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The regional heterogeneity of wind power deployment: an empirical investigation of land-use policies in Germany and Sweden

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The purpose of this paper is to analyze and compare the impacts of land-use policies on wind power deployment at the regional levels in Germany and Sweden. We use data for the period 2008–2012, and an econometric approach in which the probability of having any wind power capacity additions and the actual level of increased capacity, given that it is positive, are permitted to be determined by different processes. The results confirm the importance of land-use policies, e.g., priority and exclusion areas, and interesting differences across the two countries are found. The impact of priority areas has been more profound in Germany, while the assignment of protected areas instead has constituted a more binding policy tool in Sweden. Cross-country differences in the relevance of various explanatory variables are linked to factors such as geographical patterns, design of wind power support schemes, and the allocation of decision-making power in planning processes.

KEYWORDS: wind power; regional distribution; land-use policy; Germany; Sweden

1. Introduction

Wind power is widely considered an important technological option to decarbonize the electric power sector (IPCC 2011). Consequently, wind power is increasingly deployed in most countries across the world. Yet, the level and growth of wind power deployment vary strongly across countries (GWEC 2016). This heterogeneity can be explained by differences in natural and geographic endowments, which affect the availability of sites for – and the profitability of – wind power deployment (e.g., Gosens 2017; Mann, Lant, and Schoof 2012). The spatial patterns of wind power deployment have also been driven by variations in the political frameworks. Two categories of policies are particularly important. First, public support schemes for renewable energy sources (RES), such as feed-in tariffs or renewable portfolio standards, have had a significant impact on the profitability of wind power deployment. Second, land-use policies, such as priority areas, protected areas, etc., will determine the availability of sites for such deployment.

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Significant research efforts have been undertaken to understand the impact of RES support schemes on wind power deployment – at a global scale (Carley *et al*. 2017; Dijkgraaf, Dorp, and Maasland 2018) as well as for key markets such as the USA (Bowen and Lacombe 2017; Hitaj 2013; Maguire and Munasib 2016; Staid and Guikema 2013; Shrimali, Lynes, and Indvik 2015, Shrimali *et al*. 2015), Europe (Jenner, Groba, and Indvik 2013; Nelson, 2008), and China (Xia and Song, 2017). These studies confirm the role of public support schemes in inducing wind power deployment. In contrast, less is known as to whether and to what extent the spatial heterogeneity of wind power deployment is also driven by various types of land-use policies. This paper addresses this research gap, and the objective is to investigate – and compare – the impacts of land-use policies on wind power deployment at the regional levels in Germany and Sweden.

Land-use policy, specified in planning and environmental permitting law, determines at which sites wind turbines can actually be installed, and how they must be designed (e.g., maximum allowable heights) and operated (e.g., allowable operation hours). It may take effect through general regulations, such as the designation of priority or exclusion areas for wind power, or minimum distances of wind turbines to human settlements. Moreover, land-use policies typically specify which criteria need to be met when an operation permit is issued. So far, the importance of land-use policies for wind power deployment has been studied primarily using qualitative approaches based on case study methodology (Aitken, McDonald, and Strachan 2008; Cowell 2010; Ferguson-Martin and Hill 2011; González, Daly, and Gleeson 2016; Hajto *et al*. 2017; Hull 1995; Köppel *et al*. 2014; Larsson and Emmelin 2016; Masurowski, Drechsler, and Frank 2016; Petterson, Söderholm, and Söderholm 2010; Toke, Breukers, and Wolsink 2008; Veidemane and Nikodemus 2015). This literature stresses that land-use policies tend to vary between regions in a country, and could therefore constitute important drivers of heterogeneous wind power deployment at the regional level. In our paper, we test this hypothesis in quantitative terms.

Understanding the role of regional land-use policy for land availability is important. On the one hand, it is a means to incorporate social and environmental impacts at the regional scale into siting decisions. On the other hand, it could constitute a significant constraint to wind power deployment and, in this way, jeopardize the attainment of national and supranational RES deployment targets. Our empirical analysis helps to shed light on the practical importance of this trade-off. Of course, our quantitative approach is not a substitute for – but rather a complement to – qualitative research studies; it helps to address the general significance and magnitude of land-use policy impacts, and, not least, compare these across two EU Member States.

To our knowledge, only a few quantitative studies investigate how regional land-use policy could affect wind power deployment (Ek *et al*. 2013; Goetzke and Rave 2016; Hitaj 2013; Hitaj and Löschel 2019). Still, the results are, in this particular respect, mixed and inconclusive. One reason for this could be that these studies only consider proxy variables that are assumed to be correlated with the willingness and ability of regional authorities to provide the necessary sites for wind power. These proxies include the level of regional economic development, political preferences, and previously installed capacity (assuming that higher capacities indicate higher political willingness and institutional preparedness). However, such proxies also capture influences beyond land-use policy. For example, previously installed capacity may not only indicate strong political preferences for wind power, but also the lack of suitable sites for additional wind turbines (Goetzke and Rave 2016). In addition, the mixed results in this research will also stem from the use of different variable specifications and econometric approaches.

We add to this literature in two main ways. *First*, we include variables that measure regional land-use policy and the corresponding availability of sites for wind power deployment more directly – most notably the sizes of priority areas for wind power deployment and of nature protection areas. *Second*, we apply a consistent empirical framework – i.e., identical econometric approach, closely related variables – to explain regional wind power deployment in both Germany and Sweden.

Our choice of these countries is motivated by important contextual differences, e.g., geographical, the degree of decentralization in land-use policies, the overall extent of past wind power deployment, etc. Focusing on Germany and Sweden therefore provides contrasting cases, and an opportunity to study empirically how such differences could affect the regional allocation of wind power. Specifically, this permits an analysis of whether cross-country differences in the relevance of variables will be related to: (a) the underlying contextual heterogeneity, e.g., geographical patterns, such as Germany being more densely populated than Sweden; (b) the overall extent of wind power deployment, such as Germany being a pioneer and Sweden being a follower; (c) the national RES support scheme, i.e., feed-in tariff in Germany and RES quota with tradable green certificates in Sweden; or (d) the degree of decentralization in land-use policy decision-making, such as Sweden having a more decentralized territorial planning system than Germany (Backes *et al.* 2018; Petterson and Söderholm 2011).

The empirical analysis relies on data on newly installed wind power capacity at the German district and the Swedish municipality levels for the period 2008–2012. This variable is linked to explanatory factors that address how supportive – or constraining – regional land-use policies have been in terms of land availability (size of priority areas and exclusion areas, previously installed capacity, constituency of the governing party, etc.). We also include control variables (i.e., wind speed, population density, size of the region, etc.). Due to the presence of censored observations, the econometric analysis relies on a generalization of the Tobit model, the so-called Cragg specification (Cragg 1971). This methodological approach permits the probability of having any wind power capacity and the actual level of capacity (in MW), given that it is positive, to be determined by different underlying processes (i.e., parameters).

2. Wind power deployment in Germany and Sweden: political framework

2.1. Wind power deployment and public support schemes

Figure 1 displays the development of total wind power capacity in Germany and Sweden over the period 1990–2017. This illustrates that Germany is a forerunner in terms of wind power generation,[1] while the Swedish expansion has taken place with essentially a 10- to 15-year time lag. In 2017, the total installed wind power capacity (in MW) was more than seven times higher in Germany compared to Sweden. Moreover, from a land use perspective, it is useful to note that the density of wind power capacity in terms of MW/km^2 is almost ten times as high in Germany (in 2016).

One explanation behind these varying developments is the variation in the profitability of wind power investments across the two countries. This is driven by the difference in RES support schemes and levels, and the consistency with which these national wind power policies have been implemented. The early Swedish wind power policy provided meagre long-term certainty for investors (Åstrand and Neij, 2006). In 2003, Sweden introduced a technology-neutral green certificate system for renewable

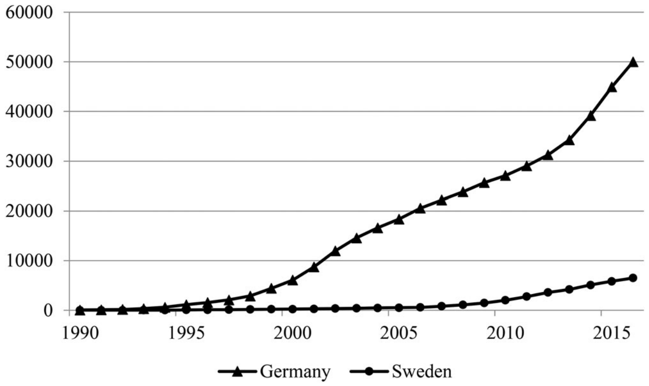

Figure 1. Installed wind power capacity (MW) in Germany and Sweden, 1990–2017.
Sources: Deutsches Windenergie-Institut (DEWI) and the Swedish Energy Agency.

electricity with the aim of securing a pre-determined market share for renewable energy sources. RES generators are awarded a certificate for every MWh they generate, and users are obliged by law to purchase certificates that correspond to a certain percentage of their electricity use. Since 2006, these certificates have been issued over a 15-year period, thus creating relatively favorable investment conditions, and with price premiums ranging around Euro 20–25 per MWh. The most significant expansions in Swedish wind power capacity therefore occurred after this year. For our purpose, it is essential to note that the Swedish RES support scheme is spatially uniform, i.e., there is no regional differentiation of certificate prices.

In Germany, the capacity of wind power started to increase significantly in the beginning of the 1990s, in particular with the implementation of the Law on Feeding Electricity into Grid (StrEG) in 1991. This law introduced a technology-specific feed-in premium guaranteed over the first 20 years of the lifetime of the plant. This support scheme was further strengthened in 2000, when the premium was replaced by a fixed feed-in tariff, which increased investment certainty (e.g., Goetzke and Rave 2016). In addition, support levels have been significantly higher in Germany compared to Sweden. For instance, while the price for a Swedish certificate averaged around Euro 20 per MWh in 2012 (the final year of the period under consideration in the present paper), in Germany even the basic tariff was more than twice as high.[2]

Finally, in contrast to the Swedish scheme, the German feed-in tariff has not been spatially uniform. The so-called reference yield model introduced in 2000 provided for higher (lower) support levels at sites where the expected wind yield is below (above) that of a legally defined reference site. This thus implies a regional differentiation of support levels as a function of windiness. Still, even though the German model partly levels regional differences in profitability, the overall profitability of investments still tends to increase with windiness (Hitaj and Löschel 2019).

2.2. Land-use policies

The land-use policy frameworks regulating the availability of sites for wind power deployment differ between the two countries. In particular, the Swedish planning system stands out as highly decentralized. In cases where the competition for land use is intense, the municipalities must in some way assent to (i.e., plan for) the establishment of wind turbines in order for the installation to take place. However, since all Swedish municipalities have a *de facto* planning monopoly, they can block wind power by simply ignoring to plan for it. In more remote areas (with less intense land use restrictions), such so-called detailed plans are not required, but as of 2008 the municipalities have been given an explicit veto right with respect to wind power. Thus, no new wind power projects can take place without municipal consent; the new veto was, in fact, applied retroactively to pending cases (Petterson and Söderholm 2011). Khan (2003) even reports that various municipal planning requirements for wind power, e.g., the way in which citizens' perceptions are consulted in the processes, may have been attributed to differences in the attitudes of specific local government officials. Furthermore, in Sweden, geographical areas may be designated as being of "national interest" for wind power. However, this is a relatively weak policy tool. For instance, if a specific area is of national interest for other purposes as well (e.g., nature conservation, national defence, mining, etc.), the legal rules have provided little guidance on how to weigh the various interests against each other (Söderholm, Ek, and Pettersson 2007; Petterson, 2008).

The German planning system is overall more vertically integrated. It builds on a multi-level governance structure with subsidiarity and counter-current principles for spatial planning (AEE 2012). The national level only determines the framework regulation, e.g., the requirement that wind power developments should be privileged in non-developed areas (in contrast to most other developments). The strongest competencies are assigned to the federal states and their planning regions. Each federal state can decide on a minimum share of its land area that should be designated for wind power. The federal states also issue guidelines for planning and permitting procedures for the subordinate governance levels. Planning regions (consisting of several municipalities) within the federal states then translate these guidelines into spatially explicit priority areas for wind power. The decision on where to establish these priority areas also needs to account for nature conservation concerns (e.g., pre-existing nature protection areas) and emission control (e.g., distances to human settlements). Municipalities, i.e., districts or towns are, in turn, responsible for setting up yet more specific municipal development plans, as well as for permitting individual developments. Still, the decisions at the local level are primarily administrative rather than political ones. In fact, the local administration has to approve a wind turbine if all legal requirements are met; it is thus strongly bound to superordinated law (Backes *et al*. 2018, 242). For example, a German municipality can typically only permit wind power that is located within a priority area defined in the regional plan (BBSR 2014).[3] For this reason, the analysis of German land-use policy cannot be restricted to the municipal level alone; it also needs to account for decisions taken at the level of planning regions and federal states.

3. Empirical approach

3.1. Conceptual framework

Empirically, we aim to understand what drives the amount of *additionally installed capacity within a region* (i.e., district in Germany, municipality in Sweden). For this purpose, Figure 2 illustrates a simple conceptual framework. It stipulates that this capacity increase will be related to two underlying factors: the profitability of wind

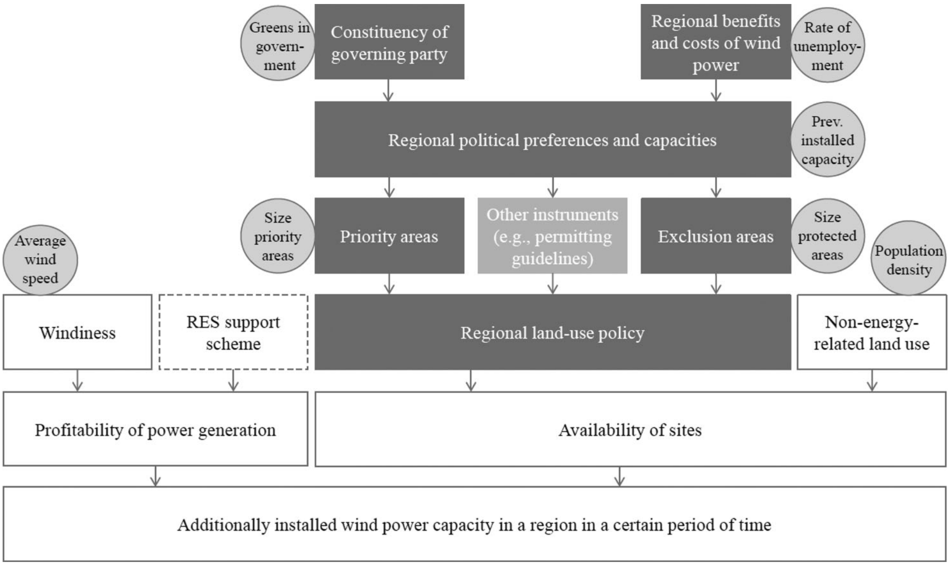

Figure 2. Drivers of regional heterogeneity of wind power deployment.
Note: Rectangles represent general explanatory factors, while circles represent the corresponding specific variables included in the econometric model.

power generation and the availability of sites for such generation. The variables employed to address these impacts are introduced and motivated below, while Section 3.2 provides information about how these variables have been operationalized and what data sources have been used.

Land-use policies directly affect the availability of sites, and we hypothesize that installed wind power capacity increases with the *size of priority areas*, and decreases with the *size of exclusion areas* (e.g., for nature conservation). Decisions on various types of land-use policies are typically taken at different levels of government. For instance, in Germany landscape protection areas are established by the federal states, while, for instance, nature protection areas or national parks lie within the responsibility of the national government. All these levels should ideally be accounted for, and differences across countries need to be acknowledged in empirical analyses (see further Section 3.2). There are also other relevant dimensions of regional land-use policy; it can materialize through other instruments, such as guidelines for the permitting of individual wind power developments (see the light grey box in Figure 2). However, such instruments are difficult to include in quantitative assessments. We therefore also consider variables that can be assumed to correlate with, for instance, general political preferences and the institutional capacity to facilitate wind power development at the regional level.

Following previous research (e.g., Ek *et al.* 2013), the *amount of total capacity installed prior to the period under consideration* is considered. We assume that a positive relationship between previously and newly installed wind power capacity indicates: (a) a generally high political willingness to facilitate wind power development; (b) good relations between the local authorities and wind power investors that have resulted from previous project developments; and/or (c) high levels of acquired institutional capacity in terms of experience with the planning and permitting of wind power.

This notwithstanding, the sign of this relationship is *a priori* unclear. High levels of previous capacity expansions could also impair new investments, because suitable and profitable sites have become scarcer as a result (Goetzke and Rave 2016), and/or due to conflicts at sensitive sites.

The willingness to facilitate wind power deployment in a region may also depend on the constituency of the governing political parties (e.g., Kirchgässner and Schneider 2003). We hypothesize that newly installed wind power capacity will be positively correlated with the *length of green party participation in the local government*. This approach, we argue, should address the role of green political positions on regional land-use policy, since it will reflect the presence of green priorities among the policy-makers who are actually in power. Previous research typically measures general attitudes of the population (e.g., Goetzke and Rave 2016; Hitaj and Löschel 2019). However, high green vote shares do not automatically imply that green preferences will be able to penetrate the land use decision-making processes, unless the green parties can collude with other parties and assume power in that way. In addition, such bipartisan coalitions also imply that even low shares of green party votes can lead to substantial decision-making power for politicians with green preferences.

The willingness to support wind power in a region could also depend on the regional benefits and costs that may be attributed to wind power (e.g., Ek and Matti 2015; Edjemo and Söderholm 2015). To capture such effects, we include the *rate of unemployment* in a region. In line with previous work (Ek *et al*. 2013; Goetzke and Rave 2016), we assume that regions characterized by economic decline, and high rates of unemployment will be particularly interested in attracting new investments by a supportive land-use policy framework. Indeed, many governments view RES deployment as a vehicle for job creation and regional growth (e.g., Swedish Government Bill 2005/06:143).

Obviously, in order to correctly identify the impacts of variables related to land-use policy, we need to control for other drivers of regional heterogeneity in wind power deployment. The regional availability of sites for wind power development will also be driven by the intensity of other competing land uses (e.g., human settlements, transport infrastructure), as well as the general natural endowment of suitable sites. We therefore include *population density* and the *size of the region* as controls for these aspects. In addition, regional heterogeneity of wind power deployment hinges on differences in the profitability of investments, and these differences are, in turn, primarily influenced by regional variations in windiness. We consequently include *average wind speed* in a region as a control.

Certainly, the profitability of wind power will also depend on the RES support scheme in place. Yet, we assume that the incentives set out by the respective support schemes are spatially uniform, and for this reason, we neglect this variable. This holds perfectly true for the Swedish certificate scheme. It applies with certain restrictions to the German feed-in tariff scheme. Despite the reference yield model used, the profitability of wind power deployment at a specific site is correlated with windiness. This was also confirmed in preliminary model estimations incorporating feed-in tariff levels in the German data sample. In the light of this, and given our ambition to keep the econometric framework as consistent and uniform as possible across the two countries, the German feed-in tariff levels have been left out of the model estimations. We do, however, comment on the relationship between wind speeds and the reference yield model when interpreting and discussing the empirical results.

3.2. Data

Table A1 in the Appendix displays the data sources from which all variables in the empirical analysis have been derived, while this sub-section focuses on explaining the relevance of the data used, including some important definitions and limitations.

The empirical investigation builds on econometric model specifications in which *additionally installed wind power capacity* (in MW) over the time period 2008–2012 represents the dependent variable. The focus on this period is motivated by the availability of data, e.g., access to information about Green party coalitions, average wind speeds and land use restrictions in Sweden. In addition, the chosen time span represents a period of significant wind power expansion in both countries, but with substantial regional variation. For Germany, the data cover the 402 districts (*landkreise*), while in the Swedish case they cover the country's 290 municipalities (*kommun*). All wind power plants issued by the four German transmission system operators (i.e., 50 Hz, Amprion, TransnetBW, and Tennet) are included, as are nominal capacities, the construction years and the spatial information, such as GPS coordinates (and/or municipality codes). For both countries, the data exclude offshore wind power. Figure 3 shows how the installed wind power capacity has been allocated across the various regions in both countries during the chosen time period. It illustrates not least how much more wind power-intensive Germany is compared to Sweden, as well as that wind power activities tend to vary substantially across regions.

For Germany, the data on the *size of priority areas* for wind power deployment, i.e., the percentage share of total land area, were only available for a more limited sample of planning regions representing 209 German districts. Consequently, the information provided for an individual planning region was equally attributed to all districts belonging to this region. Since the German data set is incomplete with respect to priority areas, we consider two German data samples in the econometric analyses: one full data sample comprising 402 German districts and a more limited sample consisting of 209 districts. We believe it is justified to also consider the full sample, even if one potentially important variable is missing, not least since this provides an opportunity to assess the robustness of the results by comparing them to the results from the more limited sample. In the Swedish case, data on the share of areas of so-called national interest for wind power were available for all municipalities in the country.

The information on the *size of protected areas*, in terms of the share of protected nature areas out of total land area in percent, is not entirely consistent across the two countries. For data availability reasons, the German data cover the percentage shares of so-called 'landscape protection' areas per total district area, thus neglecting a category such as national parks. In contrast, the corresponding Swedish dataset includes national parks and reserves, nature management areas, wildlife sanctuaries, and habitat protection areas (on forest and agricultural land). These differences are addressed when interpreting the results. Due to this difference, we also performed a robustness test, and included in the Swedish estimations, the same categories of protected areas as in the German sample, i.e., removing natural parks, etc. We comment on the results from this test in Section 4.

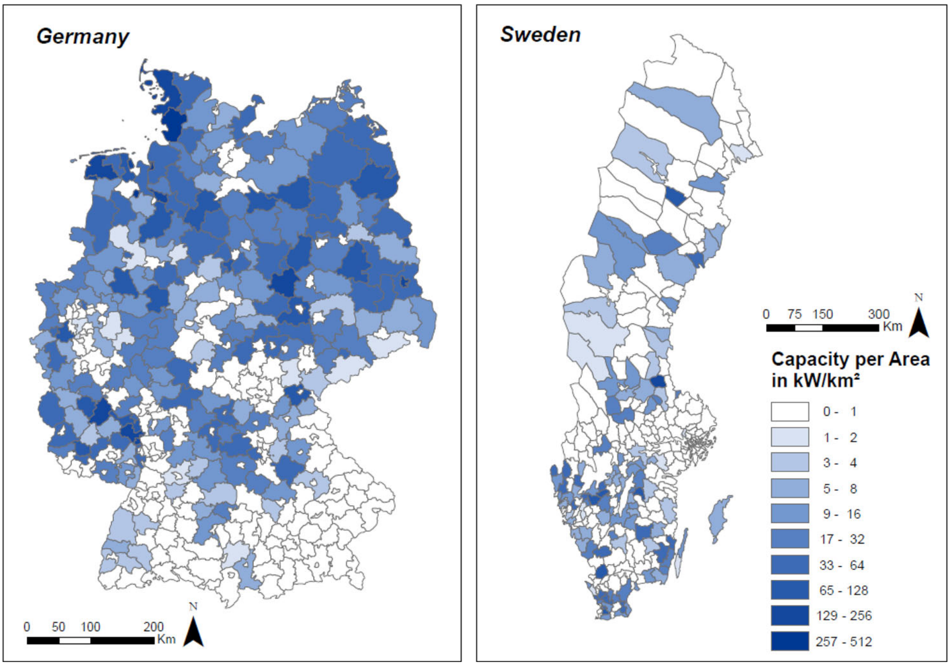

Figure 3. Additionally installed onshore wind power capacity by region (kW/km^2), 2008–2012. Sources: DGS (2014) and Energimyndigheten (2013).

As noted above, we consider three proxy variables for addressing the political willingness to facilitate wind power deployment at the regional level. *First*, we employ data on *total installed capacity within a region prior to 2008* (in MW). For Germany, these data were aggregated for each federal state, and then applied uniformly as a measure for all districts located in that state. This is because, in the German case, we use this variable as a proxy for federal state rather than municipal policy. *Second*, we collected data on the unemployment rate (as a percentage of the total workforce).

Third, we constructed a variable measuring the *length of green party participation in the governing body* of a federal state (Germany) and a municipality (Sweden). Specifically, we consider the number of years over the period 2000–2012 during which the two countries' green parties formed part of the respective governing coalitions. This operationalization permits lagged impacts of green party influence on wind power deployment; this is potentially important given the sometimes long lead times for new wind power investments. It should be noted that for this proxy variable, we are interested in the most important government level in the case of regional wind power planning, and this differs for Sweden and Germany, respectively. In Sweden, the municipal position is very strong (e.g., Petterson *et al.* 2010), while the role of the state level is much more pronounced in the German case. Specifically, in Germany, federal states and regional planning authorities take important decisions on land-use regulation, concerning, for instance, regional RES shares, the stringency and location of priority areas, etc. Thus, although German municipalities do take the final decision on whether or not a specific wind turbine is permitted, this decision is strongly influenced by state regulation. As noted above, decisions at the local level are, by definition, primarily administrative rather than political ones. In fact, the local administration has to approve a wind turbine if all legal requirements are met; it is thus strongly bound to superordinated law (Backes *et al.* 2018).

The variables *population density*, *size of region,* and *wind speed* were all used as controls. In all three cases, we used data at the district level for Germany and at the municipality level for Sweden. Population density is measured in number of inhabitants per km^2, while the sizes of the districts and municipalities, respectively, equal the land area in km^2. In the German case, the information on wind conditions was available in the form of average wind speeds in m/s at different heights over the period 1980–2001 and for a 1000-m cell resolution. For Sweden, we use average wind speeds in m/s between 2007 and 2010 at a height of 72 m, and for a 1000-m cell resolution. In both cases, we have aggregated these data within a geographical information system (GIS) to the German districts (for an assumed hub height of 80 m) and the Swedish municipalities, respectively.

Tables 1 and 2 provide descriptive statistics for the dependent variables and the included explanatory variables for the German and Swedish samples, respectively. Since the presence of high correlation rates between the independent variables would reduce the efficiency of the results, we report these rates in the Appendix (Tables A2 and A3). These linear correlation rate matrices illustrate overall low linear correlation coefficients across the independent variables.

3.3. *Model specification*

Our dependent variable, added wind power capacity (MW), equals zero for a non-negligible fraction of the observations, and conventional regression methods fail to account for the qualitative difference between limit (zero) observations and nonlimit (continuous) observations. For this reason, it is useful, as a starting point, to consider the censored regression model proposed by Tobin (1958). In this so-called Tobit model, latent wind power capacity additions, y_i^*, would be allowed to depend on the vector $\boldsymbol{X_i}$ comprising the independent variables discussed above. We have:

$$y_i^* = \boldsymbol{X}_i\boldsymbol{\beta} + \epsilon_i, \;\; \epsilon_i \sim N\left(0, \sigma^2\right) \tag{1}$$

for all districts/municipalities $i = 1, \ldots .,N$. The observed dependent variable is:

$$y_i = \begin{cases} y_i^* \;\, if \;\, y_i^* > 0 \\ 0 \;\, if \;\, y_i^* \leq 0 \end{cases} \tag{2}$$

Moreover, in the empirical estimations, we apply a $\log(y_i + 1)$ transformation of y_i, this since the error terms have to be uniformly distributed, and there is a need to avoid taking the logarithm of zeros. This is clearly a simple option; other options include imposing different distributions, i.e., the pseudo Poisson model or the inverse hyperbolic sine function (Santos Silva and Tenreyro 2006; Brown and Dunn 2011; Goetzke and Rave, 2016). However, according to Woolridge (2009), using the log(1+y) transformation for the dependent variable, and then interpreting the estimates as if this variable is log(y), is acceptable if the data on y contain relatively few zeros. Since our data cover wind power capacity expansion over a whole five-year period, we have relatively few zeros, in particular in the German sample. Moreover, the other approaches, not least the pseudo Poisson model, are difficult to implement in the double-hurdle version of the Tobit model outlined below. In fact, among over 20 studies from 2000 and onwards using the same double-hurdle model,

Table 1. Descriptive statistics for the German Data (Districts).

	N	**Mean**	**St. Dev.**	**Min**	**Max**
Dependent variable					
Additionally installed capacity over the period 2008-2012 in MW	402	22.95	56.14	0.00	725.74
Variables measuring regional land-use policy					
Priority areas in % per planning region area (2012)	209	0.54	0.79	0.00	3.75
Protected areas in % per district area (2012)	402	3.65	6.22	0.00	71.49
Variables addressing the political willingness to facilitate wind power deployment at the regional level					
Total installed capacity within Federal States prior to 2008 in MW	402	1,648.92	1,676.01	0.00	5,524.17
Participation of the Green Party in Federal State government between 2000 and 2012 in number of years	402	1.36	2.93	0.00	10.00
Unemployment rate in % (2012)	402	3.36	1.63	0.68	9.19
Control variables					
Population density, inhabitants per km^2 (2012)	402	514.40	670.84	36.855	4,465.45
Land area in km^2	402	889.86	722.58	35.60	5,495.40
Wind speed in m/s (1980-2001)	402	5.33	0.54	3.78	7.77

Table 2. Descriptive statistics for the Swedish Data (Municipalities).

	N	Mean	St. Dev.	Min	Max
Dependent variable					
Additionally installed capacity over the period 2008–2012 in MW	290	9.60	21.13	0.00	156.80
Variables measuring regional land-use policy					
Priority areas in % per municipality area (2010)	290	1.54	3.63	0.00	41.92
Protected areas in % per municipality area (2008)	290	5.88	11.53	0.00	100.00
Variables addressing the political willingness to facilitate wind power deployment at the regional level					
Total installed capacity within a municipality prior to 2008 in MW	290	20.12	29.12	1.0	101.00
Participation of the Green Party in municipality government between 2000 and 2012 in number of years	290	2.35	3.24	0.0	11.00
Unemployment rate in % (2010)	290	6.08	1.70	2.50	13.10
Control variables					
Population density, inhabitants per km^2 (2010)	290	135.01	464.32	0.20	4,410.40
Land area in km^2	290	1,833.55	2,843.26	8.82	20,714.70
Wind speed in m/s (2007)	290	6.16	0.62	4.59	7.69

only three adopted the inverse hyperbolic sine function approach (see Table 1 in Carlevaro, Croissant, and Hoareau 2012).

For our purposes, a key limitation of the Tobit model is that the choice of $y > 0$ and the value of y, given that $y > 0$, is determined by the same underlying process, i.e., vector of parameters ($\boldsymbol{\beta}$ from above) (e.g., Burke 2009). There are, however, reasons to hypothesize that a different set of parameters will determine the probability of having any wind power capacity additions on the one hand, and, if capacity additions are positive, the amount of these additions (in MW) on the other. For instance, it is likely that the probability of observing any wind power capacity additions in a region could be more strongly related to the political preferences towards wind power, not least in contexts in which the local government has a lot of discretionary (and even veto) power over the territorial planning system. In contrast, the amount of capacity installed – once having decided to permit wind power development – could, instead, be more strongly linked to wind conditions, land use constraints, etc. Very few regions possess geographical conditions that will prohibit wind power – i.e., at least a few favorable sites will exist – but wind speeds, population densities, etc., will clearly influence the magnitudes of the capacity additions.

For the above reasons, we consider a more flexible model specification of the Tobit model based on Cragg (1971); see also Ek *et al.* (2013) for a previous application to wind power. In this double hurdle model, the probability of having any wind power capacity additions (zero or positive) and the actual level of capacity, given that it is positive, are permitted to be determined by different processes (i.e., parameters). Specifically, Cragg's (1971) model is a combination of the univariate probit model and the truncated regression model. The first of these steps, the probit, can be formulated as:

$$\begin{aligned} \text{Prob }[y_i^*>0] &= \phi(\boldsymbol{\lambda}'\boldsymbol{X}_i),\ \ Z_i = 1 \text{ if } y_i^*>0 \\ \text{Prob }[y_i^* \leq 0] &= 1-\phi(\boldsymbol{\lambda}'\boldsymbol{X}_i),\ \ Z_i = 0 \text{ if } y_i^* \leq 0 \end{aligned} \tag{3}$$

If $y_i^* > 0$, this is followed by the truncated regression equation for the nonlimit observations, i.e., the (unconditional) expected value of y is (Burke 2009):

$$\mathrm{E}[y_i|z_i = 1] = \boldsymbol{X}_i\boldsymbol{\beta}' + \sigma\lambda_i, \tag{4}$$

where σ^2 is the variance of the normal (untruncated) distribution, and λ is the Inverse Mills Ratio, which essentially represented the probability that wind power capacity additions are positive over the cumulative probability of this outcome (Kennedy 2003).

The Tobit model here represents the special case in which $\boldsymbol{\lambda} = \boldsymbol{\beta}/\sigma$. Greene (1993) outlines a test of this restriction through separate estimations of the likelihood values L of the Tobit model (TO), the probit model (PR) and the truncated regression model (TR) (see also Lin and Schmidt, 1984). We have:

$$\boldsymbol{\lambda} = -2[\ln L_{TO} - (\ln L_{PR} + \ln L_{TR})] \tag{5}$$

This permits us to test the more restrictive Tobit model against the Cragg model. The final econometric results have been obtained using the mhurdle-package in the software *R* (Carlevaro, Croissant, and Hoareau 2012).

In the empirical part (Section 4), we comment on the statistical significance of the estimated coefficients. All of the independent variables outlined in Section 3.2, are included in both the probit model and the truncated model. It is, however, also necessary to address the *economic significance* of the key variables influencing regional wind power outcomes. In this respect, Goetzke and Rave (2016) provide an interesting counterfactual analysis for Germany, employing the full dataset of actual observations in a baseline assessment. With its two-tier approach, however, a corresponding analysis is very complex in the context of the Cragg specification, in particular when (as in our case) the independent variables are elements of both vectors, i.e., $\boldsymbol{\lambda}$ and $\boldsymbol{\beta}$ (see also Burke 2009). Nevertheless, in the empirical section, we include remarks where we put the sizes of the estimated coefficients into a broader context, and with a particular focus on key land use policies and constraints. This is done for both the probit model

Table 3. Likelihood ratio tests of the Tobit versus Cragg specification.

	Tobit	Probit	Truncated
Germany (full sample)			
Observations	402	402	402
Log likelihood	–593.3145	–176.4054	–403.348
df	9	8	9
Adjusted R^2	0.5053		0.493
Germany (limited sample)			
Observations	209	209	209
Log likelihood	–315.0523	–70.1543	–230.958
df	10	9	10
Adjusted R^2	0.5261		0.5079
Sweden (full sample)			
Observations	290	290	290
Log likelihood	–396.4309	–158.4322	–196.8444
df	10	9	10
Adjusted R^2	0.1519		0.2695
Likelihood ratio tests			
λ	27.1222	27.8800	82.3086
Critical values $\chi^2_{0.01}$*	21.67 and 23.21	20.09 and 21.67	21.67 and 23.21
p-value	0.000673441	0.000998911	5.61449e-14

Note: *The critical values with 8, 9, and 10 degrees of freedom (df) equal 20.09, 21.67, and 23.21, respectively, at the one (1) percent statistical significance level.

(where the marginal effects need to be computed separately),[4] and the truncated model.

4. Empirical results

As a first step in the empirical analysis, we need to test whether the data-generating process suggests that we should proceed with the double hurdle Cragg specification, or with the more restrictive Tobit model. Table 3 reports the results from the likelihood ratio test in Eq. (5). These suggest that for all three samples, we can reject the Tobit model in favor of the Cragg specification. For this reason, we report the estimation results in two parts, first those from the probit model and then those from the truncated regression model. In the Cragg specification, these models complement each other since they address different parts of the data-generating process. Table 4 displays the corresponding parameter estimates for all data samples. The first two columns show the probit and truncated model results for all German districts, thus without including information on the priority areas. The following two columns show the corresponding results using the more limited German sample, thus also incorporating information on priority areas. Finally, the last two columns in Table 4 display the double-hurdle model results for the Swedish sample.

The results show that, in the case of priority areas, we find differential impacts across the two countries. In the German model, there is a positive and statistically significant relationship between the shares of designated priority areas and the probability of observing any wind power investment. For the Swedish sample, in the probit model, we find only a marginally statistically significant impact of the share of so-called

Table 4. Coefficient estimates of the double-hurdle regression models (standard errors in parentheses).

Independent variables	Germany (full sample)		Germany (limited sample)		Sweden (full sample)	
	Probit	Truncated	Probit	Truncated	Probit	Truncated
Constant	–4.377 (2.06429)*	–6.12547 (2.93036)*	–8.70329 (3.62718)*	–3.51659 (3.25451)	–5.7998 (1.61172)***	3.38955 (2.40146)
Priority areas in % per planning region area	–	–	0.93193 (0.32372)**	0.32715 (0.17448)	–	–
Priority areas in % per municipality	–	–	–	–	0.03738 (0.02354)*	0.02863 (0.28482)
Protected area per district area in %	–0.02731 (0.02131)	0.03598 (0.05255)	–0.07936 (0.04458)	–0.03068 (0.07497)	–	–
Protected area per municipalities area in %	–	–	–	–	–0.00722 (0.00759)	–0.05808 (0.02034)**
Installed capacity within Federal States until 2007 (MW)	0.00008 (0.00006)	0.00026 (0.0006)***	0.00002 (0.00007)	0.00021 (0.00006)***	–	–
Installed capacity within municipality until 2007 (MW)	–	–	–	–	0.18542 (0.04569)***	0.04595 (0.01225)***
Participation of the Green Party in German Federal Gov.	0.00375 (0.03473)	0.03722 (0.04237)	–0.16736 (0.06152)**	–0.00905 (0.06208)	–	–
Participation of the Green Party in Swedish Municipal Gov.	–	–	–	–	0.03622 (0.02719)	0.00373 (0.03614)
Unemployment rate in %	0.0955 (0.06073)	0.40283 (0.06493)***	–0.03049 (0.08848)	0.31701 (0.07469)***	0.01053 (0.06134)	–0.00986 (0.09411)
ln population density in persons per m^2	–0.12779 (0.14116)	–0.45772 (0.21032)*	0.08177 (0.25818)	–0.42753 (0.2591)	–0.0933 (0.08733)	–0.34626 (0.12934)**
ln Land area in km^2	0.63026 (0.14686)***	0.67387 (0.25724)**	0.73185 (0.26327)**	0.33656 (0.29041)	0.23179 (0.11116)*	0.13813 (0.16823)
Average wind speed in m/s^2	0.24071 (0.20104)	0.74581 (0.24139)**	0.79743 (0.3147)*	0.75962 (0.2559)**	0.65138 (0.20084)**	–0.14188 (0.27989)
Sigma (σ)	–	1.4154 (0.08524)***	–	1.27415 (0.08818)***	–	1.1813 (0.09072)***
Number of observations	402	402	209	209	290	290
Log likelihood	–176.4054	–403.3480	–70.1543	–230.9581	–158.4322	–196.8444
Adjusted R^2		0.4930		0.5079		0.2695

Note: Statistical significance codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05.

national interest areas. Moreover, the marginal effects indicate that the economic significance of this variable is much more profound in the German case. Specifically, in Sweden, a one percentage point increase in the share of priority areas implies roughly, for the average municipality, a 1% increase in the probability of having any capacity addition, while the corresponding effect for Germany is at least seven times larger (see further Section 5).

In the case of protected areas, we obtain more or less reversed results. There is a negative and statistically significant coefficient in the Swedish truncated model, but both of the German double-hurdle model estimates generate statistically insignificant coefficients. As noted above, the data covering the share of protected areas are not entirely comparable across the two countries. For this reason, we also used an alternative Swedish sample, and tested to include the same categories of protected areas as in the German sample (e.g., removing natural parks). Still, this did not alter the results for Sweden, i.e., a statistically insignificant effect in the probit model, but a statistically significant (and negative) effect in the truncated model. The economic significance of this land-use policy is far from negligible in the Swedish case. For instance, also taking into account the logarithmic scale for the dependent variable, a 10% point increase in the share of protected area suggests a decrease in capacity added by around 3 MW (compared to the Swedish mean of about 10 MW during the studied period).

For both countries, the empirical results show that higher installed capacities of onshore wind power (up until 2007) have overall implied more positive wind power outcomes during the period. In the Swedish case, this variable is positively related to both the likelihood of having any new wind power investment, as well as to how much capacity has been installed. For Germany, however, previously installed capacity has a statistically significant and positive impact only in the truncated model. Overall, the economic significance of this variable is substantially higher in the Swedish case, both in the probit model and in the truncated model.

Green party participation in German federal state governments and Swedish municipally governments, respectively, is hypothesized to have a positive correlation with wind power outcomes at the regional levels. However, the results suggest that, overall, we cannot reject the null hypothesis of no Green party impact. We do observe a negative (and statistically significant) parameter in the probit model estimates building on the limited German data sample, but this result is not robust as the corresponding coefficient is statistically insignificant in the full-sample model. Still, it should be noted that the impact of this variable, in part, appears to be sensitive to the way in which the variable is operationalized. Notably, if Green party participation is operationalized as a dummy variable that takes the value of one (1) if this party has formed a part of the local government during the studied period (and zero otherwise), we obtain a positive and statistically significant impact in the Swedish truncated model. However, the corresponding coefficients in the German samples are still statistically significant, and the remaining results are robust overall when comparing the two different model specifications (see Table A4 in the Appendix for detailed results).[5]

Given that regional land-use policies may often be associated with regional benefits from deployment, we hypothesized a positive correlation between unemployment rates and wind power expansions. In the Swedish case, however, we cannot reject the null hypothesis of no impact, and for the German sample the unemployment rate is statistically significant only in the truncated model. This suggests that districts with high unemployment rates are not necessarily more likely to host new wind power investments, but in the presence of such investments, they tend to experience higher capacity additions. Still, the size of this impact is not particularly large; an increase in the unemployment rate by one (1) percentage point is associated with an increase in wind power capacity by around 2 MW.

The correlation between wind power deployment and population density rates has the expected negative sign in both countries. Still, this variable primarily affects the magnitudes of the wind power capacity additions, and thus not the probability for investment in the first instance. Regarding the size of regions, we find for the German sample that districts with a larger land area are more likely to have hosted wind power investment, and, overall, the capacity additions are also (ceteris paribus) higher. This result is less evident in the Swedish model estimates, although here also the probability of having any wind power tends to be higher in municipalities with large land areas. The economic significance of land area is also more profound in the German case. For instance, a district with a ten percent higher land area than another will (on average) have experienced a capacity increase that was seven percent higher. The results suggest that the corresponding effect in the Swedish case is only about a third of that in Germany.

Finally, we find a positive and statistically significant correlation between wind power deployment and average wind speeds. Still, these results also display differences across the two countries. Specifically, for the Swedish sample higher average wind speeds increase the probability of wind power investment, while they have no statistically significant impact on the level of capacity additions. The estimated marginal effects from the probit model suggest that a Swedish municipality that has a wind speed that is one (1) m/s higher than another municipality will be about 20% more likely to host wind power in the region. In the German case, however, we observe the reverse results, i.e., the coefficient for wind speed is only statistically significant and positive in the truncated model.

5. Discussion

The empirical results indicate that land-use policy, as well as other factors, have had important impacts on the regional allocation of wind power investment in both Germany and Sweden. Still, we also find important heterogeneities across the two countries. In this section, we attempt to disentangle and discuss how these differences can be understood, given the various national contexts.

5.1. Regional land-use policy: priority and exclusion areas

The empirical analysis suggests that acknowledging the role of regional land-use policy remains important for fully comprehending the spatial patterns of wind power deployment. Yet, this role will depend on the stringency of such policy in the respective regulatory contexts.

First, in the case of designated priority areas, we find a positive and statistically, as well as economically, significant impact primarily in Germany, i.e., the share of priority areas is positively correlated with the probability of observing wind power installations. The German data reveal a fairly strong preference for strong area categories, which can exclude wind power plants outside of designated areas. Our results are consistent with the notion that this policy has profoundly increased the possibility for new wind power installations. Essentially, it ensures that in Germany some regional consensus has been reached on where to allocate new wind power plants prior to the advent of potential wind power plant investors.

In the Swedish case, however, the results indicate only modest impacts of priority areas on wind power deployment. This is consistent with the observation that the designation of areas as being of "national interest" for wind power represents a relatively weak policy tool. Such a designation implies that the area should be protected against other activities that constrain the area's use for wind power. Still, if the same area is also of national interest for other purposes (e.g., nature conservation, national defence, etc.), the legal rules provide little guidance on how to weigh these interests against each other. Previous analyses of the Swedish case law confirm that these rules have been unpredictable both regarding the possibilities to avert obstructive activities as well as to explicitly promote wind power (e.g., Petterson 2008). For instance, there are several examples of land-use decisions in which the national defence interest has been prioritized, thus blocking wind power investment. In addition, since 2008, the Swedish veto right also makes it possible for the municipalities to block wind power investments regardless of how widespread the national interest areas are. The above suggests, therefore, that priority areas can spur wind power deployment – but only if they are binding.

Second, the results show that the assignment of protected areas has posed a significant constraint to regional wind power development in Sweden, while no statistically significant impacts were identified for Germany. This difference stems in part from the generally higher average protection area shares in Sweden, which even reach 100% in a few municipalities (Table 2). As noted above, this is, in turn, a consequence of the fact that the German data set is incomplete, and does not cover, for instance, national parks as in the Swedish case. Moreover, the included landscape protection areas constitute a relatively weak form of land use constraint. In fact, they allow for wind power development if certain conditions are fulfilled. This highlights again that the actual effect of land-use policies on wind power deployment is dependent on their stringency, but also that additional research is needed to shed light on the role of various types of land-use policies.

5.2. Regional land use policy: Political willingness and institutional capacity

Regional land-use policy also encompasses "softer" measures influencing the availability of sites, such as guidelines determining the ease of permitting procedures, or more generally the creation of a positive investment climate within a region. For this reason, we included proxy variables for overall political willingness and institutional capacity to facilitate wind power. Overall, we find statistically, and also economically, significant impacts for some of these variables – while simultaneously controlling for the direct impacts of priority and exclusion areas.

Our results indicate that for both countries, there is a positive impact of previously installed capacity on additions during the studied period. In other words, previous wind power expansions have primarily had a self-reinforcing – rather than a constraining – effect on further development. This finding is consistent with the notion that regions that have embraced wind power investments in the past are also more likely to do so in the future. This could reflect, for instance, a positive attitude among key decision-makers towards wind power and, in turn, deliberate actions to encourage new investment projects. Regions with plenty of experience in dealing with wind power in the planning process may also have accumulated expertize in the field as well as developed efficient administrative practices (Ek *et al*. 2013).

Germany and Sweden differ substantially in terms of wind power installations prior to 2008, and an important finding was that both the strength and the nature of this relationship differ between the two countries. Specifically, there is a statistically insignificant correlation between previous wind power experience and new capacity additions in the German probit model while, for the Swedish sample, the corresponding correlation is statistically and economically significant. The result for Sweden supports previous work (Ek *et al*. 2013), while the German results, in part, contradict the recent findings of Goetzke and Rave (2016). In the German case, however, there is a statistically significant impact in the truncated model.

This difference across countries can at least, in part, be traced back to the way in which political power is allocated. In Sweden, the municipalities have a lot of discretionary power to say yes or no to wind power. This implies, for instance, that some of the Swedish municipalities that had no capacity installed by the end of 2007 were in this situation because they had decided to opt out of wind power, and there has not been any higher-level government able to change this. Consequently, these local governments' willingness to attract investments in the latter period, e.g., by the adoption of new detailed plans, will likely also be weak. In Germany, however, the situation has been different, as decision-makers at the district level have relatively less power over the planning process compared to the Swedish municipalities. For instance, the priority areas are determined in a regional plan typically consisting of several districts. The priorities expressed in these plans are, therefore, more likely to reflect the ambitions of higher-level governments. For this reason, and as noted above, the local administration is strongly bound to superordinated law, making decision-making at the German district level more administrative than political, at least in comparison to the Swedish case.

The results addressing the political power of the two countries' Green parties indicate that, overall, this variable has not proved to be an important factor behind regional wind power development. In part, this may reflect that, in some cases, both Green parties have been split between wind power supporters and sceptics, the latter emphasizing the negative landscape impacts of windmills. There has also been broad support for wind power among the other political parties. For instance, in Sweden, coalitions consisting of the Green party and the Social Democrats will not necessarily be more likely to support wind power than a coalition in which the Social Democrats collaborate with the more liberal Center party. Although our empirical analysis does not explicitly test this hypothesis, the results for Sweden appear consistent with this notion. Similarly, Goetzke and Rave (2016) hypothesized that, in Germany, left-of-center state governments would be more supportive of wind power expansion, e.g., through less restrictive planning requirements, than right-of-center coalitions. Still, in this case the estimated coefficient was statistically insignificant. Instead, Goetzke and Rave (2016) also used country level results in the state elections as a proxy for civil society and environmental activism at the local level, and found that the share of green party votes had a positive impact on wind power outcomes.

Finally, we have noted that, in both Germany and Sweden, the promotion of wind power is often linked to it being a vehicle for regional development and job creation. The results for Germany indicate support for the hypothesis that districts with high unemployment rates have had higher wind power capacity additions. This is consistent with the results from Goetzke and Rave (2016). German districts thus appear to face incentives to attract wind power investments, which increase the demand for local workforces (e.g., construction workers). Such incentives may go beyond job creation. Since 2009, municipalities in Germany that host wind power plants receive 70% of the business tax revenues (BWE 2015).[6] The corresponding tax incentives do not exist in Sweden, and here our results do not show a positive correlation between unemployment rates and wind power deployment. This finding is surprising given that substantial wind power capacity expansions have taken place in municipalities with historically negative population trends. A partial explanation for this result could be that the time period 2008–2012, was characterized by a boom in the global mineral commodity markets. Since the northern parts of Sweden host substantial mineral resources (e.g., iron ore, copper, etc.), the regions in these areas experienced significant growth and employment increases during this period (Edjemo and Söderholm 2011), potentially also crowding out other productive activities.

5.3. Additional regional drivers: Size of region, population density and windiness

The availability of sites for wind power is influenced by geographic conditions, and our results display the roles of total land area and population density, respectively. Our findings confirm that regions with larger land areas have experienced a higher probability of wind power investments, and hosted more wind power capacity additions during the studied period. These impacts were particularly evident in Germany, in part reflecting the lower general area availability in Germany compared to Sweden. The average land area for German districts is less than half of that of Swedish municipalities (see Tables 1 and 2). This should make it easier to identify potentially favorable locations for wind power in Sweden, and significant investment activities have also occurred in sparsely populated and forest-rich regions with decent wind conditions (Energimyndigheten 2013).

In the light of this, however, it is somewhat surprising that high population densities appear to impose a more profound constraint on wind power in Sweden compared to Germany. At least a partial explanation for this paradox may be attributed to Swedes' access to holiday cottages. Surveys show that, every year, over half of the Swedish population spends time in a holiday cottage for at least a week or more, and 20% of these own the cottage (SCB 2004). Indeed, people are likely to be particularly sensitive to nuisance caused by energy production facilities when on holiday in scenic landscapes (see Lundgren (1994) for evidence of this in the case of nuclear power plants in Sweden). In addition, since the majority of the households travelled less than 100 km to the holiday cottage, this implies that, in relatively densely populated Swedish municipalities, the risks for negative wind power attitudes could be strong. In other words, the access to holiday cottages increases the footprint of the population in areas where wind power investments may be frequent.

The regional allocation of wind power deployment is also determined by the profitability of wind power generation. Our empirical results confirm the important role played by favorable wind conditions for investment. This is particularly the case in Sweden, but also, in part, in Germany where the feed-in tariff levels have been negatively linked to average wind speeds. These results suggest, therefore, that lower feed-in tariff levels do not entirely neutralize the isolated effect of higher wind speeds. One reason for this is that, by design, the total revenues of a wind power plant will first increase linearly with output, but locations with medium or high wind speeds will typically receive the same revenues (Hitaj and Löschel 2019). However, it is probably fair to conclude that small-scale wind power investments at less favorable (less windy) locations are more likely in the German policy setting compared to the Swedish one.

For the Swedish municipalities, we find a positive and statistically significant relationship between wind speeds and the likelihood of having any capacity additions during the studied period. In Sweden, wind speeds have not been connected to the remuneration level in the certificate scheme; there exists, however, a link to the designation of areas of national interest. One of the most important criteria for assigning such areas has been average wind speed estimates. This has, thus, assisted in spreading the knowledge about the distribution of wind resources in the country, and also for providing support for the local authorities when deciding if – and where – it could be appropriate to plan for wind power (Ek *et al*. 2013). Our results suggest that this type of information dissemination may have been the most important function of this planning policy tool, rather than the fact that it provides guidelines for how to weigh different land use interests against each other.

6. Concluding remarks

The overall purpose of this paper was to investigate – and compare – the impacts of land-use policies on wind power deployment at the regional level in Germany and Sweden. The results suggest that the regional allocation of wind power has not only been influenced by environmental concerns, geographic endowments and RES support schemes. Land-use policies, not least in the form of priority areas and the designation of restricted areas, are important as well. The results also reveal the importance of the political willingness to promote wind power. This is reflected in the positive correlation between unemployment rates and wind power capacity additions. Furthermore, previous wind power expansions appear to have had self-reinforcing – rather than constraining – effects on further development; i.e., regions that have embraced and attracted wind power in the past seem to possess the capacity and the willingness to also do so in the future. Overall, these findings may underpin the potential importance of “softer” means of regional land-use policy, such as guidelines, institutional resources and investment climate.

An important contribution of this paper compared to previous research was the opportunity to contrast results across two countries that have both experienced significant wind power expansions during the chosen period, but within different regulatory and institutional contexts. The results display interesting differences across the countries. In particular, the role of priority areas is much more profound in the German case compared to the Swedish one. This can be attributed to the fact that the German designated priority area has been a more stringent land-use policy compared to the designation of areas being of national interest for Swedish wind power. The de facto planning monopoly on the part of Swedish municipalities also implies that local decision-makers can block additional wind power investment in the own region, irrespective of the national designation of areas. In contrast, the assignment of protected areas appears to have been a more stringent policy in Sweden compared to Germany.

Furthermore, our empirical model specification permitted us to distinguish between the probability of having wind power on the one hand and the level of capacity additions on the other. This also revealed heterogeneity across the two countries. For instance, while the results for both countries indicated a positive correlation between previous wind power investments and new investments, in the Swedish case these results were reflected in the probit model, while the corresponding results for Germany emerged in the truncated model. This can also be traced back to the more decentralized planning system in the former country. A similar result was found in the case of average wind speeds.

Furthermore, our results that display the importance of land-use policies and highlight important differences across various national contexts, should also pave the way for additional research. Overall, one could expect the importance of land-use policies to increase in the future. The available land is going to be scarcer with additional developments, and other policies, particularly RES support schemes, tend to become less important as wind power generation reaches grid parity. While there certainly is a need for both qualitative and quantitative research, the latter should also increasingly address changes over time in the adoption and implementation of land-use policies in various national contexts. This paper has illustrated the importance of acknowledging the significance of institutional and regulatory contexts for fully comprehending wind power deployment outcomes. This should open up the field for additional inter-country comparisons also covering other RES technologies, such as solar PV, bioenergy conversion, etc. Clearly, other wind power countries, e.g., Spain, the United Kingdom, also deserve attention in future empirical research.

Moreover, there should be room for more elaborate model specifications of the underlying decision-making processes in the countries under study. This could include imposing – and comparing – different distributions (e.g., the inverse hyperbolic since function). Furthermore, our conceptual framework (see Figure 2) suggests that a nested model specification could be relevant, e.g., where land-use policy is the dependent variable in a first step, and is then used as an independent variable in a second step when explaining wind power deployment outcomes. Such an approach could represent a potential avenue for future research, which also needs to address the data availability issues that we have discussed in this paper.

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Supplemental data

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Notes

1. Until 2007, Germany was the world leader in terms of installed wind power capacity. After that, both the USA and China have reported higher capacities of wind power.
2. See also the extensive archive provided by the RES LEGAL Europe website, http://www.res-legal.eu/archive/.
3. The stringency of the priority areas in the regional plans varies from recommendation to binding prescriptions.
4. The marginal effects from the probit model are not reported in full, but detailed estimates are available from the authors on request.
5. There are some changes in the statistical significance of a few coefficients. For instance, in the Swedish sample, land area is highly statistically significant in the alternative specification (truncated model), while we find a lower level of statistical significance for population density in the (full) German sample).
6. The remaining 30 percent of the tax revenues accrue to the municipality that hosts the company owning the wind power plant.

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Appendix

Table A1. Data providers and sources.

Dependent variable	Data providers	Data sources
Additionally installed wind power capacity over the period 2008–2012 in MW	Deutsche Gesellschaft für Sonnenenergie e.V. (Germany) and Swedish Energy Agency (Sweden)	DGS (2014) (Germany) and Energimyndigheten (2013) (Sweden)
Variables measuring regional land-use policies		
Priority areas in %	Federal Institute for Research on Building, Urban Affairs and Spatial Development (Germany) and Swedish Energy Agency (Sweden)	BBSR (2014) (Germany) and Energimyndigheten (2010) (Sweden)
Protected areas in %	Leibniz Institute of Ecological Urban and Regional Development (Germany) and Statistics Sweden (Sweden)	IÖR (2015) (Germany) and SCB (2015) (Sweden)
Variables addressing the political willingness to facilitate wind power deployment		
Total installed capacity prior to 2008 in MW	Deutsche Gesellschaft für Sonnenenergie e.V. (Germany) and Swedish Energy Agency (Sweden)	DGS (2014) (Germany) and Energimyndigheten (2013) (Sweden)
Participation of the Green Party between 2000 and 2012 in number of years	German statistical online platform DESTATIS (Germany) and Swedish Association of Local Authorities and Regions (Sweden)	DESTATIS (2015) (Germany) and SKL (2014) (Sweden)
Unemployment rate in %	German statistical online platform DESTATIS (Germany) and Statistics Sweden (Sweden)	DESTATIS (2015) (Germany) and SCB (2010a) (Sweden)
Control variables		
Population density, inhabitants per km^2	German statistical online platform DESTATIS (Germany) and Statistics Sweden (Sweden)	DESTATIS (2015) (Germany) and SCB (2010b) (Sweden)
Land area in km^2	German statistical online platform DESTATIS (Germany) and Statistics Sweden (Sweden)	DESTATIS (2015) (Germany) and SCB (2010c) (Sweden)
Wind speed in m/s	German Weather Service (Germany) and Swedish Energy Agency (Sweden)	DWD (2015) (Germany) and Energimyndigheten (2013) (Sweden)

Table A2. Correlation coefficient matrix: German sample.

	Cap 08-12	Priority area	Protect area	Cap 2007	Green party	Unem-ploy	Pop dens	Land area	Wind speed
Cap 08-12	1								
Priority area	0.32	1							
Protect area	–0.19	–0.06	1						
Cap 2007	0.19	0.12	–0.16	1					
Green party	0.20	0.58	–0.05	0.05	1				
Unemploy	0.21	0.14	0.11	0.13	–0.08	1			
Pop dens	–0.23	0.05	0.48	–0.10	0.09	0.13	1		
Land area	0.43	0.16	–0.45	0.14	0.00	0.26	–0.53	1	
Wind speed	0.36	0.23	–0.20	0.13	0.44	0.02	–0.27	0.25	1

Table A3. Correlation coefficient matrix: Swedish sample.

	Cap 08-12	Priority area	Protect area	Cap 2007	Green party	Unem-ploy	Pop dens	Land area	Wind speed
Cap 08-12	1								
Priority area	0.06	1							
Protect area	–0.05	0.04	1						
Cap 2007	0.39	0.06	–0.05	1					
Green party	–0.03	–0.01	0.16	0.10	1				
Unemploy	0.15	0.02	–0.02	0.07	0.01	1			
Pop dens	–0.10	–0.07	0.10	0.05	0.10	–0.17	1		
Land area	0.26	–0.03	0.22	0.22	0.04	0.39	–0.15	1	
Wind speed	0.02	0.06	–0.02	0.24	0.04	–0.52	0.15	–0.36	1

Table A4. Estimates of the double-hurdle regression models with green party participation coded as dummy (1/0) variable. (Standard errors in parentheses).

Independent variables	Germany (full sample)		Germany (limited sample)		Sweden (full sample)	
	Probit	Truncated	Probit	Truncated	Probit	Truncated
Constant	–6.20911 (3.34027)*	–7.24773 (3.78530)*	–9.85532 (5.36741)*	–4.19665 (3.99602)	–8.72519 (1.53339)***	10.09125 (8.98713)
Priority areas in % per planning region area	–	–	0.82354 (0.39107)**	0.39664 (0.22035)*	–	–
Priority areas in % per municipality	–	–	–	–	0.11674 (0.05819)**	0.04538 (0.39018)
Protected area per district area in %	–0.01874 (0.02761)	0.03598 (0.05255)	–0.00998 (0.05114)	–0.02289 (0.09750)	–	–
Protected area per municipalities area in %	–	–	–	–	–0.00594 (0.00746)	–0.06053 (0.02863)**
Installed capacity within Federal States until 2007 (MW)	0.00005 (0.00007)	0.00031 (0.00011)***	0.00003 (0.00009)	0.00033 (0.00011)***	–	–
Installed capacity within municipality until 2007 (MW)	–	–	–	–	0.12474 (0.06007)**	0.04182 (0.02220)**
Participation of Green Party in German Federal Gov (1/0)	0.07250 (0.11974)	0.19745 (0.32091)	0.00921 (0.02284)	0.44887 (0.65332)	–	–
Participation of Green Party in Swedish Municipal Gov (1/0)	–	–	–	–	0.19773 (0.14322)	0.89113 (0.53887)**
Unemployment rate in %	0.05982 (0.07631)	0.34406 (0.17219)**	0.00934 (0.02275)	0.26733 (0.06690)***	0.09643 (0.05774)*	–0.01902 (0.03743)
ln Population density in persons per m^2	–0.09873 (0.14332)	–0.39021 (0.28032)	0.11736 (0.19740)	–0.66421 (0.40255)*	–0.00212 (0.08842)	–0.48336 (0.13967)***
ln Land area in km^2	0.77222 (0.22081)***	0.59538 (0.27982)**	0.70022 (0.31828)**	0.36504 (0.30026)	0.43011 (0.19880)***	0.16754 (0.22859)
Average wind speed in m/s^2	0.18274 (0.12109)	0.83648 (0.25843)***	0.88635 (0.48701)*	0.97649 (0.42456)**	0.93327 (0.40330)***	–0.17743 (0.33998)
Sigma (σ)	–	1.49034 (0.10873)***	–	1.38749 (0.09882)***	–	1.27558 (0.10112)***
Number of observations	402	402	209	209	290	290
Log likelihood	–171.8383	–397.0892	–76.7433	–271.0340	–178.5562	–206.0904
Adjusted R^2		0.4113		0.5602		0.2915

Statistical significance codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05.