono et al. (2018) found some form of local opposition occurred to 43 of the 53 proposals. While three or more forms of local opposition only occurred in 19 of the 53 proposals, it is unclear if that difference in opposition was due to a true lack of opposition or a simply a local inability to effectively mobilize, which the sociopolitical explanation for environmental injustice would suggest (Mohai and Saha 2015).

THEORETICAL PERSPECTIVE AND HYPOTHESES

Given the significant gap between overall support for wind energy and the consistent local opposition to wind turbine placement (Bell et al. 2013; Devine-Wright 2005; Giordono et al. 2018), it is clear wind represents a locally unwanted land use, much like the sources of toxic pollution identified by the environmental justice movement (Brulle and Pellow 2006; United Church of Christ. Commission for Racial Justice 1987). Thus, our theoretical framework posits that although the negative health impacts of wind energy are less direct than those of toxic waste dumps or other sources of point pollution, the landscape of wind energy will carry with it the same trends of distributional injustice found throughout the environmental justice literature (Agyeman et al. 2016; Brulle and Pellow 2006; Mohai and Saha 2015). Key to this framework are the economic, sociopolitical, and racial explanations for the unjust distribution of locally unwanted land uses (Mohai and Saha, 2015). Therefore, we hypothesize that wind energy infrastructure will be more common in areas with higher aggregate levels of societal disadvantage. This unequal distribution will be due to the sociopolitical explanation, meaning the difficulties of organizing and effectively opposing locally unwanted land uses; the economic explanation, meaning the economic realities of where marginalized groups live and the capitalist orientation of developers; and the racial explanation, meaning the outright, as well as structural, discrimination of marginalized groups by corporations. Thus, through these perspectives on the unjust siting of locally unwanted land uses we test one overall theoretical hypothesis:

> *Hypothesis 1*: Wind energy development is more likely in geographic areas with higher levels of societal disadvantage.

To test this larger hypothesis, we test six sub-hypotheses focused on dimensions of (dis)advantage found in society, and associated with historic distributional environmental injustices.

Income

The inequitable dumping of environmental harms on the poor is one of the most common environmental injustices identified from the start of the environmental justice movement (Agyeman et al. 2016; Brulle and Pellow 2006). Research has consistently found that locally unwanted land uses are more frequent in areas inhabited by poorer segments of society (Mohai and Saha 2015). In their review of socioeconomic status and health, Evans and Kantrowitz (2002) identified that those with lower incomes have been found to be more proximate to hazardous waste, air pollution, water pollution, ambient noise, and residential crowding. While numerous studies have found relationships between injustice and income, it is important to note that the empirical support for this has been found to depend on the source of environmental risk (Ringquist 2005). In a meta-analysis of 34 studies using income measures, this variation caused Ringquist (2005) to assert that, while there is evidence for income-based environmental inequality in the literature, the evidence is weak when considering all available studies. Although the relationship has shown mixed results, the literature suggests that we should generally expect locally unwanted land uses to be more common in areas with lower economic advantage, leading us to propose the sub-hypothesis:

> *Hypothesis 1.1*: Wind energy siting is more likely in geographic areas with lower median income.

Race and Ethnicity

More consistent than the impacts of income on environmental injustice is environmental racism (Brulle and Pellow 2006; Mohai and Saha 2015 2006; Ringquist 2005). In the same meta-analysis by Ringquist (2005), significant and consistent evidence of racial inequity was found across 48 independent studies. Noxious pollutants and other facilities were disproportionately concentrated in communities where residents were more likely to be racial and ethnic minorities. While findings have varied between studies, with some even reporting no racial environmental injustice, Mohai and Saha (2006) showed that many of the studies finding limited effects can be explained by the choice of method. When using explicitly spatial approaches, as opposed to traditional approaches using dichotomous classification of either in proximity of a hazard or not, Mohai and Saha (2006) showed that the estimates of racial environmental inequity become even larger. Given the historically racialized distribution of locally unwanted land uses similar to wind energy, which has occurred through structural racism and outright discrimination, we propose our second sub-hypothesis:

> *Hypothesis 1.2*: Wind energy siting is more likely in geographic areas with higher proportions of non-White and Hispanic residents.

Age

Our hypothesis regarding the relationship between age and the siting of wind energy infrastructure draws less on the environmental justice literature, and more on the literature surrounding community participation in natural resource management (Booth and Halseth 2011; Marshall and Jones 2005). Wind often faces public resistance from concerned local citizens. However, as discussed by Mohai and Saha (2015) and Been (1992), effective resistance requires significant time and capital. Research on the public attendance of community meetings for collaborative natural resource management has shown that attendance at meetings is not representative of the population, with attendees often being older, and more affluent, than the general population (Booth and Halseth 2011; Marshall and Jones 2005). This attendance is reflective of the larger amounts of free time enjoyed by older individuals due to both retirement and a lack of childcare. Given this, we assume that areas with older median ages will have been more effective at opposing wind energy development due to their increased level of time to engage in resistance. We formally state this as:

> *Hypothesis 1.3*: Wind energy siting is more likely in geographic areas with lower median ages.

Education and Labor Force Participation

Our hypotheses concerning education and labor force participation represent an extension of the findings of environmental justice scholarship surrounding income (Mohai and Saha 2006, 2015; Ringquist 2005), as well the necessary conditions for successful opposition to an unwanted land use at the local level. While research has often shown that locally unwanted land uses are disproportionately sited in areas with lower median income, this income is likely to be a reflection of the labor conditions and human capital (e.g. education) in a region. Thus, we would expect wind energy development to be more likely in places with lower labor force participation and lower overall education. Further, research has shown a direct relationship between areas with both lower employment and education and proximity to environmental hazards (Jerrett et al. 2001; Mohai et al. 2009; Cutter et al. 2012). Given this we propose two sub-hypotheses:

> *Hypothesis 1.4*: Wind energy siting is more likely in geographic areas with lower levels of education.
>
> *Hypothesis 1.5*: Wind energy siting is more likely in geographic areas with lower labor force participation.

Rurality

We propose rurality remains an under-explored dimension of both environmental and energy injustice. The spatial inequality faced between urban and rural areas in America has been long documented by researchers (Castle 1993; Tickamyer et al. 2017). Poverty rates have historically been, and continue to be, consistently higher in rural America and economic development has remained stagnant relative to urban areas (Weber and Miller 2017). However, while economic inequality between urban and rural sectors is often acknowledged, urban to rural environmental and energy inequalities have received less attention. Rural areas bear the large share of the burden when it comes to food, natural resource, and energy production (Kelly-Reif and Wing 2016). Thus, rural people are forced to face disproportionate environmental hazards relative to their urban counterparts simply because of their rural residence (Jones, 2011). Recent research has highlighted the important rural dimension of energy justice as it relates to the burdens placed on rural Americans by unconventional natural gas extraction, wherein rural residents endure environmental injustice resulting from procedural injustice, forced lease terms, and corporate bullying (Malin and DeMaster 2016). Further, this relationship is exacerbated at the intersections of rurality and the traditional dimensions of environmental injustice represented in our earlier hypotheses, particularly as it relates to poor rural residents (Kelly-Reif and Wing 2016; Malin and DeMaster 2016).

As stated earlier, wind energy, as currently constructed, does require a significant area of land (Denholm et al. 2009). However, it should be noted that while wind energy is unlikely to be feasible in dense urban areas, due to the diffuse nature of wind impacts and the varying scale at which wind farms can be constructed, wind energy development need not be in the *most* rural and remote areas. When considering the size of counties and census tracts in many parts of the United States, the land area required may often be available in counties traditionally viewed as urban or suburban. Given that wind turbines have the ability to be located at many levels of rurality and population density, if rurality is related to wind energy siting, it represents a form of distributional inequality simply on the basis of an unequal distribution of costs and benefits of energy production. We propose that wind energy will be more likely in rural areas, which we operationalize as population density. This hypothesis draws on both the economic and sociopolitical explanations discussed by Mohai and Saha (2015). In terms of economics, land in rural areas is generally cheaper, making investment more affordable. Related to the sociopolitical perspective, rural residents often live far apart and by definition there are fewer total residents. This makes it more difficult to organize and makes misinformation and the bullying by developers described by Malin and DeMaster (2016) more likely. Given this, we propose one sub-hypothesis related to rurality:

> *Hypothesis 1.6*: Wind energy siting is more likely geographic areas with lower population density.

Scale

In addition to the questions of injustice, we test a methodological hypothesis related to the modifiable areal unit problem (Fotheringham and Wong 1991; Nelson and Brewer 2017). The issue of scale, although often ignored, is important for understanding the relationships between social phenomena (Tickamyer 2000). Due to the unavoidable reality that the results of multiple regression analyses are a product of the chosen scale, we tested our theoretical hypotheses at three narrowing scales to provide a more comprehensive analysis of the current landscape of wind energy injustice in the United States. Given wind energy's relative absence in the energy and environmental justice literature, specific hypotheses as to how models would vary in their conclusions appear inappropriate. However, that the results will vary appears clear:

> *Hypothesis 2*: The findings regarding associations suggestive of energy injustice will vary based upon the scale of analysis considered.

METHODS

Data Sources and Data Collation

For our analysis we collated data from two sources. The United States Census Bureau American Community Survey (ACS) five-year estimates for 2012-2016, and the U.S. Wind Turbine Database (Hoen et al. 2018). We extracted our ACS estimates from the National Historical Geographic Information Systems database hosted by the Integrated Public Use Microdata Series (IPUMS-NHGIS; Manson et al. 2017). ACS estimates were extracted at both the county and census tract level for the contiguous United States.

The U.S. Wind Turbine Database, released to the public in April of 2018, hosts a comprehensive set of information regarding the location wind turbines constructed throughout the United States. The dataset is a collaboration of the United States Geological Survey, Berkeley labs, and the American Wind Energy Association. Although the year of construction is not provided for every turbine, the oldest turbines in the dataset are reported as being built in 1981, and the newest were built in 2018. The dataset contains a total of 57,646 wind turbines across 41 states, as well as Guam and Puerto Rico (Hoen et al. 2018).

To create our master datasets, we extracted the GIS shapefile of all active wind turbine locations in the contiguous United States provided by the U.S. Wind Turbine Database. We then georeferenced each wind turbine to both its county and census tract using ArcGIS. As we were interested in exclusively active inland wind turbines, we excluded the few off-shore or under construction wind turbines reported in the dataset. We then merged our ACS and wind turbine data into two longform master datasets, one for counties nested within states and one for census tracts nested within counties.

Variables of Interest

Independent Variables

The independent variables for this analysis were those sociodemographic characteristics associated with our hypotheses. We incorporated eleven independent variables representing the six sociodemographic dimensions outlined by our hypotheses: median income, race and ethnicity, median age, education, labor force, population density. A number of variables were recoded prior to model testing. Median income was recoded into thousands to increase coefficient interpretation and result presentation. We included the quadratic of median income to account for the possibly non-linear association between median income and wind energy location. We viewed the inclusion of the quadratic as a solution to the issue of including poverty and income within the same model. Due to their high level of correlation, including both income and poverty would have introduced multi-collinearity into our model. However, given the possibility that the association between income and wind siting may vary at extremely high and low levels of income, we include the quadratic term.

We represented ethnicity and race with three percentage variables: percent Hispanic, percent non-Hispanic Black, and percent non-Hispanic other. Non-Hispanic other was created by adding together the categories of non-Hispanic American Indian or Alaska Native, Non-Hispanic Asian, non-Hispanic Native Hawaiian or other Pacific Islander, non-Hispanic Other, and non-Hispanic multiple racial groups. We did not include percent non-Hispanic White to avoid our percentage variables coming close to summing to one and introducing multi-collinearity into our model. For our education term we collapsed education into a single percentage variable, percent of the population with a bachelor's degree or higher. We included two measures of labor force participation: percent unemployed and percent not in the labor force. Finally, we also included population per square kilometer as a way to assess whether the burden of wind energy is disproportionately placed on those residing in more rural areas.[1]

Dependent Variable

The dependent variable for this analysis is a dichotomous classification of either being a wind county or a wind tract. This classification means that a county or census tract has at least one wind turbine within its geographic boundary.

Data Analysis

For our analysis we estimated three binary logistic regressions in Stata 15/IC, with each subsequent model focusing on a smaller spatial scale.[2] Each of these models can be viewed as a unit-hazard coincidence model, common to environmental injustice research. Using this approach, hazards are identified within geographic units and the demographic characteristics of the affected units are evaluated to determine if the coincidence of hazard is higher for certain segments of the population (Mohai and Saha, 2006). Although other scholars have called for more explicitly spatial approaches using distance from hazard as the dependent variable(Mohai and Saha, 2006), in this paper we elected to use the more frequent unit-hazard coincidence approach due to both the lack of existing literature on wind energy injustice as well as the methodological difficulties of using a distance model at such a large scale (e.g. skew in the dependent variable due to large distances).

First, we estimated a binary logistic model at the national level predicting the likelihood of a county having at least one wind farm. In this model we included all counties within the contiguous United States and did not include any further geographic constraints. We included robust standard errors to ensure conservative estimates of significance. Next, we estimate a conditional fixed effects logit model to analyze the likelihood of a county being a wind county while using state-level fixed effects. Therefore, only the 41 contiguous states with wind energy development were included. The use of state-level fixed effects allowed us to examine what county level sociodemographic characteristics were associated with a county having wind energy development, compared to other counties within the same state. As robust or clustered standard errors are not available when using this model, we bootstrapped our standard errors to ensure conservative estimates of significance; a total of 1000 bootstraps were performed.

Finally, we estimated a second conditional fixed effects logit model using county level fixed effects to model the likelihood of a census tract having at least one wind turbine. Similar to the state level analysis, the use of county-level fixed effects allowed us to investigate whether or not there were localized issues of energy injustice systemically occurring within counties in the contiguous United States, while controlling for unobserved county level variables. Due to the chosen method of analysis, which restricted our analysis to variables that varied within county, counties with wind farms in all census tracts were excluded from the analysis. Additionally, a number of tracts had missing data on demographic characteristics due to it not being reported, in these instances we have elected to use listwise deletion due to many of the excluded tracts being atypical (e.g. comprised solely of prisons or hospitals). As with the state-level analysis, we performed 1000 bootstraps on our standard errors.[3]

To compare our findings across spatial scales we compared the significance, direction, and magnitude of odds ratios among our predictor variables, as well as which hypotheses were supported at each spatial scale. While the practice of direct comparisons between logit coefficients across groups has received negative attention in the literature (Allison 1999; Mood 2010), and at times been deemed a methodological error due to unobserved heterogeneity, in our analysis the coefficients can be compared across models (Kuha and Mills 2017). The reason for this is that the substantive outcome of interest in our models is the dichotomous outcome of whether or not a geographic unit has wind energy development, and not an underlying latent variable (see Kuha and Mills 2017). An example of when it would be inappropriate is if the variable of interest is toxicity of a chemical and the outcome used to represent the latent construct is death (Kuha and Mills 2017). Further, the use of a consistent model across each level of scale avoids further difficulties of comparisons between binary logit models (Kuha and Mills 2017).

We elected to not include a control variable of wind resource availability due to our motivating research questions. Our interests in this study were the social correlates of wind energy infrastructure, if social dimensions associated with environmental injustice are also correlated with wind resource availability, this does not change the end result of an association suggestive of an unequal distribution of the costs and benefits of wind energy. For example, urban environmental injustice associated with environmental racism is often correlated with housing values, that the effect may or may not go away as a result of controlling for housing values in a regression does not remove the environmental injustice experienced on the ground. Similarly, if rurality is correlated with wind availability and turbine placement, it does not change the fact that rural people are disproportionately bearing the burden of the transition to renewable energy. This being said, by looking only within states with wind and counties with wind in our second models, we do remove some of the noise likely influenced by those geographic areas with no possible chance of receiving wind energy infrastructure due to a lack of wind resource availability.

It is important to acknowledge that our regression models, unlike is commonly inferred, are not meant to be causal. Rather, they represent the correlated outcomes of multiple causal processes. Our intent was not to perfectly model all determinants of wind energy siting, but to understand whether wind energy, as it currently exists, is sited inequitably across the United States. Thus, while the causality and justification for our hypotheses is based on explanations developed by decades of environmental justice research, we are not explicitly testing the process behind the siting—but instead the end result of those processes—as they relate to social factors.

RESULTS

Descriptive Statistics

Summary statistics for the variables included in the models are presented in Tables 1 and 2 at the county and census tract level, respectively. There were a total of 57,316 active inland wind turbines located within the contiguous United States. They were located within 41 states, 615 counties, and 1,035 census tracts. Nationally speaking, 19.7% of counties and 1.4% of tracts had wind turbines. The highest number of wind turbines in one county was 4,564, and the largest number of wind turbines in one census tract was 3,525. The average number of turbines within wind counties was 93.2 (SD = 240.7), with a median of 34. The average number within wind tracts was 55.5 (SD = 149.7), with a median of 14.

[Table 1 here]

[Table 2 here]

National Level Model

The national county-level analysis demonstrated a number of significant ($p < .05$) associations (Table 3). Median income, percent Hispanic, and percent non-Hispanic other had a significant positive association with increased odds of being a wind county. The variable with the largest association with increased odds of being a wind county was median income (odds ratio = 1.179) followed by percent Hispanic (odds ratio = 1.026) and percent non-Hispanic other (odds ratio = 1.015). Four variables had significant negative associations with the odds of being a wind county: median income squared, percent non-Hispanic Black, percent unemployed, and percent not in the labor force. The independent variable with the largest association with decreased odds of being a wind county was percent unemployed (odds ratio = 0.779).

Results of the national county-level did not fully support any of our hypotheses. The results provided mixed support for our hypotheses regarding income and race and ethnicity and refuted our hypothesis concerning labor force participation. While the linear effect for income is the opposite of the hypothesized direction, the significant quadratic effect suggests that at a certain level of median income the likelihood of wind energy development does, in fact, decrease. Regarding race and ethnicity, we see the opposite of our hypothesized effect for percent Black, but the expected effect for percent Hispanic and non-Hispanic other. Finally, percent unemployed and percent not in the labor force demonstrated effects in the opposite direction as our hypothesis.

[Table 3 here]

State Level Fixed Effects Model

The state-level fixed effects model had fewer significant associations than the geographically unconstrained national model (Table 3). When looking at counties within states, only percent Hispanic had a significant positive association with the odds of being a wind county, although its significance was marginal ($p = 0.034$). Two variables had a significant negative association with odds of a being wind county: percent unemployed and median age. The strongest relationship observed in the model was the negative association between higher levels of unemployed and decreased odds of being a wind county (odds ratio = 0.770). The state level model supported our hypothesis regarding age, and partially supported our hypothesis regarding race and ethnicity. However, our hypothesis regarding labor force participation was not supported and a significant effect was detected in the opposite direction as we proposed.

County Level Fixed Effects Model

Six independent variables in the county level fixed effects model had significant relationships with the odds of being a wind tract (Table 3). When looking at tracts within counties we see that tracts with a lower percentage of Hispanic residents (odds ratio = 0.986), a lower percentage of residents with at least a bachelor's degree (odds ratio = 0.949), more people out of the labor force (odd ratio = 1.022), and lower population density (odds ratio = 0.997) were more likely to be a wind tract. Additionally, both the linear and quadratic terms for median income were significant. We visually present the marginal effects of this relationship in Figure 3. Considering this is a fixed effects model, we see that when holding all other variables at their mean, the predicted probability of being a wind tract increased as the difference between a tract's median income and the county average also increased. However, once the difference between the tract median income and the county average median income was $90,000 it then began to decrease. We see the most support for our proposed hypotheses in the county level model. The model supported our hypotheses associated with labor force participation, education, and rurality. Results indicated mixed support for our hypotheses surrounding income, and unlike prior models provided no support for our hypotheses regarding race and ethnicity.

[Figure 3 here]

Comparison of Models

When comparing the national, state, and county-level models, we see noticeable differences in support for hypotheses between the three models. We observed the largest number of supported hypotheses in the within-county analysis. With the exception of percent Hispanic, many of the relationships present in the national analysis, while significant, were in a direction that were counter to hypotheses and suggest there is not necessarily energy injustice in regard to the distribution of wind farms in the United States. For example, the national analysis suggested that the wind turbines are currently less likely in areas with a lower percentage of non-Hispanic Black residents, higher employment, and more labor force participation. However, as we introduced further levels of geographic constraint, by evaluating counties within states and census tracts within counties, a number of relationships dropped out of significance in the model and others became significant, providing support to a number of proposed hypotheses.

When considering all models together, four hypotheses—age, education, and rurality—received full support by at least one model. Two hypotheses, those related to income as well as race and ethnicity, received mixed support in two of our three models. While we do not see that wind energy is systemically sited within poorer tracts or counties, in both the national and county level model the curvilinear relationship shows that wind energy is systemically *not* sited in areas with very high relative median income (Figure 3). Interestingly, the effect of labor force participation received both mixed support and was fully refuted between the national and county level models. Similarly, the association between percent Hispanic switched signs between the national model and the within-county model. These findings show that, both nationally and within states, wind energy was more likely in counties with lower levels of unemployment and higher proportions of Hispanic residents. However, when we look within those counties—which were already more likely to have lower unemployment and a higher proportion of Hispanic residents—wind energy was less likely in the more Hispanic tracts and more likely in those tracts with lower labor force participation. These nuanced findings highlight the support for our methodological hypothesis regarding scale. Finally, it should be noted that no single hypothesis received support at all three scales of analysis.

DISCUSSION

Taken together, our models suggest that wind energy is unevenly distributed, at least at one spatial scale, across the contiguous United States along the dimensions of income, race and ethnicity, age, education, labor force participation, and rurality. While the evidence of an unequal distribution appears clear, the evidence of distributional injustice remains mixed. We found that the signals of distributional wind energy injustice in the contiguous United States vary by scale. This finding is unsurprising given the issues of scale that have been raised by many researchers, particularly as it relates to the human-environment relationship (Joao, 2002). That said, a particular strength of this research is that it addresses issues surrounding the modifiable areal unit problem. Our comparison of national, state, and local models highlights key statistical differences, and how scale—as defined by administrative boundaries—can hide, or alter, results. Scale likely plays an important role in our understanding of wind turbine placement, because using different scales intrinsically accounts for different factors and each scale is based on comparisons between similar units of geography.

The variation between scale highlights the importance of acknowledging the political and societal differences between geographic areas in the United States. When we compare all counties to all other counties, as we did in our national model, we are in many ways comparing ‘apples to oranges.’ In other words, counties in Iowa, as a whole, differ greatly from counties and tracts in Pennsylvania; not only in a socioeconomic context, but also in how state governments have different structural relationships with local decision-making bodies, activist or citizen groups, or municipalities. When we look at injustice at a national level, or even state level, we flatten out that intra- county variation and are likely to miss key differences. When we focus on a more local (within-county) level, we see a tendency across the United States to place turbines in certain parts of the locality, parts that are more rural, less educated, or more removed from the labor force. Therefore, we believe that the most local scale, that of within counties, is the most important for understanding how the injustice related to wind turbine placement is felt on the ground because at this level we best capture the political land-use decision making process, and the resulting localized outcomes of those decisions. However, we do believe that future research should continue to contrast models at multiple scales so as not to miss important nuance, such as we found in the case of Hispanic populations.

In our theoretical framework we have positioned wind energy development as a locally unwanted land use. However, the material impact of wind energy infrastructure on populations is likely to be far less than the sources of toxic material and point-source pollution common to environ- mental justice research. In fact, wind energy can easily be argued to be a net positive for society and renewable energy transitions are viewed by many as essential for slowing global climactic change. By showing that environmental justice theory can be applied to more environmentally benign locally unwanted land uses, and that distributional inequities can occur along the same social dimensions, we have shown that the power of certain segments of society to distance themselves from undesirable local land uses translates to renewable energy development. This highlights the power that aesthetic landscape change, such as brought on by wind energy, may have in mobilizing resistance, even absent of negative health impacts.

Further, in line with Malin and DeMaster (2016) and Kelly-Reif and Wing (2016), we consider rurality as a previously under-explored dimension of environmental and energy injustice. At the national and state level we, somewhat surprisingly, do not see a significant relationship between aggregate population density and wind energy infrastructure. However, at the within-county level the relationship is significant. This shows that, within counties with wind energy, the tracts with the lowest population density are the most likely to bear the burden of wind energy development. While this is clearly an unequal distribution between segments of society, determining whether or not this truly represents a social injustice requires further information about land- ownership, compensation, and intersectionality. Although it still requires a notable area of land, wind energy carries a more diffuse footprint than other forms of energy development, therefore it is entirely possible that wind turbines could be located in areas with more people, especially at the within-county level. If this localized trend continues, then rural people may experience land-use change well beyond what other segments of society are forced to face when it comes to the transition to renewable energy. Due to the historically urban focus of environmental justice research, rural to urban inequality has received less attention than other dimensions of inequality. Our analysis provides evidence that localized pockets of rurality within wind counties in the United States are currently bearing a larger share of the burden of the renewable energy transition than their more urban counterparts.

Finally, while there appears to be some evidence of a trend toward distributional energy injustice at each of the considered spatial scales, the odds ratios were generally small. As wind energy development in the U.S. is still in its infancy, it is important to assess any possible injustices now before they become extreme. However, as it currently stands, we do not view the injustice as severe. Although wind energy is renewable, and therefore may be viewed more favorably by those historically concerned with environmental and energy injustice, it is important to document and analyze any growing injustice that may exist.

Future Research and Limitations

While our analysis is concerned with the location of energy infrastructure, the framework of energy justice is also about access to the power that is created by that infrastructure. For this analysis we treated access to the power provided by wind turbines as invariant based upon proximity and we viewed proximity as a cost. If proximity to turbines was associated with cheaper electricity, or increased local tax revenue as discussed by Roberston and Krannich (2013), then research would require balancing that benefit, with the cost of the energy infrastructure. Future research should explore this perspective and determine how reduced energy rates associated with proximity to development is viewed by society, as well as how tax revenue generated from wind energy is distributed across the population.

We found that tracts with lower labor force participation rates were more likely to have wind energy development. Future research should explore this distinction in greater detail. Specifically, as it pertains to the distinction between retired individuals and discouraged workers—meaning those who are not retired but have stopped looking for work. If the effect is driven by retired Americans, the relationship would likely represent a qualitatively different form of inequality than if it is driven by discouraged workers who could not find gainful employment and have stopped looking.

It is important to acknowledge that any injustice from wind energy siting is likely felt the strongest at the intersection of the social dimensions examined here. While we did not explore the intersectional nature of distributional injustice in this analysis, future research should explore how the distribution of wind infrastructure may systemically operate across multiple marginalized identities. As with all forms of intersectionality, the experience of injustice across multiple identities is unlikely to simply be additive, but rather multiplicative in nature (Hancock 2007).

In our analysis we only evaluated distributional injustice, while this form of injustice is certainly related to other forms of injustice, we have not evaluated the entire picture. The data available to us, and used in this study, cannot analyze procedural or recognition injustice. Future research should gain access to data and communities in a way that understands energy injustice as it relates to procedure and recognition. In-depth qualitative analyses are needed to add context to the observational models we present here. In step with this, we did not evaluate how land ownership patterns influence wind energy siting. While the impacts of wind energy development are likely to be felt by all in a community, not just those who have wind turbines on their land, future research should attempt to understand the role of land ownership in this issue.

Finally, this study represents the state of wind energy distribution at one point in time, while we only included active commercial wind turbines, some of the turbines were built as early as 1981. This highlights a common question in environmental injustice research—was a locally unwanted land use placed inequitably, or did marginalized populations move near the land use after it was built? Given our analysis was focused on the distribution of wind energy as it exists today, we view this question as beyond the scope of our paper. However, future research should attempt to use migration data to understand the impact that wind energy development has on both regional and local migration.

Conclusion

We found that the signs of distributional injustice exist along the social dimensions of income, race and ethnicity, age, education, labor force participation, and rurality when looking at the existing distribution of wind turbines in the United States. However, these findings varied significantly by scale and the majority of our hypotheses were not fully supported. When looking within counties in the contiguous United States we saw that wind turbines are more likely to be sited in areas with lower education, lower labor force participation, and lower population density. Additionally, areas of high relative median income were less likely to have wind energy development than areas with low to medium levels of relative median income in our national and county level models. While the inequality does not appear to be extreme, researchers should continue to monitor the distribution of wind energy as it continues to boom throughout the continental United States.

NOTES

[1] The census produced definition of rural/urban was not used, because we believe that the census definition for urban, which is determined at the census block level, does not properly define what makes some places more rural or urban than others (Isserman, 2005). Other available county level measures of rurality, such as the USDA's rural-urban continuum codes, were also not used because as county-level variables they would not be appropriate for inclusion in the tract level analysis.

[2] We elected to not use a spatial-econometric model, such as a spatial lag regression

for two reasons. First, spatial regression models generally do not account for fixed effects. Meaning that if a separate spatial regression model was run, it would be using fundamentally different assumptions than the produced fixed effects models; likely producing very different results. Second, accounting for a lagged or weighted wind turbine variable, as with a spatial lag regression, might overcorrect for spatial, or neighborhood, effects in the analysis.

[3] To test the model's sensitivity to outliers of population density we also ran the model with only tracts with population density of 10,000 people per kilometer or less, the results were consistent with the full model.

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TABLES

Table 1: Summary Statistics for Wind Counties

	Mean	SD	Min	Max
Median Income (Thousands)	47.786	12.472	18.972	125.672
Median Income Squared (Thousands)	2438.995	1425.961	359.937	15793.451
Hispanic (%)	8.985	13.663	0.000	98.959
Non-Hispanic Black (%)	8.970	14.502	0.000	86.185
Non-Hispanic Other (%)	4.641	7.253	0.000	92.400
Median Age	41.059	5.325	21.500	66.000
At Least a Bachelor's Degree (%)	14.151	6.166	2.632	55.328
Unemployed (%)	3.203	1.287	0.000	12.854
Not in Labor Force (%)	33.156	7.007	15.565	83.772
Population Density (Thousands per km)	102.020	690.319	0.0437	27597.69

Table 2: Summary Statistics for Wind Tracts

	Mean	SD	Min	Max
Median Income (Thousands)	60.308	28.731	4.621	250.001
Median Income Squared (Thousands)	4462.506	4845.252	21.354	62500.504
Hispanic (%)	23.085	26.319	0.000	100.000
Non-Hispanic Black (%)	10.551	19.500	0.000	100.000
Non-Hispanic Other (%)	9.209	11.394	0.000	100.000
Median Age	37.962	7.552	8.600	78.700
At Least a Bachelor’s Degree (%)	20.305	14.318	0.000	80.199
Unemployed (%)	3.956	2.354	0.000	23.414
Not in Labor Force (%)	28.378	8.090	0.000	98.981
Population Density (Thousands per km)	2894.404	5014.839	0.054	189430.266
Observations	21153			

Table 3: Models predicting likelihood of at least one wind turbine

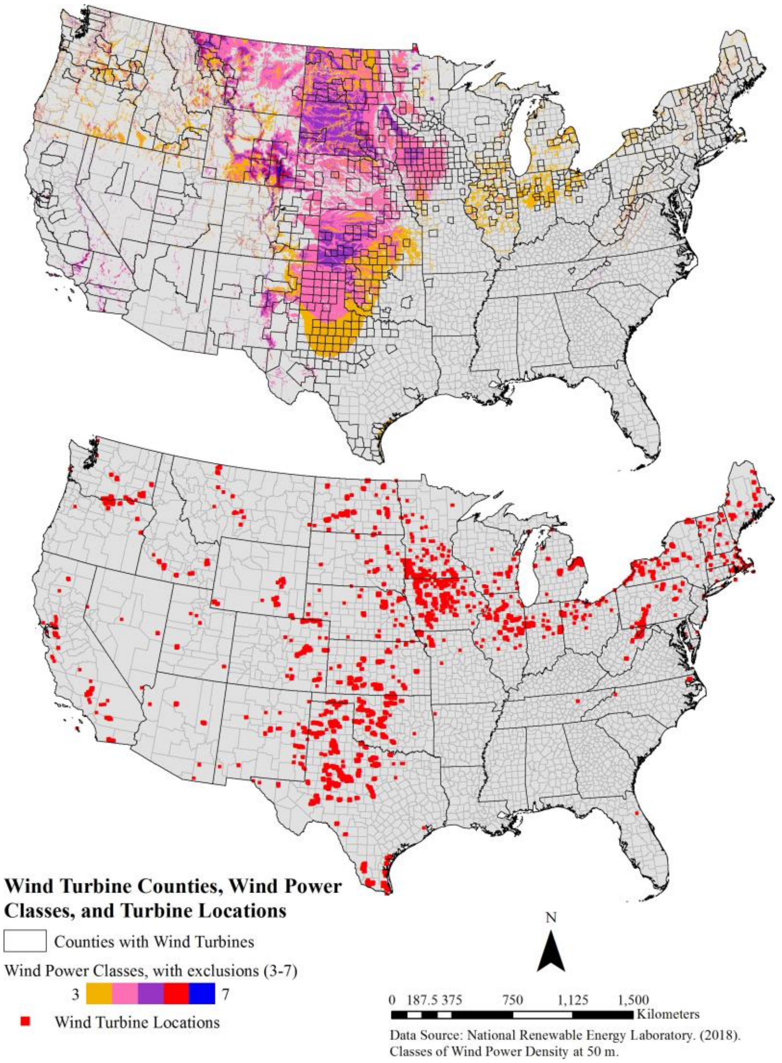
	National County Model	Within-State County Model	Within-County Tract Model
Median Income (Thousands)	1.179***	1.055	1.044***
	(5.28)	(1.13)	(3.44)
Median Income Squared (Thousands)	0.999***	0.999	.9997**
	(-5.09)	(-1.48)	(-2.93)
Hispanic (%)	1.026***	1.016*	0.986*
	(7.80)	(2.13)	(-2.41)
Black (%)	0.927***	0.981	1.003
	(-7.91)	(-0.56)	(0.31)
Non-Hispanic Other (%)	1.015*	0.994	0.995
	(2.21)	(-0.54)	(-0.66)
Median Age	0.982	0.947**	1.003
	(-1.49)	(-3.24)	(0.31)
At Least a Bachelor's Degree (%)	1.010	0.996	0.949***
	(0.97)	(-0.24)	(-4.94)
Unemployed (%)	0.779***	0.770***	0.963
	(-5.17)	(-3.32)	(-1.07)
Not in Labor Force (%)	0.973*	0.983	1.022**
	(-2.28)	(-1.11)	(3.09)
Population Density (km)	1.000	1.000	0.997***
	(0.67)	(-0.09)	(-5.83)
Log Likelihood	-1332.063	-1071.877	-1617.553
Wald Chi-Square (df = 10)	299.02***	48.73***	135.61***
Observations	3108	2436	20277
Groups	NA	41	521

Exponentiated coefficients; *z* statistics in parentheses

For the national model robust standard errors were used. For the within-state and within-county models, 1,000 bootstraps were performed.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

FIGURES



Wind Turbine Counties, Wind Power Classes, and Turbine Locations

Data Source: National Renewable Energy Laboratory. (2018). Classes of Wind Power Density at 50 m.

Figure 1: Wind Turbine Counties and Turbine Locations in the United States, 2018

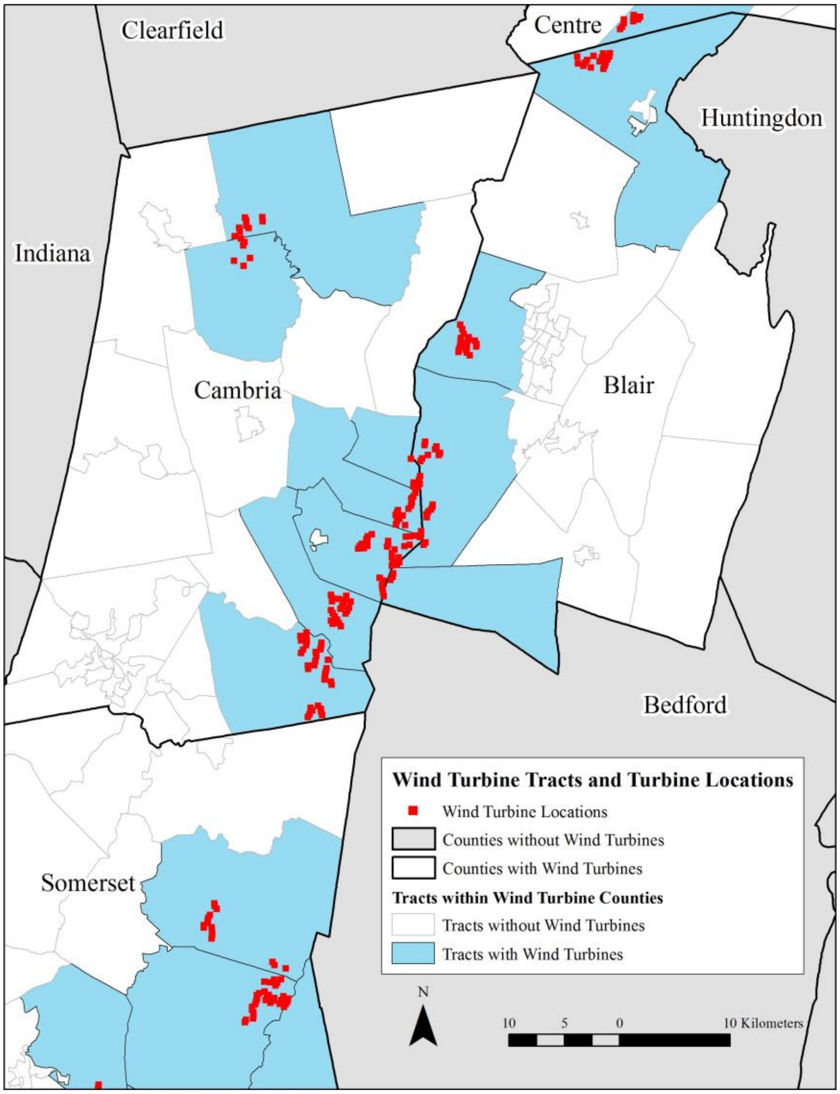


Figure 2: Wind Turbine Tracts and Turbine Locations in Central Pennsylvania, USA, 2018

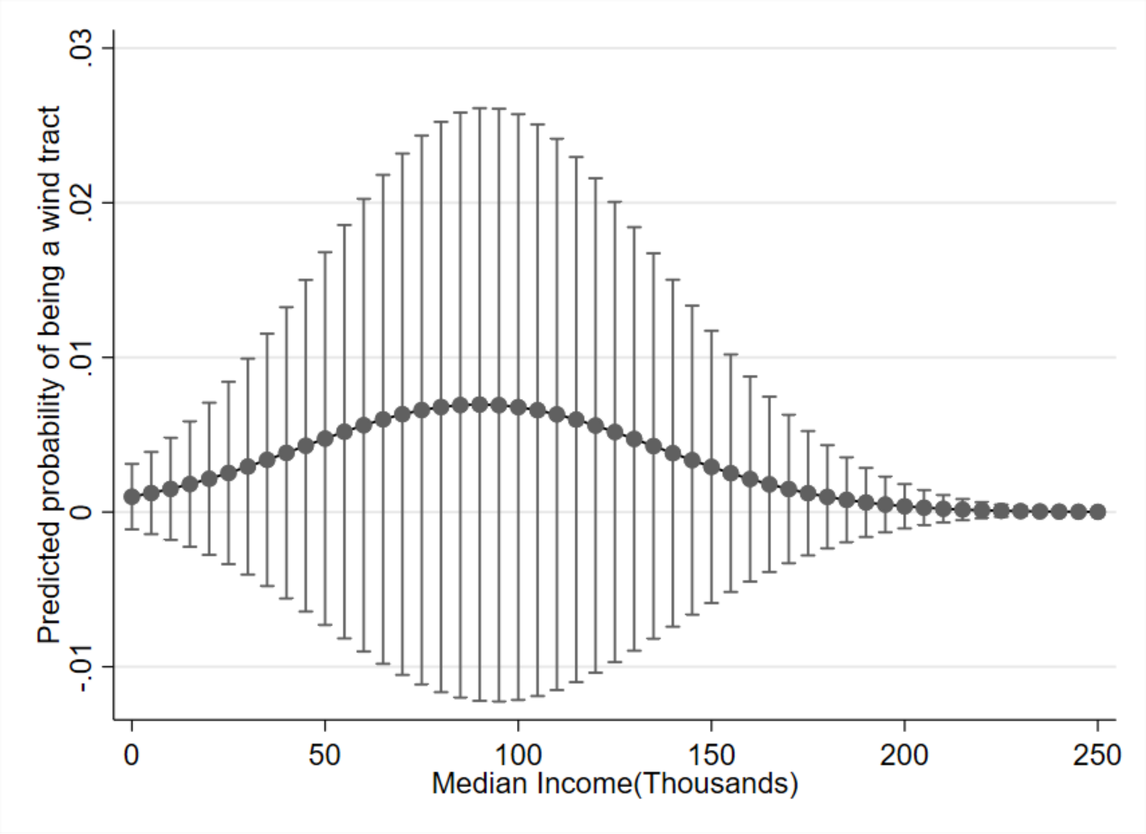


Figure 3: Predicted probability of being a wind tract relative to level of median income, all other variables at their mean. Vertical bars represent 95% C.I.